LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Engineering Science
Degree Programme in Industrial Engineering and Management

Aleksi Vainio

MAINTENANCE DEBT: EVALUATION METHODS AND CASES IN FINNISH INFRASTRUCTURE AND INDUSTRY

Master's Thesis

Examiners: Prof. D.Sc. Timo Kärri

University lecturer. D.Sc. Tiina Sinkkonen

Instructor: Executive Director, Finnish Maintenance Society, Promaint ry. Jaakko Tennilä

ABSTRACT

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Maintenance debt: evaluation methods and cases in Finnish infrastructure and industry

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Examiners: Prof. D.Sc. Timo Kärri and University lecturer. D.Sc. Tiina Sinkkonen
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Keywords: maintenance debt, maintenance deficit, maintenance backlog, repair debt, asset depreciation

Maintenance debt is a topic that has not seen much focus in scientific research. Yet in recent times, the term is often talked about in news and articles. Reports on the state of Finnish infrastructure have brought attention to the fact that crucial infrastructure assets are aging, and investments are not at sufficient levels. Additionally, investments in the Finnish industry have been lower than capital deprecation for several years, leading to a decrease in physical capital.

The purpose of this thesis is to define and present a classification of maintenance debt as well as what methods exist for estimating the amount of maintenance debt. Additionally, practical cases in industry and infrastructure are analyzed with the goal of evaluating the amount of maintenance debt based on financial statement data.

The key results of the thesis include classifying maintenance debt into 3 sub-categories: operational, refurbishment, and improvement debt. In addition, four different evaluation methods are presented: the maintenance backlog, replacement cost, technical value, and balance sheet value models. The balance sheet value model was used in the case studies of two companies, allowing maintenance debt evaluations to be made based on financial statement data. However, several limitations and other observations were made regarding the results.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
School of Engineering Science
Tuotantotalouden koulutusohjelma

Aleksi Vainio

Kunnossapitovelka: laskentametodit ja tapaukset Suomen infrastruktuurissa sekä teollisuudessa

Diplomityö
2022
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Kunnossapitovelka on aihe, johon ei ole juurikaan kiinnitetty huomiota tieteellisessä kirjallisuudessa. Termi on kuitenkin varsin ajankohtainen ja siitä puhutaan usein uutisissa sekä artikkeleissa. Suomen infrastruktuurin tilaraportit ovat kiinnittäneet huomiota siihen, että keskeiset infrastruktuurit kuten rakennukset, tiet ja vesiverkostot ikääntyvät samalla kun korjausinvestoinnit eivät ole riittävällä tasolla. Lisäksi investoinnit suomalaiseen teollisuuteen ovat olleet useiden vuosien ajan pääoman alenemista pienemmät, mikä on johtanut fyysisen pääoman häviämiseen Suomen teollisuudesta.

Tämän diplomityön tarkoituksena on määritellä kunnossapitovelka käsitteenä, esittää sen luokittelu sekä eritellä mitä menetelmiä voidaan käyttää sen määrän laskentaan. Lisäksi analysoidaan käytännön tapaukset teollisuudessa ja infrastruktuurissa, joissa tavoitteena on laskea korjausvelan määrä tilinpäätöstietojen perusteella.

Diplomityön keskeisiä tuloksia ovat kunnossapitovelan luokittelu kolmeen alaluokkaan: operatiivinen-, kunnostus- sekä parannusvelka. Lisäksi esitetään neljä erilaista laskentamenetelmää: korjausvelka-, jälleenhankintahinta-, tekninen arvo- ja tasearvomalli. Kahdesta eri yrityksestä tehdyissä case tutkimuksissa käytettiin tasearvomallia, jonka avulla tilinpäätöstietojen pohjalta voitiin tehdä kunnossapitovelkalaskelmat, mutta tuloksista huomattiin myös useita arviointitavan puutteita ja huomioitavia tekijöitä.

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I would also like to thank my parents and my friends for supporting me throughout my studies, and for the people I have had the pleasure of meeting during this time of my life. The journey and writing this thesis have been challenging at times, but I am glad to have persevered and seen it through!

Espoo, 14th of June 2022

Aleksi Vainio

1 INTRODUCTION

1.1 Background

Industrial company investments in physical assets have trended downward, and companies have experienced greater annual depreciation compared to investments. Additionally, in pursuit of cost-effectiveness, companies have foregone preventive maintenance tasks and done the bare minimum to keep their infrastructure or machinery operational. This lack of investment and operational maintenance leads to so called maintenance debt, a topic which has not seen much focus in scientific research. Despite the lack of research focus, maintenance debt is topical, and the term is often used in various articles, news, and reports. (Finnish Construction Industry; Salminen & Kiuttu 2021; Zhang 2018; Finnish Association of Civil Engineers 2021)

While academic research on maintenance debt is scarce, the topic has been inspected by nationwide reports on the state of infrastructure. In the ROTI report (2021, p. 5) on the state of Finnish infrastructure, it has been estimated that Finland's infrastructure contains large amounts of maintenance debt due to its age and the lack of investment. The report states that for example the Finnish road network is by and large built in the 1960s and requires functional renovations in addition to improving its condition.

Additionally, the Finnish Water Utilities Association estimates that 30 % of Finnish water service networks and 37 % of built sewer networks will be over 60 years old by the year 2040. Total investments in water management should be doubled from 400 to 770 million euros a year and rehabilitation investments quadrupled to gain control of the maintenance backlog. (Kuulas 2020, p. 9; Finnish Association of Civil Engineers 2021, p. 5-7)

In other words, crucial infrastructure assets are aging while investments are not at sufficient levels. The same aging infrastructure phenomenon has been observed in other developed countries such as the United States (Alm et al. 2021; American Society of Civil Engineers) as well as in industry. Statistics by the Finnish technology industry state that around 6,4 billion euros of physical capital has disappeared from Finnish industry since 2008 and investments in fixed assets have been lower than capital depreciation for several years (Palokangas 2021, p.

59-60). While investments in physical assets do not directly reflect on maintenance that has been carried out, it does indicate that industrial fixed assets, e.g. buildings and machinery are aging due to a negative trend in investments that cover refurbishment as well as upgrades.

This thesis is done for Finnish maintenance society Promaint ry. It is the Finnish branch of the European Federation of National Maintenance Societies. Earlier research produced or funded by Promaint has focused on other aspects of maintenance. Their most recently funded thesis, released in 2018, focused on modeling the size of the Finnish maintenance market.

1.2 Research questions and objectives

The purpose of this thesis is to define and present a classification of maintenance debt as well as methods for evaluating the amount of maintenance debt. Additionally, practical cases in industry and infrastructure are analyzed with the goal of evaluating the amount of maintenance debt based on financial statement data. The research questions are as follows:

1. *What is the classification of maintenance debt?*

2. *How can the amount of maintenance debt be evaluated?*

3. *What are the results and lessons from the case evaluations of maintenance debt based on financial statement data?*

The study is limited with its focus on Finnish infrastructure and industry. The domestic focus can be seen in the empirical case analysis part of the thesis, which is done on an example from industry in Stora Enso, and infrastructure in Vaasa Water. For the case studies, financial statement data was gathered from as long a time period as was available from publicly available databases, in this case from the years 2003 through 2019.

The thesis aims to present a classification of maintenance debt based on its definition as well as how it can be evaluated. Being able to accurately identify and define a concept, in this case maintenance debt, is beneficial for further research and discussion of the topic. Future research might focus on the negative implications and ways to manage maintenance debt.

1.3 Research methods and data

The main research method used in this thesis is analysis based on financial statement data. The literature review on maintenance debt research focuses on identifying what constitutes maintenance debt and how it can be classified and evaluated. Maintenance debt is a topic that has seen limited focus in scientific research, which is why defining the term and classifying it has elements of concept analysis, however, not enough to call it a research method used in this thesis.

The goal of the literature review is to define maintenance debt based on maintenance standards and other fundamental sources. Scientific textbooks and articles as well as maintenance standards (SFS & ISO) will form the basis for the literature review in the paper. Additionally, as maintenance debt is a relatively unresearched term some web and newspaper articles as well as websites of maintenance organizations will be used for direct quotes on maintenance debt itself. In addition, publications by municipalities and groups linked to them are used for this reason, and they served as crucial sources for different evaluation methods.

Practical cases of maintenance debt in infrastructure and industry will be studied in the empirical part of the paper. For the purposes of the case studies, financial statement data is used in addition to information from annual reports. Data was gathered from Voitto+ database and annual reports available on the case companies' websites. Data was available for both case companies from the years 2003 through 2019, and evaluations were made utilizing the balance sheet value method presented in the thesis.

1.4 Structure of the thesis

After the first introductory chapter, chapters 2 through 5 make up the theoretical part of the thesis, focusing on defining the main topic of maintenance debt as well as its classification and evaluation methods. Chapter 2 details standardized maintenance goals, types, and its role as a part of asset management and managing the asset life cycle. Chapter 3 focuses on neglected maintenance, asset risk and how assets develop failures.

The main topic of maintenance debt will be examined in chapter 4, where the situation in Finnish infrastructure and industry is presented in chapter 4.1, followed by the classification of maintenance debt in chapters 4.2 and 4.3. Furthermore, the methods for evaluating maintenance debt are presented in chapter 4.4. Chapter 5 makes up the practical cases and empirical part of the thesis, while the overall summary of the results and suggestions for future research are presented in chapter 6. The structure of the thesis is displayed in Figure 1 below.

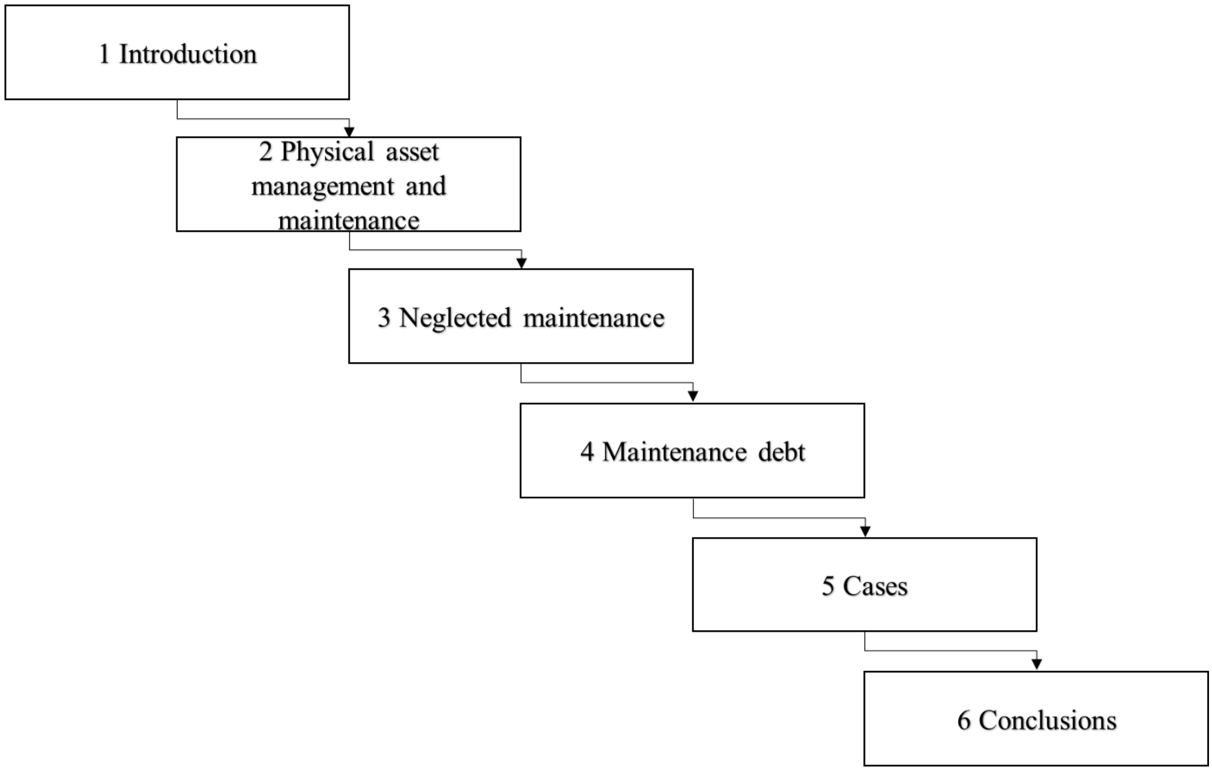

Figure 1. Structure of the study

2 PHYSICAL ASSET MANAGEMENT AND MAINTENANCE

2.1 Maintenance objectives

The definition of maintenance by the SFS-EN 13306 (2017, p. 8) standard is: “the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.” This definition suits the view that companies buy assets to perform a function. Securing the ability of assets to perform their function is what is expected of maintenance. This thesis focuses on maintenance related to physical assets, e.g., components, machines, plants, buildings, and other forms of infrastructure such as the road and water utility networks.

