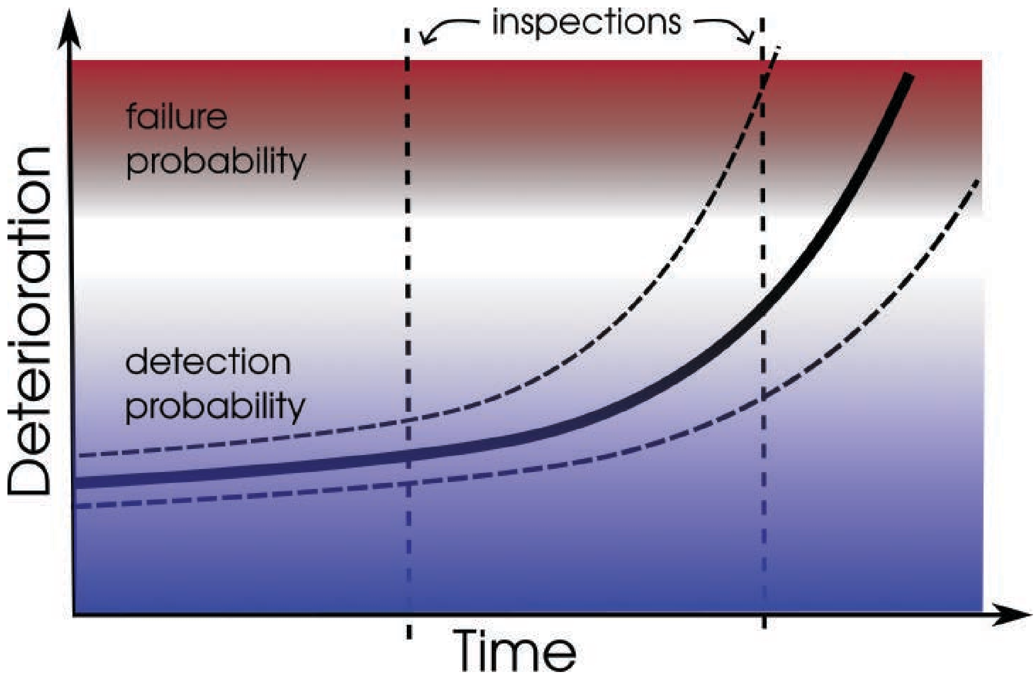

ASSET MANAGEMENT

A brief introduction with focus on the ISO 55000 standard and mechanical deterioration of railway related assets

Edition 2.0

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To Gunilla, Ludmila, Ralph and Albert

"The cracks in the wall
have grown too long"
Deep Purple – Wasted sunsets

Front:
Increased deterioration over time with uncertainties, and probability in identifying the deterioration at inspections

Anders Ekberg and Elena Kabo,
Gothenburg, Sweden 2022

Contents

1 Introduction

Asset management is, with the definition in [1] the 'coordinated activity of an organization to realize value from assets'. Here, an 'asset' is an 'item, thing or entity that has potential or actual value to an organization'. This could essentially refer to all activities of an organisation related to all things that this organisation considers to be of value.

In this brief introduction we will narrow the scope significantly. First we will focus on physical assets subjected to significant mechanical deterioration – that is wear and tear. Secondly, we will focus on railway related assets. This typically relates to track and railway vehicles that need to be regularly maintained.[1]

The introduction will also discuss management of such assets in the light of the ISO 55000 series of standards. The aim is to provide an understanding of how the ability to analyse and predict mechanical deterioration can (and should) be incorporated in an asset management system.

The text is organised top–down in the sense that it sets out with an introduction to the ISO 55000 series. This overview is narrowed down to show how knowledge and predictive abilities regarding mechanical deterioration fits into asset management. It is followed by an overview of different modes of mechanical deterioration and failures, and how these can be assessed in risk analyses. A standardised and mandated way of performing risk analyses is the common safety method for risk analyses, which is described in chapter 4. The overview is then concluded with some brief comments on railway applications.

2 The ISO 55000 series of standards

The ISO 55000 series of standards consists of three fairly brief documents

- ISO 55000 Asset management — Overview, principles and terminology [1]
- ISO 55001 Asset management – Management systems – Requirements [2]
- ISO 55002 Asset management – Management systems – Guidelines for the application of ISO 55001 [3]

This outline of the series is the same as for the ISO 9000 series, which deals with quality management systems.

Just as following the ISO 9000 does not guarantee that your activities have a high quality, following ISO 55000 does not guarantee that you have an efficient asset management system. What it provides, however, is a systematic and documented approach that allows your asset management system to be audited.