The fundamental objectives of maintenance strategy include the following (SFS-EN 13306, 2017 p. 6):

- ensuring the availability of assets to function as required, at optimum costs
- considering the safety, the persons, the environment and any other mandatory requirements considering the item
- considering any impact on the environment
- upholding the durability of the item and/or the quality of the product or service provided considering costs

Maintenance objectives can also be defined as targets for maintenance activities. Examples of such targets are increasing availability, reducing costs, improving quality, preserving the environment, improving safety, and preserving asset value. (SFS-EN 13306, 2017 p. 9) However, defining maintenance by its fundamental objectives can provide a view that is too concise and narrow, focusing on corrective maintenance.

Another common view is that maintenance is a part of asset management and consists of maintenance, adjustment, preservation and development of production assets. The standardized maintenance process includes the following sub-processes presented in Figure 2 below (SFS-EN 17007, 2017 p. 12-13):

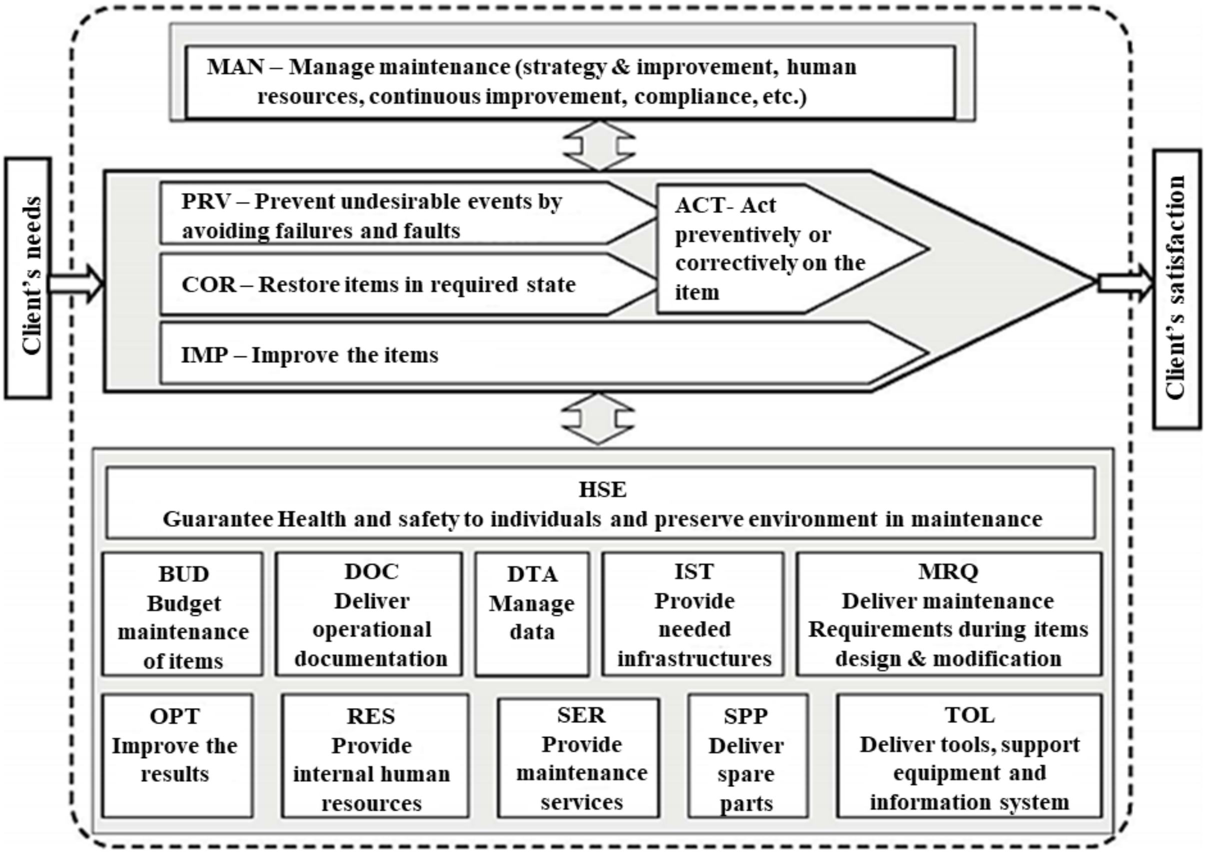

Figure 2. Maintenance process (Adapted from SFS-EN 17007, 2017 p. 12)

The three main process families are the management process as well as the realization, and support processes. The management process includes determining the maintenance objectives and allocating the resources to achieve them. The management process makes sure the realization and support processes are working together systematically. Management includes measuring and monitoring the realization and support processes and improving performance based on the results. (SFS-EN 17007, 2017 p. 8)

The realization processes have direct contribution to achieving the expected result from maintenance and include all activities related to the realization of the asset, such as restoring assets in their required state. The support processes provide necessary resources to the other processes, making the support processes essential for other processes to function. Support processes include activities associated with human, financial and material resources for example. (SFS-EN 17007, 2017 p. 9)

What is noteworthy about maintenance processes included in the realization processes is that in addition to implementing preventive and corrective repair actions maintenance should consider itself with improving the items. Maintenance debt can often be seen as the cumulative sum of neglected repairs but neglected improvements may also constitute neglected maintenance. Other sources also state maintenance activities should include determining the end of an asset’s life cycle as well as when and how an asset should be upgraded or modernized (Järviö & Lehtiö 2017, p. 19).

2.2 Maintenance types

Maintenance types are actions intended to verify the operating state of an item, keep the item in the desired operating state or bring it to the desired operating state. In the SFS-EN 13306 (2017, p. 58) standard maintenance types are divided into improvement, preventive maintenance and corrective maintenance as presented in Figure 3 below.

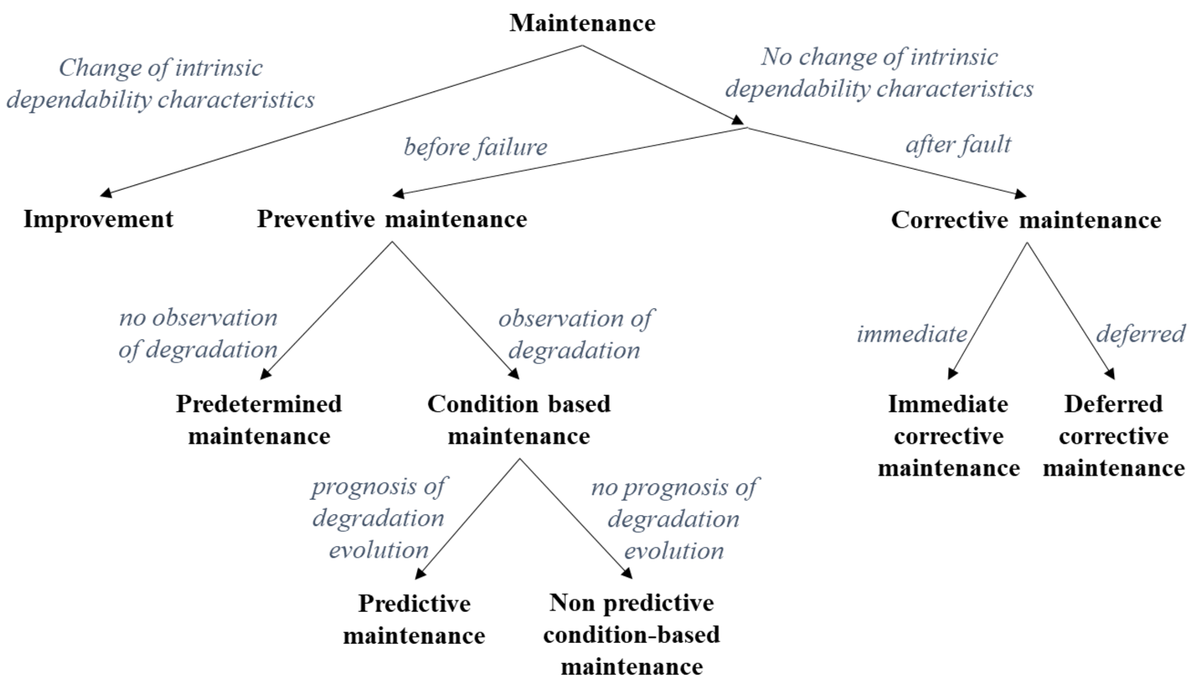

Figure 3. Maintenance types (Adapted from SFS-EN 13306, 2017 p. 58)

Preventive maintenance constitutes maintenance carried out to assess and/or to mitigate degradation and reduce the probability of failure of an item. There are two main groups of preventive maintenance: predetermined maintenance is carried out in accordance with established intervals of time, whereas condition-based maintenance includes assessment of physical conditions and maintenance actions based on the inspected asset condition. (SFS-EN 13306, 2017 p. 34-35)

Corrective maintenance constitutes actions taken to restore the required function of a faulty item and put it into the original state with respect to safety in operation. Corrective maintenance is reactive and takes place after the occurrence of a fault or failure, whereas preventive maintenance takes place before failure. (SFS-EN 13306, 2017 p. 38)

Improvement has to do with all technical, administrative, and managerial actions, intended to better the reliability, maintainability or safety of an item without changing the original function. Modification is the term used when the intention is to change one or more functions of an item. (SFS-EN 13306, 2017 p. 36-37) Refurbishment can be defined as bringing used products up to the same quality or the same quality standard as they were in previously. It includes the replacement of damaged and critical parts and making the product look like new. (DLL 2018, p. 4)

2.3 Asset life cycle

The life of an item is defined as the period from its conception to its disposal. The life of physical asset is defined as a period from its conception or acquisition to its disposal or transfer to the other responsible organization. Assets often go through recognizable life stages. The description and naming of the stages can have differences between assets or, their uses and organizations. (IEC 60300-3-3, 2004 p. 7; SFS-EN 16646, 2014 p. 7-9)

The life cycle of a physical asset is the period of value realization from a physical asset by an organization (SFS-EN 16646, 2014 p. 7-9). Life cycle refers to the phases included in the management of an asset (ISO 55000, 2014 p. 13). A life cycle and its stages are presented in Figure 4 below, consisting of 6 phases from concept to disposal.

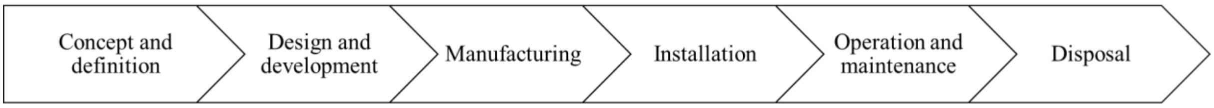

Figure 4. Asset life cycle (Adapted from IEC 60300-3-3, 2004 p. 12)

The lifetime of an item is the time interval during which an item is able to perform the required function, not terminating until the item is no longer technically or economically repairable as a result of failure. When managing its physical assets, the organization should consider all the life cycle stages and their impacts (SFS-EN 16646, 2014 p. 9)

The useful life of an asset begins at the start of its operation and ends when the failure rate becomes too high, or when the item is considered irreparable. Useful life can also end because of economic, environmental or safety reasons. The useful life of an asset is the time period where there is a low risk of failure and a high reliability rate. (Hastings 2015, p. 378)

A life cycle asset management plan is formed by identifying the how the asset will be operated, and what maintenance, restoration and renovation activities should be associated with it, as well as the planned life, and the disposal plan of the item (Hastings 2015, p. 151). An accumulation of maintenance debt can be the result from not following the set asset management plan, and perhaps shorten the planned useful and operational life of the item or cause other unexpected breakdowns and errors. In other words, how the asset will be maintained, upgraded, and ultimately retired should be decided early in the asset life cycle.

2.4 Maintenance as a part of asset management

Asset management constitutes the “co-ordinated activity of an organization to realize value from assets” (ISO 55000, 2014 p. 14). An extended definition by Hastings (2015, p. 10) states that given a business or organizational objective, asset management is the set of activities associated with:

- identifying what assets are needed

- identifying funding requirements
- acquiring assets
- providing logistic and maintenance support for assets
- disposing and renewing assets

The aim of asset management is to enable the organization to have the assets that are suitable to its needs, and to provide support so that these can function properly. In other words, the aim of asset management is to enable an organization to realize value from its assets while it pursues organizational objectives. Asset management supports the realization of value while balancing financial, environmental, and social costs, risk, level and quality of service, and asset performance. Moreover, it enables managing an asset analytically over the different stages of its life cycle which can start with the realization of the need for the asset, through to its disposal. (Hastings 2015, p. 10; ISO 55000, 2014 p. 3)

Optimal asset management minimizes the total life cycle cost of an asset and hence maximizes value for investment and stakeholders' satisfaction (Okoh et al. 2016, p. 22). Successful utilization of an asset management plan throughout an asset's life cycle lengthens the useful life period of an asset, maximizing return value from an investment. The efficiency of maintenance can be assessed based on overall equipment effectiveness (OEE), which is composed of availability, performance rate and quality rate. (SFS-EN 16646, 2014 p. 32)

Maintenance has an important relationship with asset management that is not limited to the operational maintenance stage in an item's life cycle. The role and tasks of the maintenance function include among other factors a significant role in planning and deciding physical asset solutions and active participation and consultative roles in the acquisition, design, manufacturing and installation phases of an asset's life cycle. (SFS-EN 16636, 2014 p. 18-19)

For the operational life cycle stage of an item the maintenance function is largely responsible or has active participation in asset management tasks such as defining the maintenance strategy and maintenance plan as well as active maintenance operation. Moreover, the maintenance function has consultative or active participation in the decision-making process of whether an asset should be upgraded or disposed of. (SFS-EN 16636, 2014 p. 18-19; Järviö & Lehtiö 2017

p. 19) In other words, the maintenance function is in many ways closely interlocked with asset management and has consultative as well as more active roles in the decision-making process and active tasks over the entire asset life cycle from concept to disposal.

3 NEGLECTED MAINTENANCE

3.1 Neglected and deferred maintenance

The continuous demand for short-term profitability has in many instances led to inefficient long-term decisions as operational maintenance costs have been forcefully decreased (Komonen, 2012). Regular preventive maintenance is key to maximizing service life and minimizing service disruptions. Neglecting the maintenance of infrastructure or production assets by deferring it to future years may be an easy option in the short term, but this creates several indirect issues. Over time, more corrective maintenance may be required, which tends to be more costly than planned maintenance (Sinkkonen 2015, p. 28; Smith & Hinchcliffe 2004, p. 3). Additionally, neglecting preventive maintenance can accelerate asset deterioration, reducing the expected remaining useful life and compromise the function of assets. (Chemweno et al. 2016, p. 133-134).

Deferring maintenance tends to reduce the expected remaining useful life, as it accelerates asset degradation. On the contrary, implementing preventive maintenance tends to prolong the asset's remaining useful life and reduce the need for replacement parts. However, there can be downsides to implementing extensive repair actions such as unnecessary stoppages, higher spare parts costs and lowering asset performance when equipment is restored to the same or worse condition than before (see e.g. Chemweno et al. 2016, p. 134-140).

It is also worth noting that deferring maintenance has effects for others as well, not just the asset owner. For example, substandard roads with potholes cause damage to vehicles, leading to higher costs for drivers. The opposite is also true, an infrastructure in good condition supports the overall economy and attracts investment to the area, contributing to economic growth and employment. (Asset Management BC 2019, p. 11)

It is important to note that extensive preventive maintenance isn't always the right way to execute maintenance in all situations (Sinkkonen 2015, p. 28) and research exists to suggest that depending on e.g., the market situation deferred and/or corrective maintenance may be the right way to go (Komonen et al. 2012), and in some cases even a run-to-failure strategy can be the most feasible option for e.g. non-critical and low-cost assets (Arjomandi et al. 2021, p. 12).

For these reasons, a balance is often necessary between doing the bare minimum and on the other hand carrying out extensive maintenance actions. More importantly, the optimal balance needs to consider aspects such as fault severity and impact of the maintenance actions on the asset's remaining useful life. In literature many analytical models and frameworks have been proposed for optimizing maintenance decisions such as intervals for performing preventive maintenance (e.g. de Almeida 2012). But the science in that area is far from definitive as well as outside the scope of this thesis.

3.2 Asset failure patterns

When infrastructure or production assets age, the condition deteriorates due to wear and tear. Counteracting these effects and maintaining the ability of an asset to perform its function is a key part of maintenance operations. However as stated in the previous chapter, the pursuit of cost-effectiveness can result in neglected maintenance, allowing the condition of the asset to continuously deteriorate. An asset failure constitutes the loss of the ability of an item to perform a required function (SFS-EN 13306, 2017 p. 26). A generic potential-to-failure curve is presented in Figure 5 below.

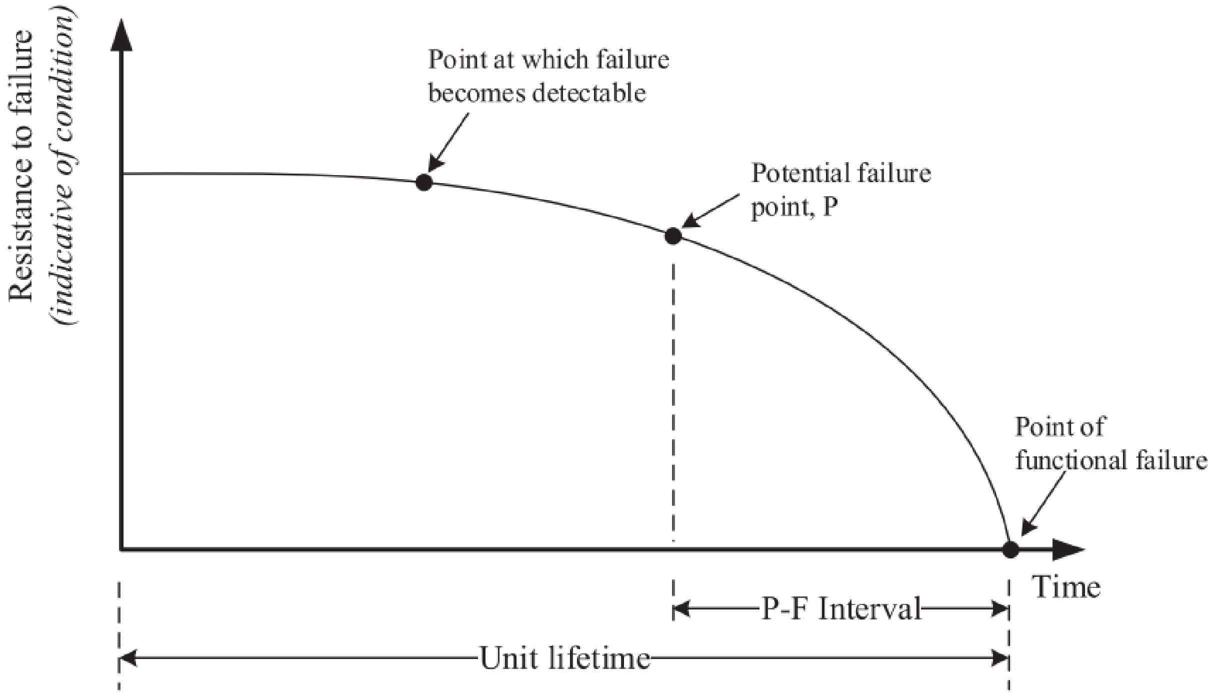

Figure 5. A generic P-F Curve (Ochella et al. 2021, p. 4)

It is named the P-F curve because it indicates the point at which the failure of an asset becomes detectable. This point is indicated as the potential failure point, P, in Figure 5 above. In the beginning of the life cycle of an asset, failure is undetectable for a certain time because all the indicators and measurements, such as temperature and oil pressure, do not yet show signs of degradation. However, eventually the damage becomes severe enough to be detected by the indicators. The time from the actual point of detection of potential failure to the point of functional failure is referred to as the P-F interval. It is beneficial for the P-F interval to be long enough for both the decision-making and for carrying out actual maintenance to extend asset life. (Ochella et al. 2021, p. 4)

The longer the P-F interval, the more time there is to make an informed decision on what the maintenance action plan should be. In cases where the condition of the asset is not closely inspected e.g., in infrastructures such as water and sewage networks, the P-F interval is shortened which promotes the emergence of unexpected failures. In a study Koukoura et al. (2021, p. 1) note the benefits of a longer P-F interval, highlighting that reduced operation and maintenance costs can be achieved by planned interventions before asset failure.

Moreover, not all assets develop failures the same way. There is a generally accepted 'bathtub curve' depicting the failure rate of an asset throughout its life cycle, presented in Figure 6 below. The curve depicts three different life-cycle stages. In the early stages of deployment, there are some residual sub-standard parts and materials that are not noticed by the manufacturer. Initially these factors produce a failure rate that is larger than the expected long-term failure rate. This first phase is called the infant mortality stage. (Smith & Hinchcliffe 2004, p. 48)

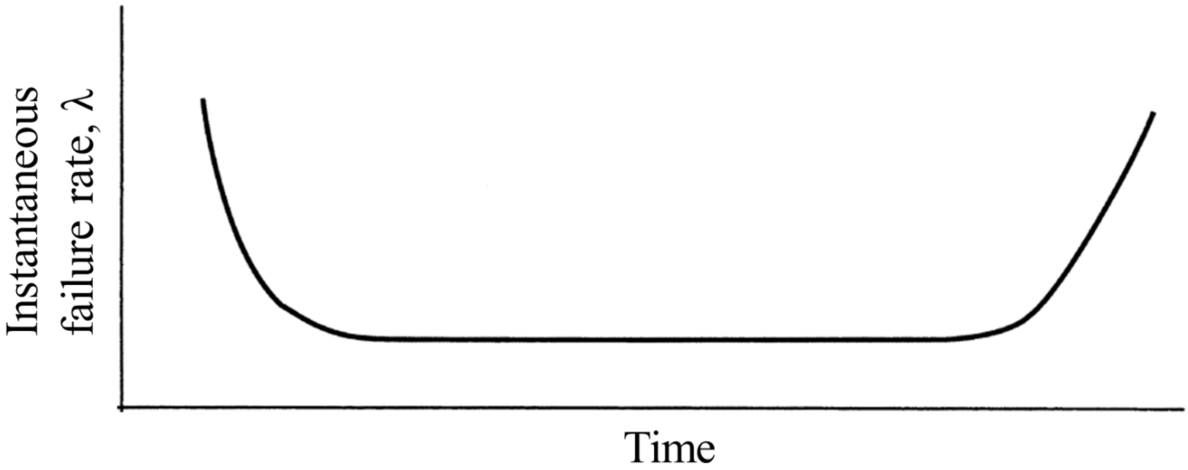

Figure 6. The "bathtub" model (Adapted from Smith & Hinchcliffe 2004, p. 48)

When the early asset infancy stage is complete, it is followed by the constant failure rate phase. In this phase failures are more random, and the reliability of the asset has become more stable. In the final third phase asset aging and wearout start developing due to fatigue, deterioration as well as changes in material property. Because of this the failure rate start to increase. This third phase is called the aging and wearout stage. (Smith & Hinchcliffe 2004, p. 48-49)

In addition to the bathtub model other failure models exist, namely the six patterns of failure shown in Figure 7 below, that are commonly depicted in literature on Reliability Centered Maintenance (RCM). It is notable that while patterns A, C and C illustrate a direct relationship between age and probability of failure, patterns D, E and F illustrate otherwise. That is, most failures occur randomly. (Regan 2012, p. 9)

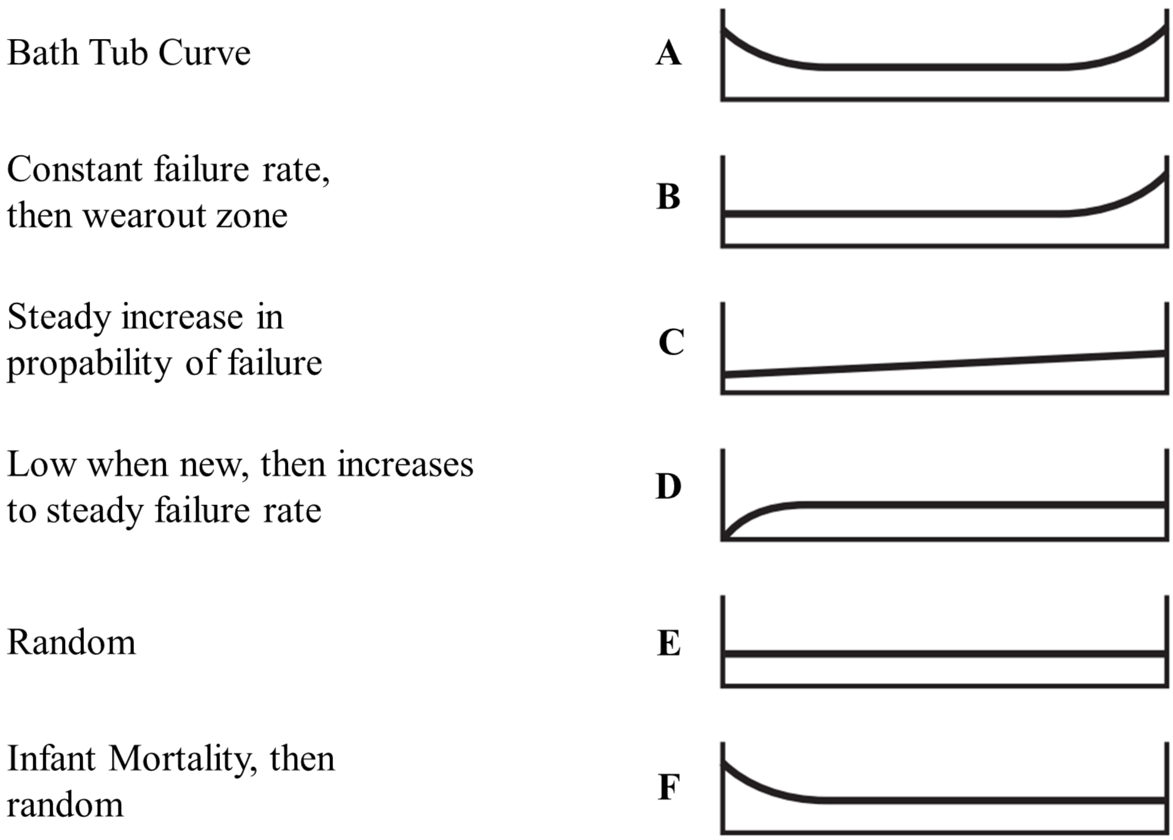

Figure 7. Six Common Failure Patterns (Adapted from Regan 2012, p. 9)

The failure rate of an asset can’t always be controlled by preventive maintenance actions. For example, extensive efforts to control the failure rate of an asset with extensive preventive maintenance can be counterproductive and make things worse by reintroducing infant mortality all over again. (Regan 2012, p. 12) On the other hand, neglecting preventive maintenance to control the failure rate leaves corrective maintenance as the remaining option.