[1] Strictly speaking, this could also include e.g. station buildings, signalling systems etc. However since the mechanical deterioration is typically only a (small) part of the deterioration of such assets (with exceptions such as driving and locking devices in switches), the discussion in this brief introduction is not fully applicable.

2.1 ISO 55000 – Principles and terminology

ISO 55000 [1] outlines the general principles of asset management and motivates the use of asset management in general, and of the standard in particular. Much should be fairly obvious, but some items are worth consideration also in the context of this introduction. A statement that should be obvious, but in many cases is not fulfilled is that asset management requires accurate asset information, but that an *asset management system* is more than a system to manage this information.

Personnel involved in asset management need suitable competences – not the least the case in the topics related to this introduction. ISO 55000 requires these competency requirements to be specified in the asset management system.

The asset management systems sets out from an asset management policy that describes how asset management should be applied. The implementation of this policy is then concretised and documented in a strategic asset management plan (SAMP). The overall outline of the asset management system is presented in figure 1.

Of particular importance are changes in asset management – in the current context, this could be introduction of new vehicles, change of maintenance contractor etc. In such cases ISO 55000 stresses the importance of risk assessment and control.

Incidents, emergencies and unexpected events are indications that there may be flaws in the asset management system. For all these events, an investigation should be made regarding if improvements to the asset management system are needed, and to prevent recurrence and mitigate effects. See also section 3.3.

The final chapter in ISO 55000 contains definitions of terms used in relation to asset management.

2.2 ISO 55001 – Requirements

ISO 55001 [2] concretises ISO 55000 by formulating requirements. One important item in the context of this summary is that the standard explicitly states that no technical requirements are specified.

Just as in ISO 55000, the standard sets out from general requirements on the organisation etc. It states that the scope of the asset management system (including the asset portfolio covered), which stakeholders it relates to etc, shall be defined and documented. This demands results in a requirement that a strategic asset management plan (SAMP) shall be developed. The SAMP contains the asset management objectives of the organisation. It is thereby an extension of the asset management policy that should be established by the top management, see figure 1.

To fulfil the asset management objectives in the SAMP, the organisation shall 'establish, document and maintain' asset management plans. One important part of relevance to this introduction is that this includes to determine methods and criteria to take decisions and to prioritise activities and resources. It also includes specifications of how results will be evaluated.

The standard then includes a section on support. Apart from the fairly obvious requirements that the activities shall be supported by sufficient resources and competent staff, the standard also has fairly strict demands on information management. This especially includes documentation required by ISO 55001 and other regulatory requirements, but also other information necessary

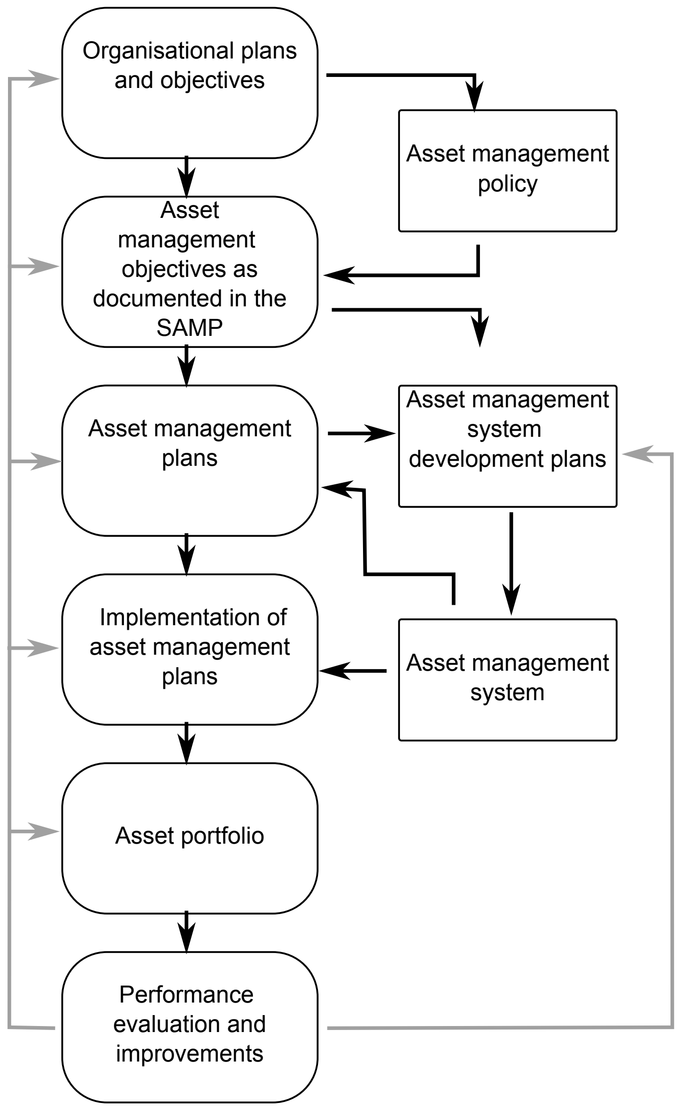

Figure 1: Key components in an asset management system following ISO 55000 [1].

for the asset management system to be efficient. From the perspective of the current introduction, this relates to information regarding status and predicted future deterioration of the assets. These topics also relate strongly to the requirements in ISO 55001 on performance evaluation. Here, the first requirement is to determine what needs to be monitored and measured. For these parameters, 'methods for monitoring, measurement, analysis and evaluation, as applicable, to ensure valid results' should be determined. This includes timing of measurements and evaluations. There is also a requirement to evaluate and report asset performance, and the effectiveness of the asset management system including risk management. Information to support this evaluation shall be documented.

The extensive demands for documentation relate to the demands in ISO 55001 on internal audits and management reviews.

As mentioned in relation to ISO 55000, there are strict requirements regarding the handling of non-conformities (e.g. incidents, emergencies and unexpected events). This includes both corrective/mitigating actions and preventive actions. The latter includes requirements to 'establish processes to proactively identify potential failures in asset performance', and evaluate which proactive actions that are suitable.

2.3 ISO 55002 – Guidelines

ISO 55002 [3] provides guidelines on how to fulfil the requirements in ISO 55001. Since these guidelines should be applicable to all types of organisations and all types of assets, they are very general and essentially reiterates ISO 55000 and ISO 55001 with some clarifications and considerations for different situations.

One clarification is the relation between

- the asset management policy – a short statement regarding principles to be applied in order for asset management to support the organisational goals
- the strategic asset management plan (SAMP) – which should be a high level plan[2] that includes asset management objectives
- asset management plan(s) – that specifies activities on an asset level

With respect to the objectives of asset management, ISO 55002 clarifies that the organisation should measure how the objectives are fulfilled. It is recommended that such measures should be specific, measurable, assignable, realistic, and time-related (i.e. SMART). It also emphasises the importance of understanding the overall objectives of asset management before implementing evaluation practices. Such objectives may for example relate to (life cycle) costs, reliability, availability, performance, environmental impact, and safety. To this end, important tools are techniques such as Life Cycle Analyses (LCA) for environmental impact, Life Cycle Cost (LCC) analyses for estimations of economic return, Reliability, Availability, Maintainability, Safety (RAMS) analyses to assess operational performance. Note that in operations where mechanical deterioration is significant, an important factor in all these analyses is the character and magnitude of the deterioration.

[2] Yes, the standard is a bit ambiguous in the uses of 'strategy' and 'plan'.

Depending on the organisation, there may be a need for several asset management plans where specific asset management activities are specified for different asset categories. Railway organisations are taken as an example. Here, there are typically asset management plans for different asset categories (e.g. for stations, track etc). Note that the reality often is much more complicated since there may be different organisations responsible for different assets. Their objectives with asset management may differ, and even to some extent be conflicting. Further, plans for different asset classes may be divided into different maintenance activities for different categories. For example, the type and periodicity of track management will depend on the type of track and character of operations.

Asset management plans need to be regularly reviewed so that they fulfil the overall objectives. Here ISO 55002 notes that there may be solutions that fulfil the overall objectives without requiring more assets. For example, the demand can be adjusted by an altered pricing. In the context of railway management this could relate to only operate the most profitable lines and increase ticket prices. Though this might fulfil strict business objectives, it will not fulfil societal, environmental and political objectives since railways are a core part of the societal infrastructure. This is the reason why the state in many countries purchases railway operations that are uneconomical from a pure business perspective.[3]

The assessment of the asset management plans should be complemented by a review of the strategic asset management plan to assess whether it has sufficient capacity to fulfil overall objectives.

In all assessments, risk analysis has a central role. This concerns both risks related to individual assets and the asset management system itself. The approach proposed by ISO 55002 essentially sets out from an inventory of asset classes with information regarding these and how they are assessed. Potential risks are then identified, and pertinent (existing and planned) risk controls identified. The risks are then analysed. Probability and consequences are evaluated to establish a risk level and whether (and how) this level evolves over time.[4] Based on this assessment, it is evaluated whether existing control and inspection plans are sufficient and fulfil regulations. The final stage is then a decision on how risks should be handled. Here, the decision process should also consider life cycle cost aspects. In cases where available funding does not meet suggested actions, an iterative process to prioritise is suggested.