Preventive maintenance is done pre-emptively to avoid possible failures and replacing worn-out parts before actual failures occur. As noted in the previous chapter, total costs arising from a corrective repair action are usually higher than costs of preventive maintenance due to the acuteness of the work. Preventive maintenance aims to prevent breakdowns, but in some cases, it may be more economical to run the production equipment to failure. The core principle of RCM in maintenance research is being aware of asset risks and managing the consequences of asset failure, rather than trying to prevent all failures from occurring (Regan 2012, p. 3).

3.3 Asset risk and criticality analysis

As stated earlier, the goal of asset management is supporting the realization of value from assets. Criticality analysis is contributes to this goal by providing a basis for prioritizing assets within a maintenance management program. It can be a vital tool to maximizing the availability of assets. (Márquez et al. 2018, p. 144)

When deciding which assets should have the priority in maintenance, several qualitative as well as quantitative methods exist in literature. One of the main uses of criticality analysis for maintenance purpose is that it is used to provide input into asset management so that the most critical equipment is given a higher priority for preventive maintenance, refurbishment as well as replacement. (Adams et al. 2016, p. 104)

Although different methods exist, they vary mostly in depth. What connects all methods for calculating asset criticality is that the criticality number (C) is calculated from factoring the propability of failure (PoF) or occurrence (OC) with the severity (SE) of a possible failure (Adams et al. 2016; Márquez et al. 2016; Suwanasri et al. 2021). According to company specific maintenance objectives and key indicators, the criteria and the relative weighting to assess severity and probability may have big differences. A general criticality matrix is presented in Figure 8 below, where criticality values wary from low (L) to medium (M), high (H) and very high (VH).

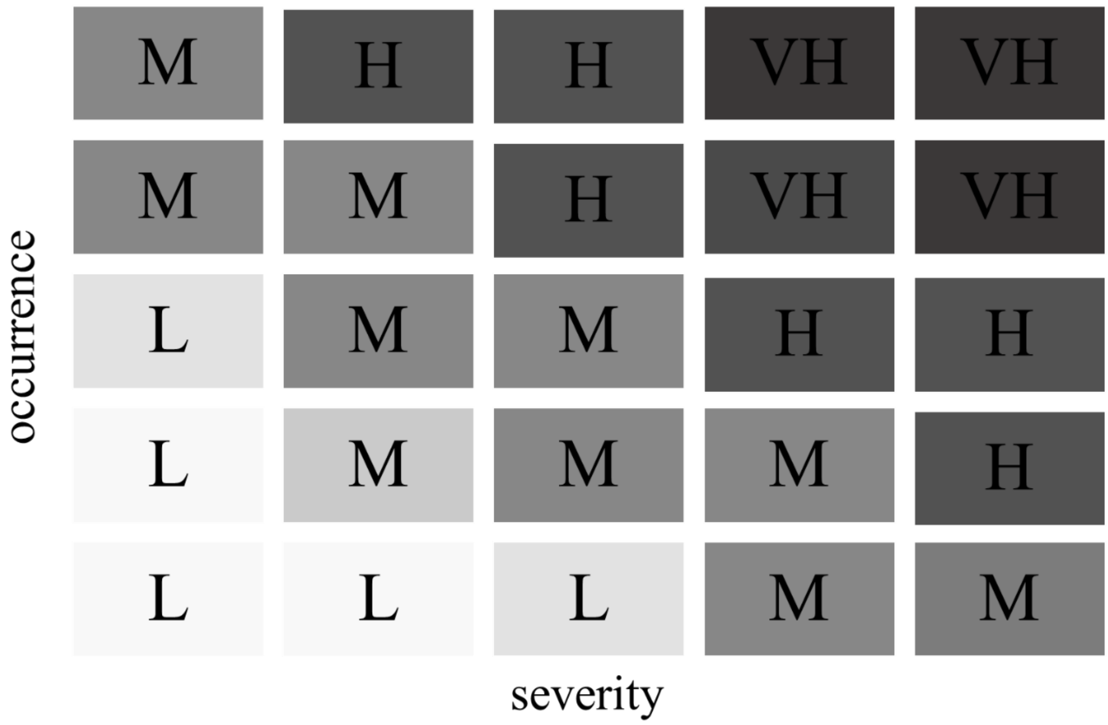

Figure 8. Criticality matrix (Adapted from Suwanasri et al. 2021, p. 4)

Of course, assets with the higher criticality number (C) will be recognized to be the more critical assets and will deserve special attention from maintenance management. Criticality can also be looked at from different perspectives such as efficiency, safety, environment and finance (Suwanasri et al. 2021, p. 4) Ultimately how criticality analysis is utilized is a matter of maintenance strategy. As an example, assets that are deemed highly critical may be prioritized and allocated most if not all maintenance resources, while non-critical assets may be left to run to failure or maintained with a tight limit on budget.

In summary, asset criticality is a useful indicator for determining optimal time of maintenance or replacement for assets to minimize operational maintenance costs. For successful asset management, asset-intensive organizations both private and public must understand the risk profile associated with their asset portfolio and how this will change over time. (Adams et al. 2016, p. 103)

4 MAINTENANCE DEBT

4.1 Maintenance debt in Finnish infrastructure and industry

Maintenance debt is a relatively new concept, and many asset owners do not even know their assets or especially the condition or development needs of their assets. The pursuit of cost-effectiveness results in neglected maintenance which in turn incurs maintenance debt and raises its amount. By one definition maintenance debt is a calculated figure that describes how much money has not been invested in fixed assets in recent years, so that the assets would still be in good condition (Vehmaskoski et al. 2011, p. 4). Another definition says that maintenance debt refers to the sum of maintenance work that should be done to restore the asset to good condition fit for current use (Finnish Association of Civil Engineers 2013, p. 6). There are several other definitions thrown around in infrastructure reports and news articles which goes to show the need for clarification and further research on the topic.

The concept of maintenance debt can be used to describe both the current situation and present the need for maintenance. In addition, it can be used to assess existing policies and their effectiveness, and to predict future developments. The amount of maintenance debt is an important factor in longer and shorter-term action planning. (Kesälä & Koivula 2012, p. 3)

One of the primary reputable sources on maintenance debt is the ROTI-report on the state of Finnish infrastructure made by the Finnish Association of Civil Engineers (RIL), which brought up the term maintenance debt as early as 2007. This biennially published report produces expert information on the state and trends of Finnish infrastructure such as buildings, transport networks including roads and railways, as well as other utility infrastructure like the water supply network. In this chapter and study, we will classify and examine Finland’s infrastructure through these 3 groups: buildings, transition network and civil engineering systems.

According to their 2017 report, Finland’s buildings contain approximately 30 – 50 billion of maintenance debt, the transition network 5 billion with another billion of debt in public utilities such as the water supply network (Finnish Association of Civil Engineers 2017, p. 4). Additionally, according to the latest report released in 2021, an average of EUR 9.4 billion should be invested in renovations of residential buildings in 2016–2025. In the next ten years, the maintenance debt in Finnish residential buildings will continue to grow by EUR 1.1 billion. In the municipalities' service building base, the evaluated maintenance debt is 9 billion euros. Considering all today's operational needs and quality requirements, the need for renovation of municipal buildings amounts to EUR 16.5 billion. (Finnish Association of Civil Engineers 2021, p. 5)

The road network dates largely back to the 1960s. In addition to improving fitness, it needs a functional update to meet current requirements. Currently the Finnish government spends approximately 1 billion euros a year on basic transition network repair, slightly over half of which is spent on the road network. The amount has remained at the same level for 15 years, during which inflation has eaten up a third of the purchasing power. Due to the lowering level of spending the condition of the road network has continued to deteriorate, making the required repairs more expensive. According to statistics by the Centre for Economic Development, Transport, and the Environment (ELY) the road network already contains approximately 1 billion euros worth of maintenance debt. **(**ELY 2021, p. 2-3**)** The Finnish Transport Industry (Väylävirasto) estimates a maintenance deficit of 1.6 billion in the road network, with 2.9 billion overall in the transition network (Finnish Transport Industry 2020, p. 3). Their estimate for the classification of maintenance debt in different elements of the Finnish transition network is presented in Table 1 below.

Table 1. Maintenance debt in the Transition Network, Million € (Data from Finnish Transport Industry 2020, p. 3)

Pathway type	Road network	Railway network	Waterways	Total
line sections	1292	893	8	2193
engineering struct.	249	92	10	352
appliances	0	222	17	239
equipment	38	30	3	70
Total	**1580**	**1237**	**37**	**2854**

The Finnish Transport and Communications Agency (Traficom) notes that trading and industrial companies' logistical costs amounted to roughly 13,5 % of their revenue in 2019 (Traficom, 2021). The share of logistical costs varies depending on area of industry and location. A well-functioning transition network lowers companies' logistical costs, and in addition to cost benefits companies gain efficiency gains from a good logistical network. Companies can receive raw materials and supplies as well as deliver end products without delays and warehousing costs. A study funded by various central governmental agencies, unions and other groups estimated that a refurbished road network would cause an average 6,8 % reduction in transmission costs to Finnish forest industry alone. In 2012 that would amount to yearly savings of roughly 25 million. In transmission costs of all industries the savings would be double. (Holm et al. 2015, p. 13-18)

Moreover, the water supply network also dates largely back to the 1950s and 60s (Figure 9). Total investments in water supply should be almost doubled (400 million € -> 770 million €) and investments in the renovation of water supply networks must be quadrupled to manage maintenance debt and ensure the reliability of the networks. (Finnish Association of Civil Engineers 2021, p. 5) The renewal period for these networks is at hand, as the technical life of the pipes is about 50 years (Vesi.fi, 2019).

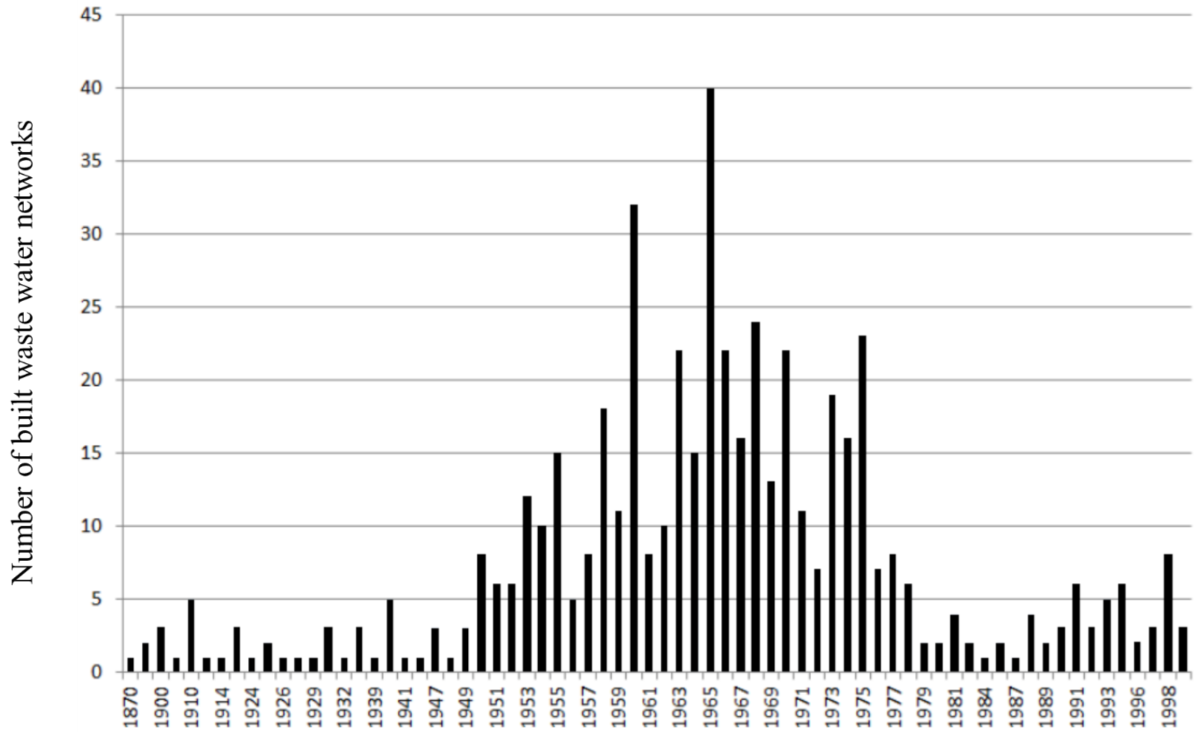

Figure 9. Number of built wastewater networks by year (Adapted from Finnish Environment Institute 2017, p. 3)