It could be noted that for the most complicated steps in the analysis above (at least regarding assets subjected to mechanical deterioration), ISO 55002 is very vague. For example, it is only stated that the risk analysis should be made through suitable processes. In this introduction we will be a bit more specific in section 3.3 although a full understanding requires extensive studies in fatigue and fracture, and similar topics.

One important note is that the proposed approach for estimating risk levels (through estimating probability and consequence) often neglects risks that have a low probability, but very severe consequences. ISO 55002 emphasises that it is important that the asset management system shall monitor and evaluate the probability for such events to occur. For mechanical systems,

[3]Or, in cases where the state owns the operator, they put demands on operating also ‘uneconomical’ lines in their operational directives.

[4]In cases with significant mechanical deterioration it will. And usually to the worse.

this is often more easily said than done since they typically involve the interaction of a number of unlikely events, and in some cases disobedience to established routines.

ISO 55002 elaborates on the demands in ISO 55001 on competences in that it suggests that the organisation should map its present competences towards those required to identify competence gaps. It also elaborates on how to handle information and documentation. In short, the approach to fulfil demands in ISO 55001 needs to be tailored depending on the nature of assets and organisation.

To carry out activities in the asset management plan(s), the organisation are recommended to establish processes to plan and and follow up production.[5]

Management of change is given some consideration. In essence, the standard recommends a thorough assessment before changes (in the asset management system and/or in the assets themselves) are introduced. In the context of the current introduction, one could note that the standard considers ageing (i.e. deterioration) of assets as a change. It is suggested that the organisation should have the capacity to take evidence based decisions on changes, and the ability to systematically consider different scenarios in the entire organisation. For railway assets subjected to mechanical deterioration, this is a major challenge since there are numerous interacting deterioration mechanisms, that include threshold phenomena and exponential risk growth.

ISO 55002 also acknowledges that outsourcing of asset management related activities are common. It stresses that this should in essence not change the demands on the asset management system. This means that the higher the level of outsourcing, the more essential it becomes to control the supplier. If the extent is high, it may require the supplier to establish its own asset management system. Outsourcing also requires the organisation to consider the involved risks. ISO 55002 especially emphasises risks that can't be transferred, such as deteriorated public relations due to operational disturbances.

Regarding evaluation, ISO 5002 stresses the use of measures, documentation and assessment. In the context of the current introduction, it could be noted that this process is significantly improved if objective measures of relevant parameters are used, see e.g. [4].

ISO 55002 provides an overview of what an audit should consider. One important aspect, is that it stresses that there should be a connection between the technical aspects of asset management and the financial analysis. This is often a challenge in cases of mechanical deterioration, especially when it is related to risks. In essence, the complication boils down to that a derailment that does not happen carries no costs.

As in ISO 55000 and ISO 55001, handling of non-conformities is taken very seriously. Here, ISO 55002 elaborates the requirements in ISO 55001 by specifying processes that should be established, implemented and maintained by the organisation to control, investigate, mitigate, and prevent non-conformities. With the massive amount of proposed processes, it could be good to mention that ISO 5502 is clear on that the actions should be in proportion to the estimated risks.

Finally, the standard stresses the need for continuous improvement. Here it explicitly mentions the strive for new knowledge and new technology e.g. through involvement in research and development, and in forums for knowledge exchange.

[5] Somewhat surprisingly, the production itself is not mentioned.

3 Mechanical deterioration in asset management

For assets where mechanical deterioration is a major part in reducing asset value and increasing risks of failures and safety, limiting deterioration naturally carries a high priority. Management of asset deterioration requires a knowledge of deterioration mechanism and their key influencing factors. It also requires an ability to predict future deterioration and to estimate risk levels. This knowledge is key to the requirement in ISO 55001 of being able to take asset management decisions, prioritise activities and resources.

This chapter first contains a brief introduction to gradual deterioration. Some mechanisms of mechanical deterioration are mentioned, but the aim is not to go into specifics, but rather to highlight similarities between the different modes of deterioration.

The second section focuses on more rapid failures where failure occurs after one or a few load cycles. This topic also relates to demands in ISO 55000 to carry out investigations in cases of failures[6] and to identify risks and suitable proactive measures.

The final parts deal with risk assessment, which is a requirement in ISO 55000 and also in many homologation processes. An initial discussion on more general aspects of risk analyses is here followed by an overview of common safety methods for risk analyses (CSM-RA) which in some cases are required for modifications of railway assets.

3.1 Gradual deterioration – wear and tear

Assets exposed to a time varying mechanical loading[7] will deteriorate over time. In this introduction, we will briefly discuss deterioration due to plastic deformation, wear, material fatigue, and material transformations. Note that the border between these phenomena is somewhat floating, and that the phenomena interact.

Plastic deformation implies a material response that results in permanent deformations after unloading. This relates for example to yield of steel components, and settlements of ballast and soil. In most cases the plastic deformation is confined to areas of stress concentrations. In cyclic loading, repeated plastic deformation may cause the initiation and growth of cracks and subsequent brittle fracture. If load levels are very high plastic collapse may occur.

Wear is the continuous loss of material from the surface of a solid body due to contact and relative movement of a solid, fluid or gaseous in contact with the body. This relates for example to wear of railheads, and continuous rounding of ballast stones. Wear will alter the contact geometry, which often reduces wear rates (wear-in), but may aggravate the situation. The worn geometry may increase the risk of other forms of failure, such as derailment due to flange climbing, which can be considered to be an instability phenomenon and may cause derailments. Another example is rounding of ballast stones that decreases the lateral track resistance and may increase the risk of track buckling, which is also a stability phenomenon.

[6] In fact, this requirement exists even in cases of 'unexpected events'.
[7] In a broad sense including also in combination with environmental impact that can e.g. cause corrosion.

Material fatigue is the process when cracks form and grow in a solid body due to repeated loading. Examples are crack formation in rails, and cracks in sleepers. As a crack grows, the loading of the crack typically increases. Eventually, the material strength (the fracture toughness) is exceeded and there will be a catastrophic failure.

Material transformations in this context means that the material reacts with the environment in a detrimental manner. Examples are rusting of steel, degradation of polymers, and martensite formation due to high temperatures.

The initial requirement in ISO 55001 on performance evaluation is to determine what shall be monitored and measured. Regarding mechanical deterioration, even this is a major challenge. The reason is that the four categories of deterioration mentioned above include a vast amount of variants for which different factors are important. Typically, each form of deterioration also involves a large amount of influencing parameters, which not all can be directly monitored or measured, see [4].

This leads to the establishment of asset management plans. In essence, this can be established in two ways: either by employing historical data to perform forecasting, or by employing (numerical) simulations. The first approach is applicable in cases where suitable statistical data exist and the conditions are fairly constant. What this means will be discussed shortly.

Numerical simulations require a knowledge of which deterioration phenomena that are relevant, how the deterioration can be predicted, and suitable input data. A major challenge is to include all relevant aspects in the simulations, while at the same time not make the simulation models more complicated than what is required, and what the quality of input data allows. Since input data are often uncertain, a good practice is to carry out sensitivity analyses. This is especially important since deterioration phenomena have two features in common that significantly complicate predictions.

The first is that they are all (more or less) *threshold phenomena*: Plastic deformation only happens when a threshold loading is exceeded. For example, yielding of steel does not occur unless the yield limit is exceeded. The same goes for fatigue where the yield limit is replaced by the fatigue limit. In the same manner, no significant wear, or corrosion occurs unless conditions allow for it.

The second complication is that once the load (in a broad sense) exceeds a threshold is exceeded, the deterioration increases significantly – typically exponentially. For example, the fatigue life can be described by the equation

$$\sigma_{\mathrm{a}} = A \cdot N^{B} \tag{1}$$

where σ_{a} is the stress amplitude (i.e. the ‘loading’), N is the fatigue life (i.e. ‘component life’), and A and B are material parameters. Consequently, the component life will be very sensitive to the applied loading (and the material parameters). This makes a further argument for the use of sensitivity analyses.

Due to this non-linear character of deterioration phenomena, the use of historical data to predict future deterioration rates is cumbersome when operational conditions change. To make matters worse, altered operational conditions can completely alter the deterioration pattern. An example of this is the introduction of harder steel in rails and wheels that can increase operational lives, but also change the dominating mode of deterioration from wear to (rolling contact) fatigue.

3.2 Rapid (instantaneous) failures

Failure modes briefly described in this section essentially occur as a consequence of one load cycle. In most cases there should however be indications before the final failure. This will be discussed below.

Plastic collapse implies such severe plastic deformations that the structural integrity cannot be sustained.

Brittle fracture relates to the unstable growth of a crack causing a final fracture.