The deteriorating condition as well as the fact that maintenance and investments have been deferred can be clearly seen in the increase of disturbances and other issues in the water supply network, demonstrated in Figure 10 below. Civil engineering systems have a special characteristic in that they are often not visible. Because of this their existence is often forgotten, and unawareness over their actual condition is common. Maintenance and repair activities are remembered only when some system develops a functional fault. At this point a sizable maintenance debt has had time to develop and the required repair job ends up being more expensive in life cycle costs when compared to continuous planned maintenance. This is the case when it comes to the water supply network for example. (Kesälä & Koivula 2012, p. 6)

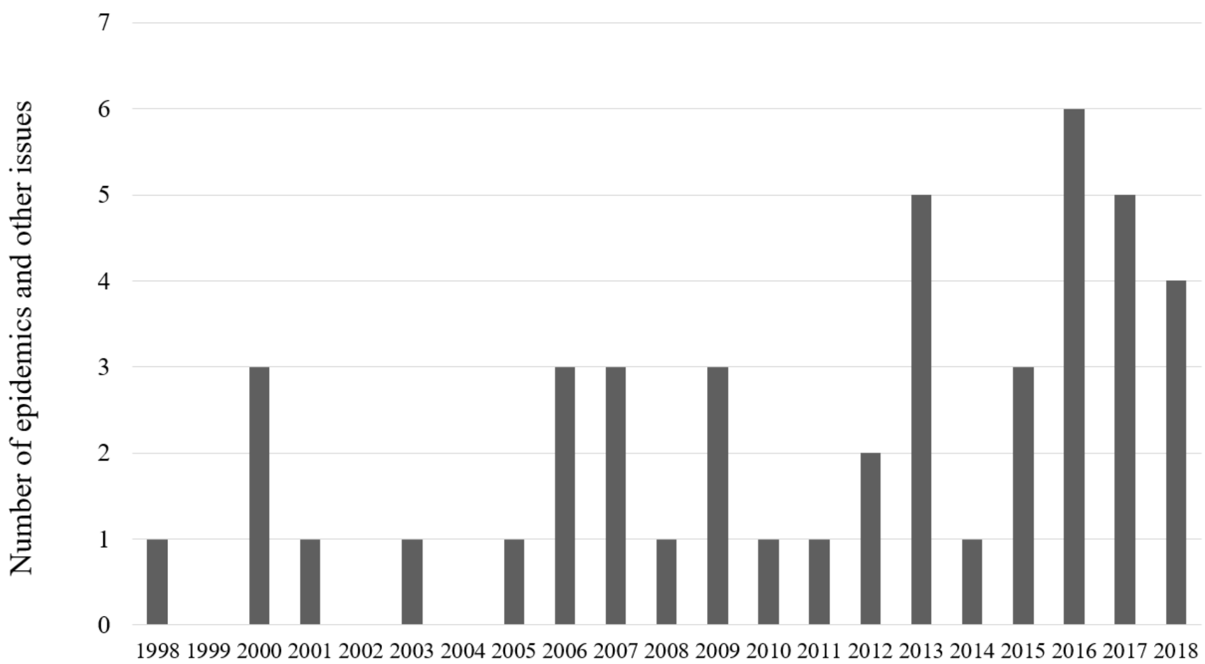

Figure 10. Water supply epidemics and other issues 1998 - 2018 (Adapted from Belinskij & Saarinen 2019, p. 2)

In this thesis we are examining maintenance debt in Finnish industries in addition to infrastructure, and with that said it is important to note that maintenance debt in infrastructure also effects industry. According to the Finnish Forest Industry ‘the smoothness of domestic logistics is a vital condition for successful exports’ (Koskela, 2021). As mentioned in chapter 3.1, a well-maintained infrastructure supports the overall economy, but the inverse is also true.

Estimates by the ROTI report state that the currently existing maintenance debt in Finnish infrastructure in effect lowers the national GDP and employment rate by 2 % yearly, and company turnover by 57 billion over 10 years. (Finnish Association of Civil Engineers 2017, p. 4)

In industrial companies fixed assets consist mainly of buildings, machinery, and other equipment, where the same definitions for maintenance debt apply. While maintenance debt in Finnish infrastructures has been estimated and reported in a few reports, such as the ROTI report, in addition to studies by governmental agencies and municipalities, the same cannot be said for branches of industry. Some reasons for this may be evident, as estimating the maintenance debt in infrastructure based on current condition or based on government spending is difficult but doable, but those methods aren't applicable to industries, where fixed assets are company-specific, less homogenous, and often more technical than a piece of concrete road. Companies may analyze the amount of maintenance debt in their own assets based on internal data if such estimates are done at all.

However, regarding macro trends in industrial maintenance it is stated predictive maintenance is one of the highest-ranked business cases in manufacturing industry (McKinsey Global Institute, 2016). Meanwhile, many industrial companies are falling behind due to underinvestment in developing maintenance, resulting in substantial maintenance debt (Lundgren et al. 2021, p. 203). While there are no evaluations for the amount and development of maintenance debt in industry, some indication about the condition of fixed assets in industry may be found by looking at investment statistics.

Statistics by the Finnish technology industry state that around 6,4 billion euros of physical capital has disappeared from Finnish industry since 2008 and investments in fixed assets have been lower than capital depreciation for several years, see Figure 11 below (Palokangas 2021, p. 59-61). While investments in physical assets do not directly reflect on maintenance that has been carried out, it does indicate that industrial fixed assets e.g., buildings and machinery have been aging due to a negative trend in investments that cover refurbishment as well as improvement investments.

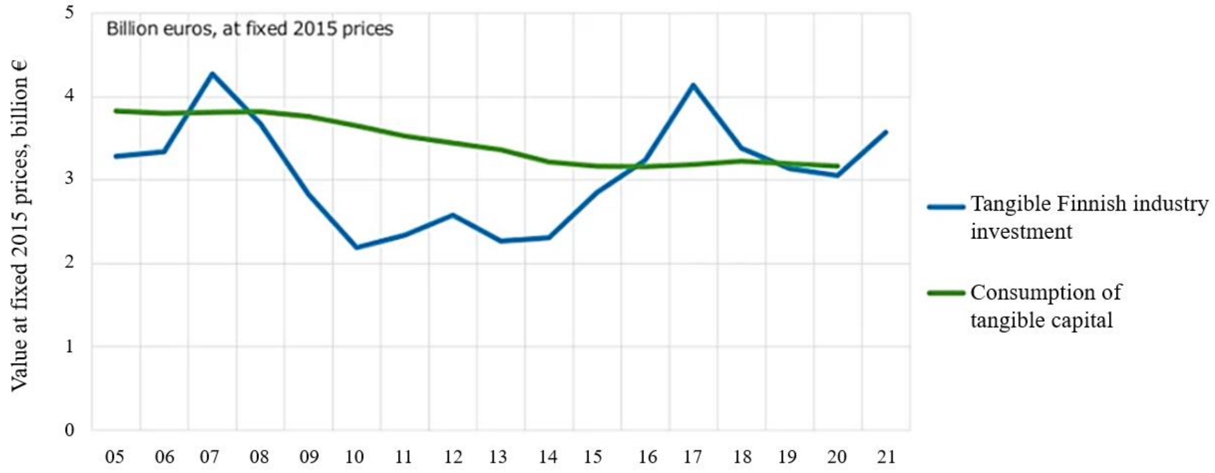

Figure 11. Tangible investments by Finnish industry vs. tangible asset consumption (Palokangas 2021, p. 60)

Additionally, statistics show that when compared with many European counterparts, Finland has lagged behind in tangible industrial investments (Figure 12). One might think Finnish industry needs well-conditioned assets fit for purpose to stay competitive. In order to achieve that, investments should be made to improve its productivity, quality and ultimately cost-effectiveness.

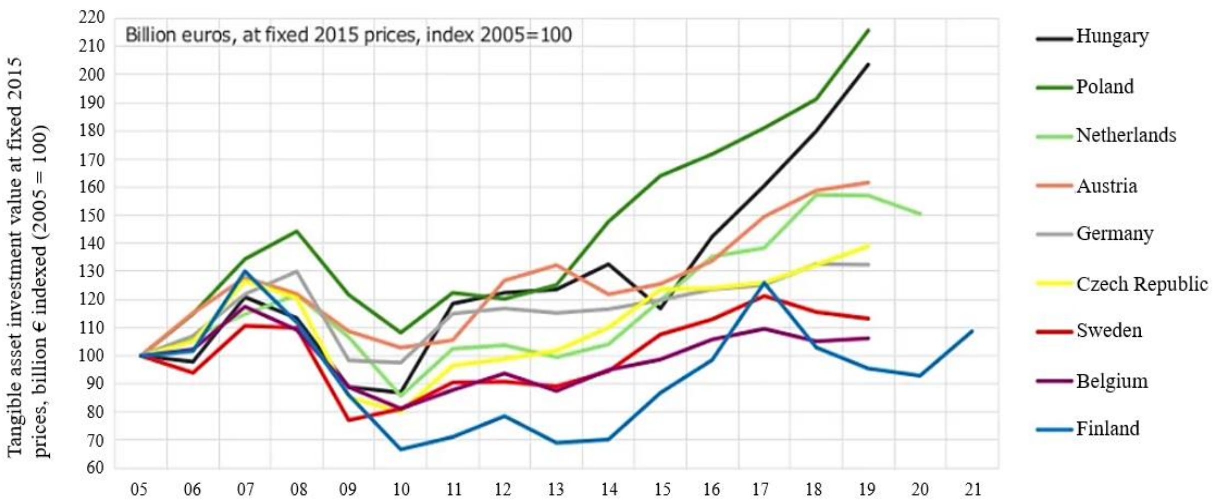

Figure 12. Investments in tangible assets yearly, indexed (Palokangas 2021, p. 62)

Yet statistics show that total investments (tangible and intangible) dropped from 2010 onwards and when considering inflation haven’t returned to their old levels. In fact, investments in the electricity and electrical industry have roughly halved between 2010 and 2018 (Figure 13), which outshines the fact that investments in other industries have stayed equal or in some cases grown.

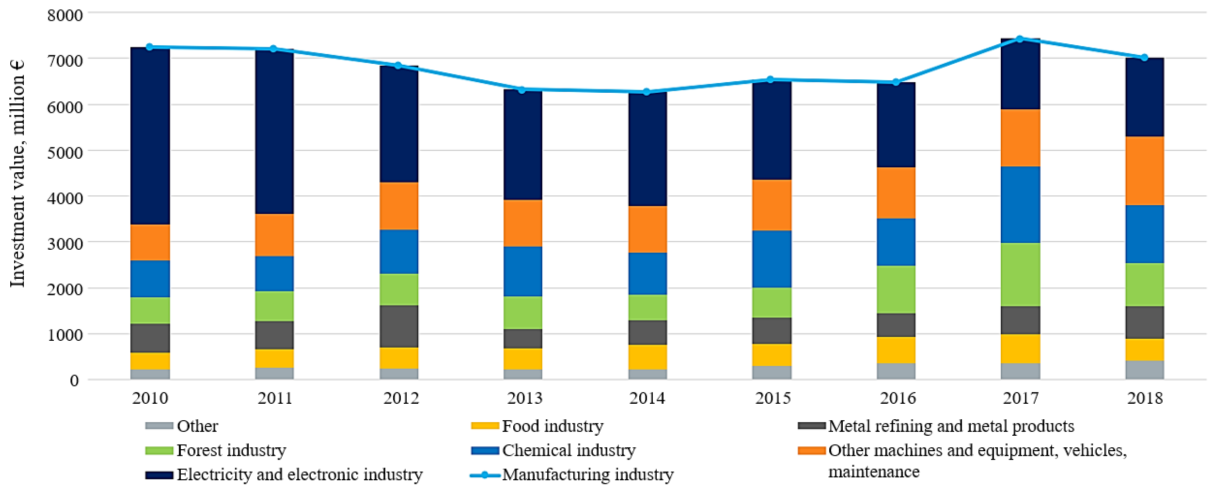

Figure 13. Investments by industry 2010 – 2018 (Finnish Forest Industries 2018, p. 4)

With the distant geological location of Finland and the challenges that it presents, additional delays or hinderances caused by a faulty transition network cannot be afforded (Finnish Forest Industries 2021) Finland's industrial competitiveness will continue to be based on well-functioning infrastructure, especially it's transport connections, and this requires an active dialogue with the business community.

In summary, it is estimated that the total yearly bill caused by the existing maintenance debt in Finnish infrastructure amounts to 3,4 billion euros a year, or 1300 euros per household. It causes a yearly decrease of 2 % in GDP and jobs (approximately 37 000 jobs) and reduces company turnover by 57 billion euros over 10 years. (Finnish Association of Civil Engineers 2017, p. 4) Estimates for the existing amounts on maintenance debt in Finland's key infrastructures (buildings, transition network and civil engineering systems), in comparison to asset values and Finland's projected budget for 2022 are presented in Table 2 below.

Table 2. Maintenance debt in Finland's infrastructures, value of the infrastructures and Finland's projected budget for 2022. (Data from ELY-keskus; Finnish Association of Civil Engineers 2021, p. 48; Finnish Government 2021)

	Buildings	Transition network	Civil engineering systems
Amount of maintenance debt (billion €)	30 - 50	3 - 5	1
Total value of assets (billion €)	500	55	51,6
Maintenance debt / value of asset group (%)	6 - 10 %	5 - 9 %	2,4 %
Maintenance debt / Finland's projected budget 2022 (%)	46 - 77 %	5 - 8 %	1,5 %

Moreover, a study conducted by IMF regarding the macroeconomic effects of public investment notes that well defined and efficiently conducted public infrastructure investments have added to economic growth in both short as well as the long term within the past 30 years. Additionally, it is noted that well defined and efficiently completed public infrastructure investments have lowered the public Debt-to-GDP ratio. (Abiad et al., 2014) Considering the negative effects of the currently existing maintenance debt in Finland as well as the possible benefits of eliminating maintenance debt for Finland's competitiveness and industries noted in this chapter one would consider it beneficial for Finland to invest in its infrastructure.

4.2 Basis for classifying maintenance debt

As mentioned in chapter 2 of this thesis on asset management and maintenance, maintenance is defined as: "the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (SFS-EN 13306, 2017, p. 8). In the same chapter the maintenance process was detailed. Key elements of the maintenance realization process (see Figure 14 below) consist of 3 sub-processes, prevent, restore, and improve (SFS-EN 17007, 2017 p. 12).

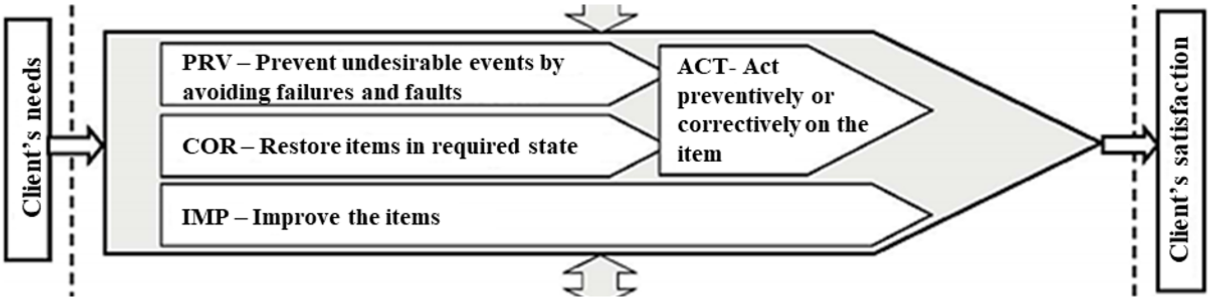

Figure 14. Elements of the maintenance realization process (Adapted from SFS-EN 17007, 2017 p. 12)

In the Finnish Road Network Administrations report on the ERANET maintenance backlog model (2009, p. 13) it is stated that maintenance actions are often grouped in-to 3 main groups: routine maintenance, programmed maintenance, and renovation investments. Routine maintenance refers to smaller tasks both in duration and impact, programmed maintenance depicts long-acting maintenance actions meant to restore an assets condition to optimal level, and renovation investments include major overhauls meant to restore or improve an asset's condition.

Additionally, in the technical value evaluation principle (presented in chapter 4.4) three distinct categories of maintenance debt are presented: maintenance debt, need for refurbishment and need for improvement (Korhonen et al. 2018, p. 10-11). In summary, classifying maintenance in these 3 categories is common and it provides the basis for the classification proposed in this thesis.

4.3 Classification of maintenance debt

Operational maintenance debt

Operational maintenance debt represents the first category, and it includes frequent, day-to-day, or monthly routine maintenance tasks that are neglected, accumulating maintenance debt. These tasks are smallest in budget and length (timeline $t < 1$) e.g., changing a fuse or a monthly oil change on an engine, and the goal is often to prevent undesirable events by avoiding failures and faults. These routine maintenance costs are directly recognized as expenses in the organization's income statement.

Operational maintenance tasks have the potential to maintain or restore an asset's condition up to the optimal level (e.g., 75 %). Accumulating operational debt is gradual as small maintenance tasks have little effect on the current value of an asset initially. However, if routine maintenance is neglected and operational debt is accumulated over a long period of time it is possible to develop more serious faults and failures that have a more sudden and major impact on asset value, e.g., complete engine failure due to dirty oil, requiring a completely new engine.

Refurbishment debt

Regarding maintenance tasks mentioned in chapter 2, refurbishment can be defined as bringing used products up to a certain, pre-determined, quality standard. It involves the replacement of worn and critical parts, and aesthetically making the product look like new. (DLL 2018, p. 4) Refurbishment debt is accumulated from neglecting medium-sized maintenance tasks and projects (timeline $1 < t < 5$), that are done once a year or less frequently. An example would be renewing the pistons of an engine or restoring a worn-out bridge using more modern materials.

Based on the type of maintenance project some costs are directly recognized as expenses in the income statement and some are recognized as investments and deducted over multiple years through depreciations. Individual refurbishment projects can have a notable impact on an asset's value, even restoring it above the minimal limit of optimal condition up until a good-as-new condition level (90 – 100 %).

Improvement debt

By one definition improvement is the combination of all technical, administrative, and managerial actions, intended to better the reliability, maintainability, or safety of an item without changing the original function (SFS-EN 13306, 2017 p. 36-37). Within this thesis and classification this group includes the largest maintenance projects in size and scope that are done once a decade or less frequently, e.g., upgrades, rehabilitations and replacements that extend an asset's useful life. An example would be a major production equipment overhaul or upgrade.

All maintenance tasks in this group are recognized as investments and deducted from the income statement through depreciations. Additionally, completing improvement maintenance projects will always bring asset value above the minimal limit of optimal condition, sometimes improving it above 100 %. The classification of maintenance debt is detailed in Table 3 below.

Table 3. Classification of maintenance debt

	Operational maintenance debt	Refurbishment debt	Improvement debt
Maintenance type	Routine	Restoration	Improvement projects
Frequency	Day-to-day or monthly tasks	Once a year or less frequently	Once in an asset's life cycle
Cost	Low	Medium	High
Timeline	t < 1	1 < t < 5	5 < t
Costs recognized as	Expenses	Expenses OR investments	Investments
Getting rid of debt will	Maintain or restore asset condition to optimal (e.g., 75 %)	Restore asset condition up to good-as-new (90-100 %)	Improve asset condition (100 % or higher)

4.4 Methods for evaluating maintenance debt

There is no uniform way of evaluating maintenance debt, as at the outset it is difficult to dictate what definition you're going by e.g., whether maintenance debt is the cost of bringing an asset back to optimal condition or is maintenance debt a cumulative figure of neglected maintenance?

In addition, even when going by the same definition it isn't easy to objectively evaluate what counts towards maintenance debt and how you assess asset condition.

Maintenance backlog model

In 2009 the ERANET Maintenance Backlog Model was developed and reported by an international consortium consisting mainly of national road administrations. The project (named ERANET) developed the first guidelines for evaluating maintenance debt in the road network. The use of the model requires that asset information can be grouped, and sufficient condition information is available. (Finnish Road Administration 2009, p. 6)

In the model maintenance debt is defined as "the amount of unfulfilled demands at a given point in time in explicit reference to the predefined standards to be achieved. Maintenance debt can be expressed in functional (non-monetary) or monetary terms and it refers to single components, sub-assets or to the whole road infrastructure asset of a given road network" (Finnish Road Administration 2009, p. 6).

The model has been adapted and seen variations by e.g., the Finnish Transport Industry (Dietrich et al. 2017) and by municipal groups (e.g. Kaarlehto & Lauksio 2017). The basic evaluation principle has remained the same and is depicted in Figure 15 below. The basic phases are (Finnish Road Administration 2009, p. 12; Dietrich et al. 2017, p. 11):

- Grouping assets into sub-groups
- Choosing condition indicators and gathering information
- Presenting maintenance goals and predefined standards for the sub-groups
- Assessing functional, non-monetary maintenance deficit as the amount below predefined standards
- Transforming functional debt into monetary maintenance debt by pricing the optimal maintenance measures required to remove the functional deficit

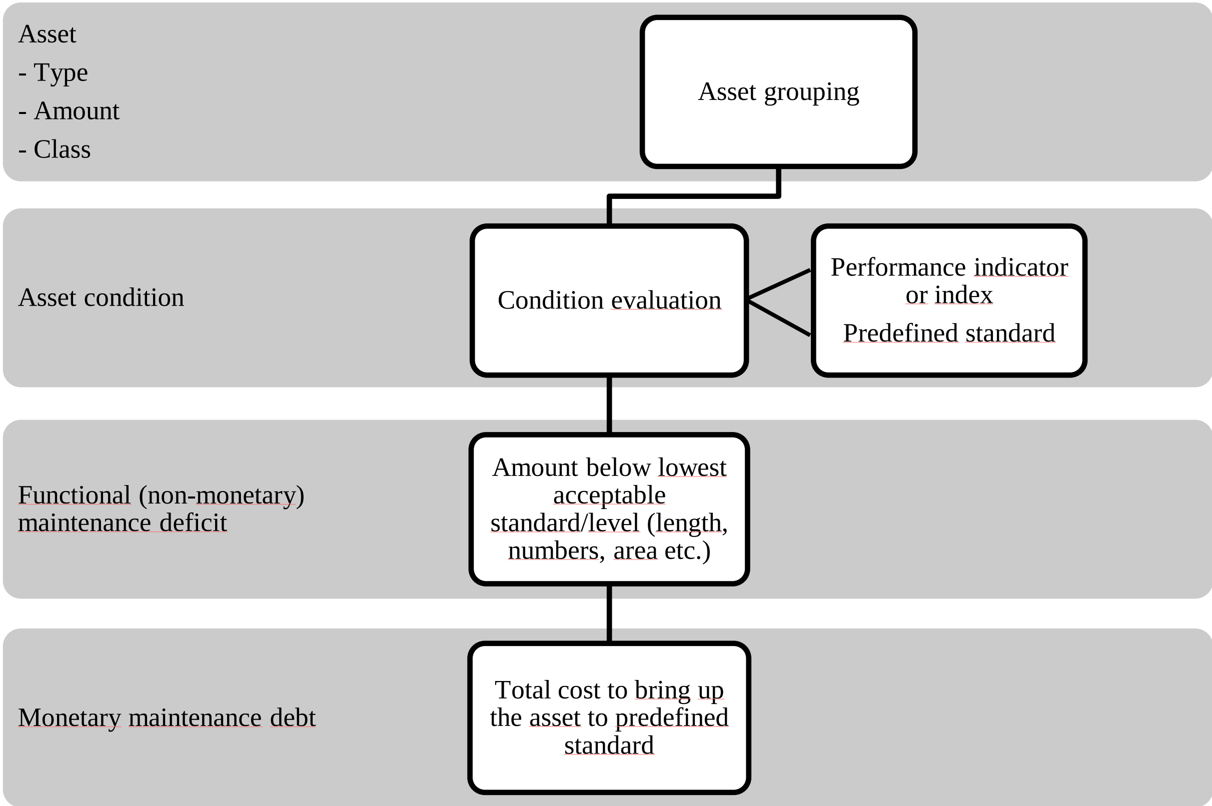

Figure 15. Maintenance backlog model principle and phases (Adapted from Finnish Road Administration 2009, p. 12; Dietrich et al. 2017, p. 11)

In the evaluation asset information is grouped based on type and class. Asset type defines the amount, condition, maintenance strategy and maintenance requirement. Asset class defines the functional meaning and predefined service level requirements, e.g. critical assets have higher requirements.