Instability includes buckling phenomena and dynamic instability. Buckling implies that a structure that can sustain increased (typically compressive) loading with limited deformations, will sustain very high deformations after a threshold load is exceeded. The classic case is Euler buckling where a column buckles as a consequence of high compressive loads (see figure 2a). The critical buckling load may be drastically reduced due to geometrical imperfections. The overcritical strength as the critical load is exceeded depends on the type of buckling. For Euler buckling the strength decreases, whereas for plate buckling it often increases. A classic review of buckling phenomena can be found in [5].
The energy required for the instability cannot exceed the loss in potential energy obtained through the deformation. Whereas static instability occurs under the influence of a static load (typically gravity), dynamic instability (excessive vibrations, see figure 2b) requires energy to be 'continuously' supplied. An extensive review of instability phenomena can be found in [6].

All of these rapid failure modes often have some pre-indications.

Plastic collapses relate to an extreme load, but unless that load magnitude is very much higher than operational loads, local plasticity (with related plastic deformations) is likely to occur before the final fracture.

Brittle failures require the existence of cracks in the structure. Unless the material is highly brittle (for example glass and ceramics), these cracks are usually possible to detect by inspections before final fracture occurs.

Conditions close to buckling are difficult to detect. In theory they can be identified by low frequency eigenmodes of structural vibrations. In practice this may not be possible either due to high damping of the structure, or due to difficulties in applying the dynamic load.

Structures susceptible to dynamic instability tend to exhibit severe vibrations also under non-catastrophic conditions. As an example, the Tacoma Narrows bridge in figure 2b was called Galloping Gertie due to high vibrations even before the event that caused it to collapse.

a  b 

Figure 2: a) Euler buckling (Euler-2) and b) Dynamic instability (Tacoma Narrows bridge).

3.3 Failures – risk assessment

3.3.1 Slow and rapid failure processes

In a risk assessment, the speed of the failure process is important. If the process is fairly slow, the progressing deterioration may be monitored and mitigating actions may be employed before catastrophic failure occurs.

This is usually not possible in rapid failure processes. Then, safety factors on loads and structural strength are required to ensure that catastrophic failure does not occur.

The two philosophies can be combined in a *defect tolerant design and inspection* strategy. Here the gradual deterioration is monitored with inspection intervals sufficiently short to prevent the degradation to reach a stage where (with sufficient safety factors) rapid failure occurs.

Note that the division in ‘rapid’ and ‘slow’ is indicative and presumes a certain load magnitude. For example progressive plastic deformation is typically a fairly slow process. However if the load magnitude is very high, plastic collapse – which is a rapid form of failure – may occur.

3.3.2 Failure probabilities

The next step in the analysis is to evaluate the probability of failures. In many codes this is (explicitly or implicitly) included by the use of prescribed safety (or partial) factors, typically included in various coefficients on strength and loads. In essence, this approach is intended to ensure that the probability that the load exceeds the strength is sufficiently low. This is indicated in figure 3a where the intersecting area (grey) represents the probability of failure.

This design code procedure targets the probability of failure.[8] This is mainly suitable in the design process. In an asset management perspective and when dealing with slowly progressing failure processes, it is more feasible to relate the probability to the progressing deterioration. Such an approach is sketched in figure 3b. Here inspection intervals can be assessed so that the probability of deterioration progressing to final fracture will be sufficiently low. Note that the inspections are also related to a probability on properly quantifying the deterioration. As an example, you can use non-destructive testing (e.g. eddy current or ultrasonics) to assess a crack length, but there will be an uncertainty in the detected length. Typically the uncertainty (as percentage of the total level of deterioration) is larger for lower levels of deterioration (in this case the length of the crack). This uncertainty is indicated as the graded shading in figure 3b.

Inspection intervals should be sufficiently short that the probability of not capturing progressive deterioration before a final fracture is sufficiently low. In figure 3b inspections are indicated by vertical dashed lines. It is seen in figure 3b that for the highest deterioration rate (upper dashed curve) and lowest failure strength (lowest horizontal dashed line), a failure just before the second inspection is predicted.

In this context continuous monitoring can be considered as an extreme case where the inspection interval tends towards zero. In theory, this would provide a full accuracy towards failures. In reality this is not the case. Some reasons are that the monitoring may not provide a full quantification of the deterioration, that progression of deterioration may evolve in a non-predictable (non-linear) fashion, and that failure may occur due to single overloads. For that reason, it is useful to combine (continuous) monitoring with numerical simulations and predictions of deterioration. If these simulations are (continuously) updated based on the monitoring, we have a so-called 'digital twin'.

Another challenge with continuous monitoring is how they affect the reliability: If the monitoring is safety related, a sensor failure might require the systems to shut down. Also here, the combination with numerical simulations can be valuable to identify sensor readings that appear unrealistic.