The functional amount of assets below predefined standards is defined based on condition information and limits that have been set for them (performance indicators). Ultimately the monetary maintenance debt represents the total cost of bringing assets up to predefined standards, which is a specific, detailed estimation of maintenance debt. (Dietrich et al. 2017, p. 8)

However, while in principle the established evaluation model contains all the necessary elements for determining the maintenance debt. Some of them are explained more precisely and some more loosely. The model does not go into detail on how the evaluation should be done and there is plenty of room for subjective choices. (Finnish Road Administration 2009, p. 3)

Replacement cost model

Some evaluation models used in reports by public infrastructure owners such as municipalities (see e.g. Rantanen 2014; Vainio & Kaarlehto 2017) present a slightly simplified way of estimating the amount of maintenance debt. In this model maintenance debt is defined as the difference between an assets current and optimal condition as a percentage of an asset's replacement cost. An example of this is presented in Figure 16 below.

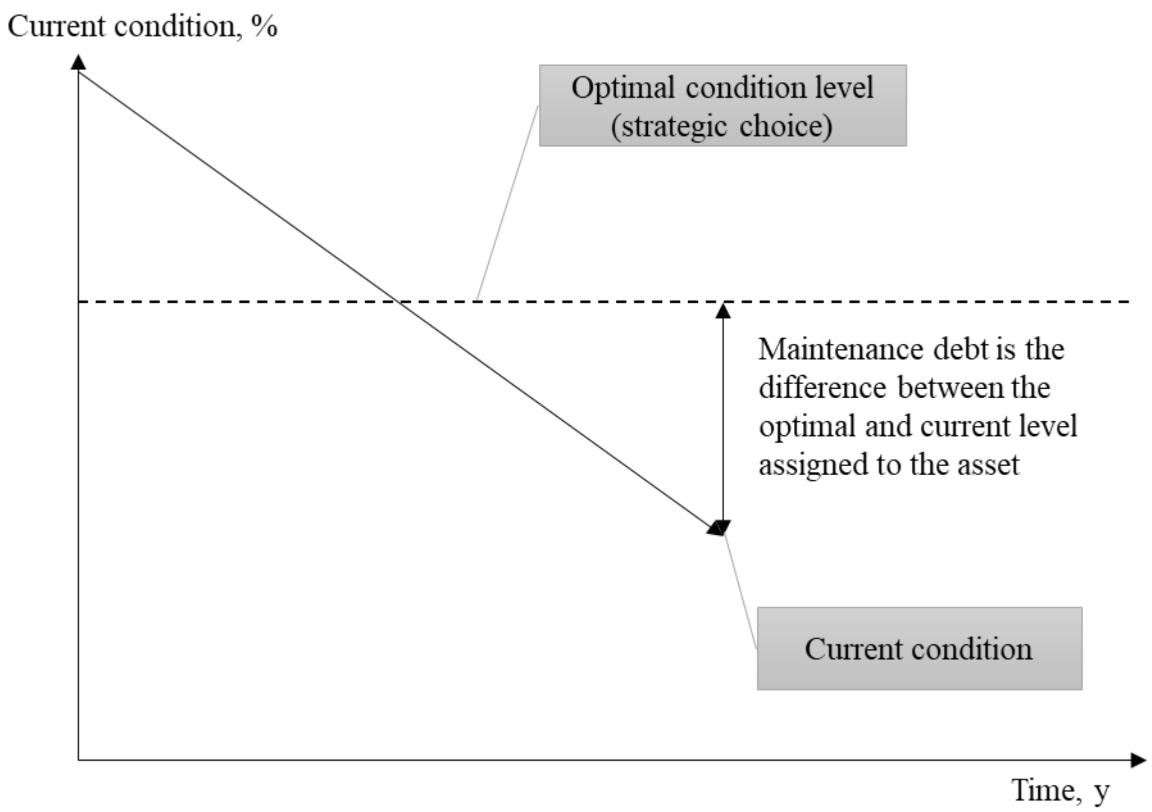

Figure 16. Replacement cost model principle (Adapted from Rantanen 2014, p. 12)

A main principle in this model is that at the beginning of an asset's life cycle the condition is at 100% from which point the condition will deteriorate. The optimal condition can be a strategic choice and set manually, e.g., at 75 % of asset value. The optimal condition represents the limit to which the condition level of the asset can deteriorate to without it accumulating maintenance debt.

Current condition is the second crucial variable. It can be approximated by physical measurements, or by completely theoretical models, or by a hybrid model that combines both methods. In the example by Rantanen (2014), different elements of a road network were given condition grades, and relative weights that ultimately represent asset condition level (%) in a scorecard. The third and final variable required to do this evaluation is replacement cost.

A practical measurement provides the most accurate way of estimating current condition, but at the same time it requires the most resources as the assets have to be physically inspected. For this reason, relying on this method alone makes it impossible to approximate a large group of assets.

On the other hand, theoretical models enable evaluating asset condition for large groups of assets. The challenge for theoretical models is reaching sufficient accuracy for their results. Rather than by measurement, an assets current condition is modelled by for example it's age. In this case one also needs additional information such as the maintenance history of an asset, which one wouldn't need in a pure measurement model. Theoretical models are largely based on asset deterioration over time. (Rantanen 2014, p. 17-20)

In a hybrid model example, assets would be divided into homogenous groups, and measurements from a few units would be used to model the condition and ultimately maintenance debt of the entire group of assets. The results would thus be more scalable than by pure measurement, and more accurate than by a pure theoretical model. (Rantanen 2014, p. 4)

Technical value model

A third model for evaluating maintenance debt is based on the replacement cost and technical value of buildings. It is similar in principle to the replacement cost model mentioned previously, only it is slightly more advanced. In the model technical value is derived either theoretically from the deterioration of replacement cost (1,5 – 2 % per year on average) while considering investments that affect balance sheet value, or by assessing technical value practically. At the outset it is like a purely theoretical replacement cost model where asset condition and its deterioration are modelled in a linear or non-linear way. (Korhonen & Niemi 2016)

This model separates from other evaluation methods by one main factor. It separates estimating maintenance debt, need for basic refurbishment, and need for basic improvement maintenance. Maintenance debt is accumulated once asset condition deteriorates below 75 %, while need for refurbishment and improvement maintenance is evaluated once asset condition drops below 60 %. (Korhonen et al. 2018, p. 10-11)

The target or optimal level is also different for the 3 different sub-categories. For maintenance debt the target level is 75 %, but refurbishment details the amount of investment needed to restore the asset back to original optimal condition and has a target level of 90 %. Lastly, need for improvement details the amount of investment needed to restore the asset back to optimal condition as well as functional improvements from modernizing the asset to fit present day needs, having a target level of 120 %. The principle of the model is presented in Figure 17 below. (Korhonen et al. 2018, p. 10-11)

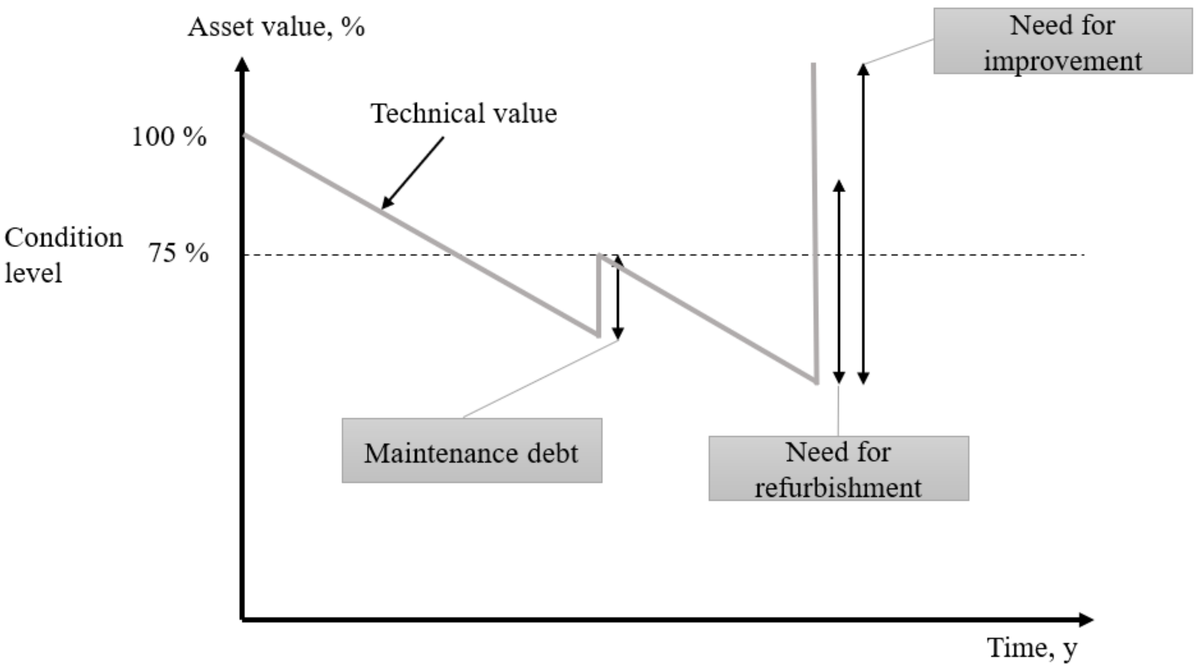

Figure 17. Technical value model principle (Adapted from Korhonen et al. 2018, p. 11)

Balance sheet value model

The fourth method for evaluating maintenance debt is based on balance sheet values and its changes through capital expenditures and depreciations. In this method maintenance debt is defined as the negative differential of investments and depreciations. In other words, this method defines maintenance debt as the deficit of investments in fixed assets when compared to the yearly depreciations. This type of evaluation has been used e.g., by the Finnish Ministry of Finance (2020) in its budgetary estimates for maintenance debt in the transition network. An example of this is presented in Table 4 below.

Table 4. Maintenance debt evaluation utilizing balance sheet values, thousand € (Finnish Ministry of Finance 2020)

	Investments	**Depreciations**	**Change**
2000	291	399	-108
2001	224	399	-175
2002	591	488	103
2003	398	508	-110
2004	628	555	73
2005	420	582	-162
2006	425	609	-184
2007	455	633	-178
2008	642	484	158
2009	753	507	246
2010	542	515	27
Overall	**5369**	**5679**	**-310**

This method estimates maintenance debt as a cumulative figure of insufficient investment. As mentioned earlier in this thesis, one of the original definitions by Vehmaskoski et al. (2011, p. 4) states that maintenance debt is a calculated figure that describes how much money has not been invested in fixed assets in recent years, so that assets would still be in good condition. In this case maintenance debt can be seen as a cumulative sum figure of neglected maintenance tasks or a cumulative deficit in funding over an asset's life cycle. An example of this method on a macro-scale is estimating the progress and development of maintenance debt based on different levels of funding, as has been done by e.g. the Finnish Transport Industry (2020, p. 21).

5 CASES IN INDUSTRY AND INFRASTRUCTURE

5.1 Stora Enso

Overview

In this chapter a case study of Stora Enso is presented. Stora Enso Oyj is a manufacturer of pulp, paper and other forest products headquartered in Helsinki, Finland. The company has some 22 000 employees and is one of the largest forest and paper industry companies in the world. In 2021 the company's turnover amounted to 10,2 billion € with an operational EBIT of 1,5 million €. (Stora Enso)

For the purposes of the case study, maintenance debt is analyzed using the balance sheet value method detailed in chapter 4.2, where maintenance debt is defined as the negative differential of investments and depreciations. In other words, this method defines maintenance debt as the deficit of investments in fixed assets when compared to the yearly depreciations. To estimate investments in fixed assets the following formula is proposed (Hatinen & Kärri 2010, p. 35):

$$Fixed\ asset\ investments_n = Fixed\ assets_n - Fixed\ assets_{n-1} + Depreciations_n \quad (1)$$

Yearly change in maintenance debt will be evaluated from the yearly differential in fixed asset investments and depreciations, and ultimately as the cumulative change over the whole time period. To evaluate maintenance debt, data was gathered from financial statements in the Voitto+ database regarding depreciations and fixed asset values in buildings, machinery, and other tangible assets from the years 2019-2003. Sadly, data was not available past year 2003.

Appendix 1 details the data gathered from Stora Enso's financial statements for the years 2003-2019, including planned and other depreciations in fixed assets, as well as fixed asset values by year. At first glance it is noticeable that the balance sheet value of fixed assets has decreased significantly, and the sum in 2019 is less than half of what it was two decades ago. The same drop can be seen in each asset category, be it buildings and structures, machines and hardware or other assets.

Planned depreciation makes up most of the experienced depreciation overall, but other depreciations amounted to large lumps of lost asset value following the year 2008. Non-planned depreciation may prove a challenge to maintenance debt estimation, as it does not represent the same type of steady yearly degradation of an asset as planned depreciation. Planned depreciations appear to have little variation and decrease at the same rate as total fixed assets year by year.

Evaluations

Appendix 2 details the results of the evaluation of Stora Enso's investments in fixed assets as well as the yearly differential. Yearly investments experienced great variation, with the highest yearly total at 371 million € and the lowest at 17 million €. The average yearly investment was 153 million €, whereas the average amount of experienced depreciation was approximately 226 million €.