From the discussion above, it is clear that there are a number of uncertainties involved in assessing progressive deterioration. This motivates the use of explicit sensitivity analyses where numerical simulations are employed to quantify the effect of varying load and strengths.

By employing a large number of simulations (i.e. Monte Carlo simulations), also the probability of different responses can be assessed. Since it is the most detrimental combinations that are of interest, the analysis should focus on these, for example by using importance sampling in the Monte Carlo simulations. Note that the evaluated estimation of deterioration probability will not be better than the estimation of load and strength distributions. There will also be an additional uncertainty (or bias) related to how well the simulation model can mimic reality.

3.3.3 Failure consequences

So far, we have analysed the probability of deterioration (rates) and failure. However we have not discussed which failure probability that can be deemed as acceptable. This is a highly complex topic since failure may include casualties and major economic losses. On the other hand, too

[8] In a broad sense. For example, in the case of fatigue it considers the probability that fatigue cracks will be initiated, or that the fatigue life will be below a certain number of load cycles.

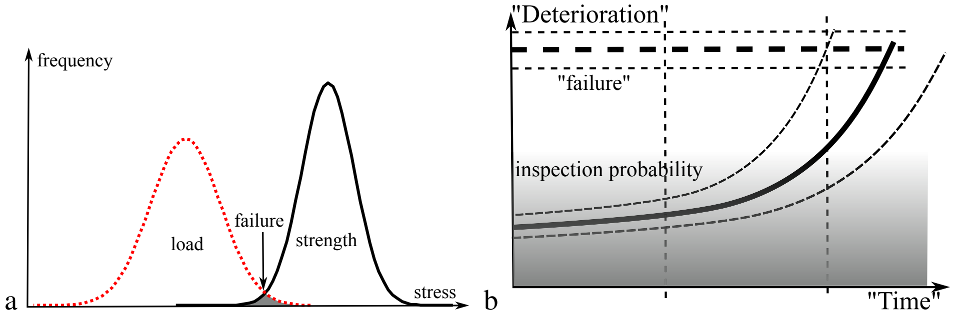

Figure 3: a) (Normal) distributions of load and strength. b) Distribution of deterioration rates.

extreme safety levels may prevent development that may save lives and provide economical benefits, see e.g. [7].

Without going into economical or ethical details, it can be noted that acceptable probabilities for failures are implicitly defined in various design codes. Here, the consequence of failure is an important factor. Acceptable levels are usually divided into classes depending on whether a failure introduces small or large risks for injuries/fatalities and/or economical losses. Typical levels of acceptable probabilities for structural failures may be on the order of 1/10 000 to 1/10 000 000 over a 50 year period. For components where consequences are negligible, much higher probabilities may be allowed. The extreme case is consumables, where in essence the only consideration is that the replacement shall not cause unnecessary inconveniences.

Although the discussion above mainly relates to the design process, it is equally valid for the asset management phase. The difference is that the design is fixed, and the focus will be on predicting risks and consequences related to continuous deterioration.

4 Common safety method for risk analyses (CSM-RA)

Since there are many uncertainties related to risk analyses, and the consequences of failures in the railway sector may be enormous, there is within the European Commission a demand to performed structured risk analyses following a common safety method for risk analyses (CSM-RA), see [8]–[10]. These risk analyses should be performed when there are significant changes that may affect the safety of the (railway) system. Here ‘significant changes’ essentially implies that one (or more) of the following criteria is not fulfilled

- failure consequences are small
- the novelty of the solution is insignificant
- the complexity of the change is small
- consequences are easy to monitor
- it is possible to revert to the system to a state as it was before the change

Note that the assessment of whether the solution is a significant safety related change or not shall be documented.

If there is a significant safety related change, a risk assessment shall be carried out. Just as the asset management system standards, the regulations do not in general prescribe how the risk analyses are to be carried out. Instead, the main aim is to ensure a structured and documented approach. This approach is outlined in Commission [10] and reproduced in figure 4. This is an iterative process that continues until 'all safety requirements necessary to accept the risks linked to the identified hazards' are demonstrated.

The process depicted in figure 4 comprises three main parts that can briefly be described as

- system definition – where a number of factors that define the system to be assessed are described. This includes
  - the purpose of the system
  - function of the system and its elements (including e.g. human, technical and operational elements)
  - system boundaries, interfaces and interacting systems
  - system environment
  - existing safety measures and safety requirements identified by the risk assessment process
  - assumptions that determine the limits for the risk assessment
- risk analysis including the hazard identification – where identified hazards and safety measures shall be registered in a hazard record. Then any of three paths are possible:
  - Use existing codes of practice to manage the risks
    This could for example relate to existing codes for rail welding that are applicable and fulfilled also for a modified process being assessed.
  - Use of a reference system
    A similar system exists and has been in safe operation under similar operational and environmental conditions. If the system deviates it should be demonstrated that the new system reaches at least the same level of safety.
  - Explicit risk estimation
    An example could be FE analyses and subsequent fatigue analyses to ensure a sufficient fatigue strength under operational load conditions.
- risk evaluation – where it is assessed whether the risk is acceptable

After the risk evaluation, the evaluation shall be demonstrated by the 'proposer' (contracting entity or manufacturer) and assessed by an independent assessment body.

Note that the description above is only intended as an overview. The regulations include additional requirements.

To facilitate implementation, the European Railway Agency has compiled guidelines and examples that are available on its homepage (https://www.era.europa.eu). In particular, the guideline [11] contains a detailed comment of the Common Safety Method regulation [10].

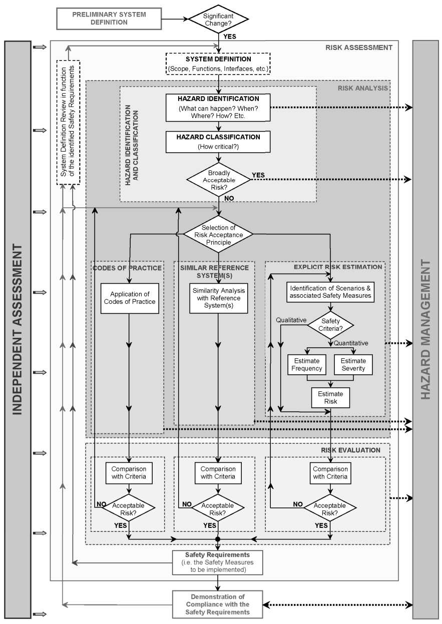

Figure 4: General outline of risk management process. From Commission [10].

In the context of risk assessment, it should be noted that the European Commission also demands that safety management systems are monitored to ensure that they function as intended, see [12] and figure 5.

5 Some further comments on railway applications

Railway operations are related to massive investments in infrastructure and vehicles. These assets have a (very) long life and are in general subjected to (mechanical) deterioration. Maintenance of these assets relate to a large portion of the life cycle costs. Both maintenance actions and consequences of improper maintenance may lead to massive costs.

It is therefore vital to have a functioning asset management system. In addition to general requirements for asset management systems, it will need to have proper means to predict deterioration of the railway system. This includes a identification of relevant deterioration processes and mechanisms, data to quantify current status, tools to predict future deterioration, knowledge to plan suitable maintenance actions, and the competence and resources to carry out the required maintenance.

This short compendium supports the establishment and development of such a system. It also describes in an overview fashion how material deterioration can be handled. In the case of railway systems, this often includes very high loads and complex deterioration phenomena. Often, the deterioration will influence the safety of the railway system. For this reason, the overview also includes an overview of risk analyses. Note that both predictions of deterioration and assessments of risks require detailed knowledge and analyses related to the deterioration/failure

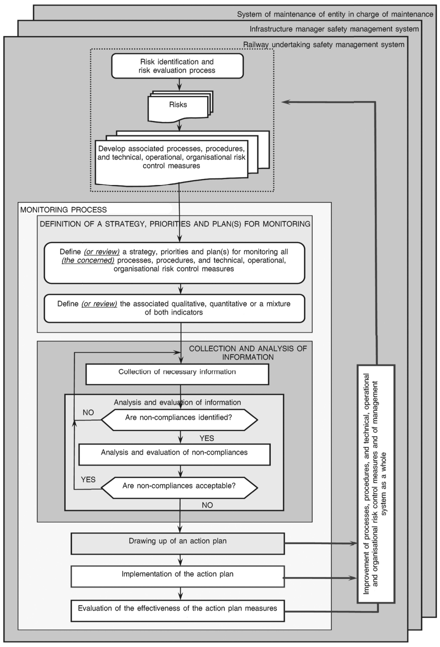

Figure 5: Monitoring of the risk management process. From Commission [12].

processes of interest. These aspects are not covered in this brief report. Instead the reader is referred to the specialist literature, e.g. [4].

Finally, it should be noted that many people are dependent on the railway system. Failures in management that results in operational disturbances or, worse, accidents, are therefor likely to be public news.

References

[1] ISO, "Asset management — overview, principles and terminology," International Organization for Standardization, ISO ISO 55000:2014, 2014, p. 19.

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