Yearly change was mostly negative, as is represented in Figure 18 below. The greatest deficit was experienced in 2009, which is explained by both the bump in non-planned depreciations as well as low investments that year. Another dip was experienced in 2013 for the same reasons. Positive differentials were experienced on a few years, yet the average differential amounted to -73 million € a year.

Figure 18. Investments less depreciations, yearly (Stora Enso)

Results

The overall goal of the evaluation is to estimate the amount of accumulated maintenance debt. Figure 19 represents the amount and development of maintenance debt as the gap between cumulative investments and depreciations (lines). Total investments in fixed assets amounted to approximately 2,5 billion €, whereas depreciations amounted to approximately 3,6 billion €. The final differential between the two amounted to approximately 1,2 billion €.

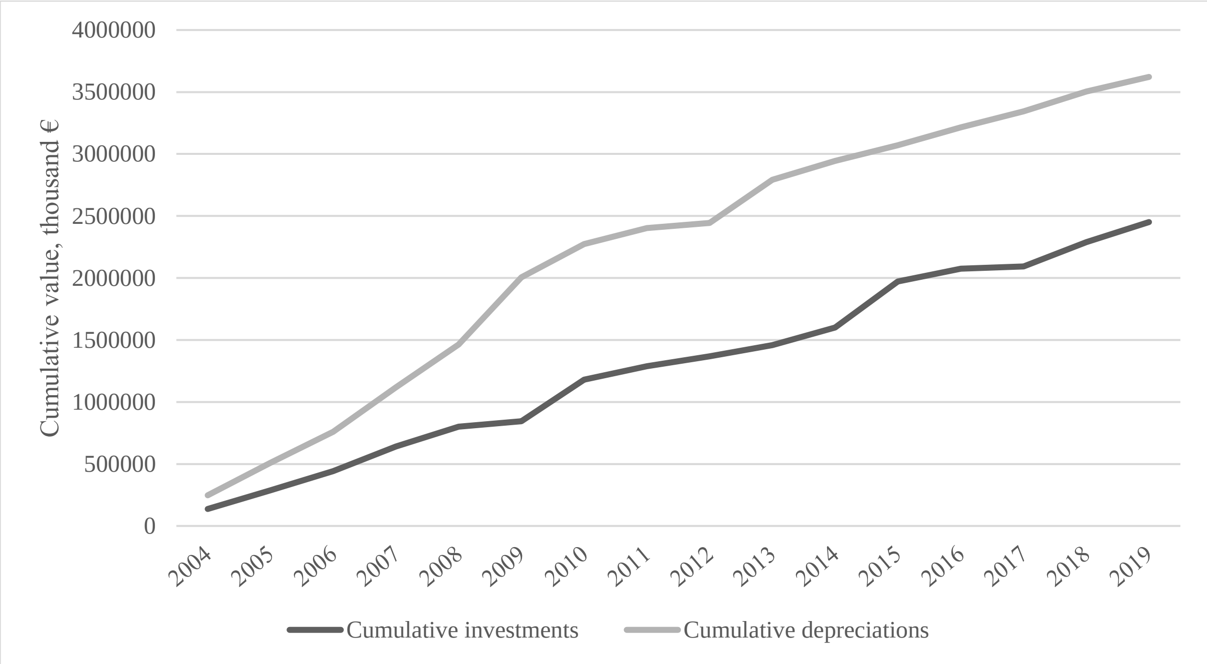

Figure 19. Cumulative investments and depreciations (Stora Enso)

The results represent the fact that from a balance sheet value perspective Stora Enso has sustained greater depreciations compared to investments, leading to significant decrease in the value of its fixed assets, from roughly 2 000 million in 2003 to 864 million € in 2019. While there may be varied reasons for the decrease, one might see this as an indication of a decrease in the productive capacity of Stora Enso. In this context it is interesting to note that the 2002 annual report states that a long-term Asset Restructuring Programme was launched to improve the quality and cost-effectiveness of the company's assets. It included targeted investments, machine specialization and divestment of less competitive and non-core production assets. (Stora Enso 2002, p. 5-10)

In addition, it is important to note other possible factors that may have influenced this progression. As noted earlier, planned depreciations made up most of the experienced depreciation overall however there were large sums of other depreciation experienced after the year 2008 and in 2013, possibly relating to the economic turmoil at the time. Moreover, company mergers, acquisitions, selling of fixed assets are other examples of behaviors that affect balance sheet values and thus results of the type of evaluation that is done in this case study.

In 2002 Stora Enso’s turnover was 12,7 billion € (Stora Enso 2002, p. 3), yet in 2010 sales amounted to 10,3 billion € (Stora Enso 2010, p. 26) and in 2019 total sales were 10,1 billion € (Stora Enso 2019, p. 4). From a turnover standpoint the company has not only stagnated but deteriorated. When you add inflation to the consideration, which cumulatively amounts to roughly 32 % from 2002 to 2019 (Inflationtool), the decrease in turnover becomes more apparent.

It can be said then that the results of the evaluation seem to point in the same direction with the development of Stora Enso’s sales. However, it is difficult to say how much this relates to the type of maintenance debt described in the classification chapter of this thesis. Stora Enso has experienced larger depreciations than investments, yet one cannot say that investments in production assets have necessarily been insufficient as other factors can be the reason for this development. The decrease in the balance sheet value of fixed assets may be deliberate, e.g. as companies aim to generate more value with their capital, as appears to have been the case with Stora Enso’s Asset Restructuring Programme.

In more modern news Stora Enso has announced the closure of a number of its production facilities, e.g. factories in Kemi and Kvarnsveden were announced for closure in 2021 (Mehtonen & Heikinmatti, 2021). Most recently the company announced it has started the process of selling 4 of its 5 paper factories, with experts naming the bad outlook of the paper business and the strategic goals of the company to move into other markets as the reasoning for this development (Uusitalo et al. 2022).

In summary, utilizing the balance sheet value method the total differential in Stora Enso’s investments and depreciations amounted to 1,2 billion € between 2002 and 2019, during which time span the value of its fixed assets more than halved. Planned depreciations made up most of the announced depreciation overall, yet other depreciations, asset sales and divestments due to company strategy are other factors that contribute to the differential.

5.2 Vaasa Water

Overview

In this chapter a case study of Vaasa Water is presented. Vaasa Water is a public utility company established in 1915 that in total serves over 70 000 inhabitants around the Vaasa municipality. The company provides its customers with water supply services, the most important of which are delivering household water and its distribution, as well as sewage disposal and treatment. The combined length of its water and sewer networks is 1581 km. If joined together, it would stretch all the way from Vaasa to Amsterdam. In 2020 net revenue amounted to 15,5 M€. (Vaasa Water & Vaasa Water 2020, p. 7)

To analyze maintenance debt in Vaasa Water the same balance sheet value method presented in chapter 4.4 and used in the Stora Enso case previously will be used. For the purposes of the case analysis data was gathered from annual reports from the year 2003 until 2019. Data was gathered regarding depreciations and fixed asset values in buildings, solid structures and equipment, as well as prepayments and other uncompleted acquisitions. To evaluate investments in fixed assets, the same formula (1) will be applied as was the case in the previous chapter.

Appendix 3 details the gathered data from 2003 until 2019. Within the time span, the balance sheet value of total fixed assets grew from 23,7 to 34,6 M€. This development is contrary to the one observed in Stora Enso, where balance sheet values more than halved between a similar timespan.

Solid structures and equipment include the pipe networks in fresh and wastewater management, and they make up most of Vaasa Waters fixed assets, amounting to 22 M€ in 2002 (89,6 % of total), whereas buildings amounted to 2,3 M€ (9,4 %), and machinery to 0,2 M€ (0,9 %). The value of each category grew withing the timespan, and in 2019 the same classes amounted to 28 M€ (81,7 %), 4,3 M€ (12,5 %), and 0,5 M€ (1,3 %) respectively.

Planned depreciation made up practically all the experienced depreciation and there were no notable other depreciations experienced within the timespan. The yearly amount of depreciation stayed stable when compared to the amount of fixed assets, staying between a margin of 10 – 12,5 %. There were two notable periods of rapid change in the value of fixed assets. Firstly, a rapid growth was experienced between 2009 and 2012, where the total value grew from 23,6 M€ to 33,6 M€. which can be explained by large investments made into the wastewater management plant of Pått. In the 2009 annual report it is stated that this represented the largest single investment in Vaasa Water's history, and in practice the company's operations will be guided by the large investments and their financing until 2012 (Vaasa Water 2009, p. 6-10). Furthermore, a 4,5 M€ decrease was experienced between 2014 and 2015. This can largely be explained by the transition of ownership of the stormwater network to the Vaasa municipality (Vaasa Water 2015, p. 15).

Evaluations

Appendix 4 details the results of the evaluation of investments and the differential with depreciations. Yearly investments experienced great variation, ranging mostly between 2 and 9 M€ a year. Due to the outlier in 2015 where fixed asset values deteriorated by more than depreciation, the formula produced a negative value for investments, which was replaced by a value of 0. It should be noted that this is a weakness of the evaluation method, and in reality, the amount invested was somewhere close to the average yearly investment of 4,4 M€.

While depreciations remained stable, major investments were experienced between 2010 and 2012 as well after 2017. The effect of these periods of heavy investment can be seen in the yearly net differential (change) evaluated in appendix 4. It is also demonstrated in Figure 20 below. It can be observed that the net change was near neutral from 2004 until the major investments from 2010 onwards. The negative outlier year in 2015 produced the largest negative differential of -3,9 M€, however the average yearly change was positive, amounting to approximately 0,8 M€

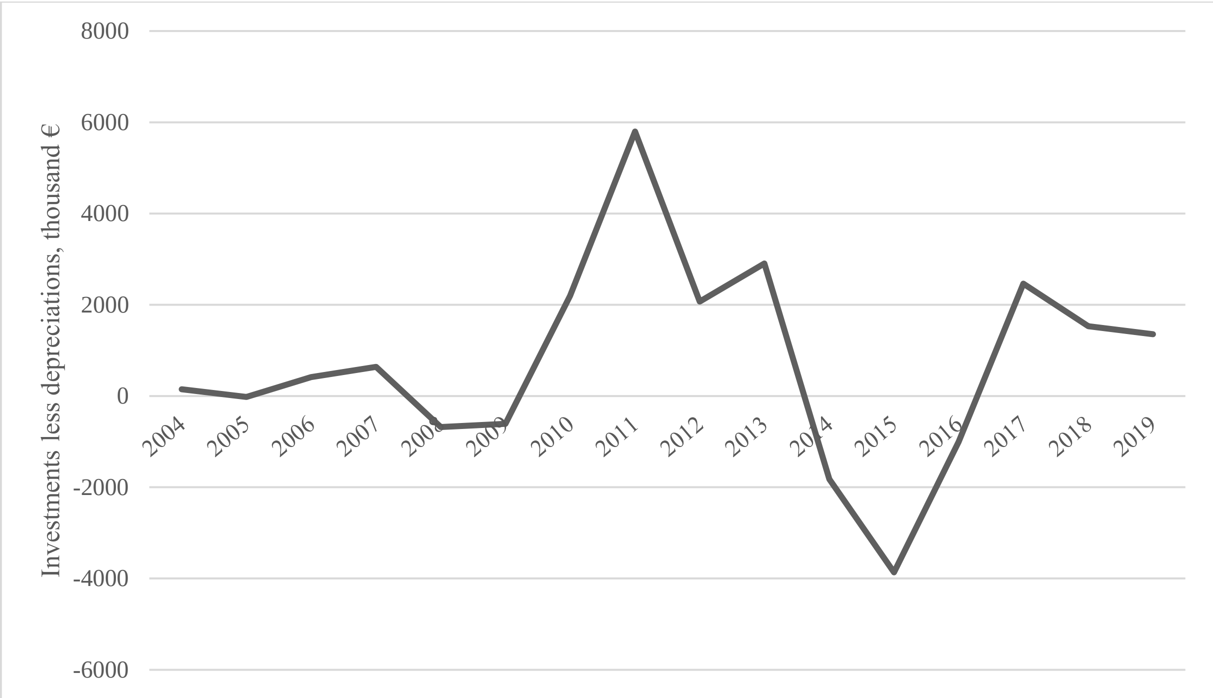

Figure 20. Investments less depreciations, yearly (Vaasa Water)

Results

The objective of the evaluation is to look at the cumulative differential of investments and depreciations. The results of the evaluation can be observed in appendix 4 as well as Figure 21 below. It can be observed that investments and depreciations were roughly at the same level until 2010, after which the experienced investments outweighed depreciations.

In total the cumulative change was positive and amounted to 11,5 M€, which would indicate that from a balance sheet value standpoint Vaasa Water has no evaluated maintenance debt. However, as with the results in the previous case analysis of Stora Enso, the context of the results is crucial to analyze and inspect to understand what they represent.

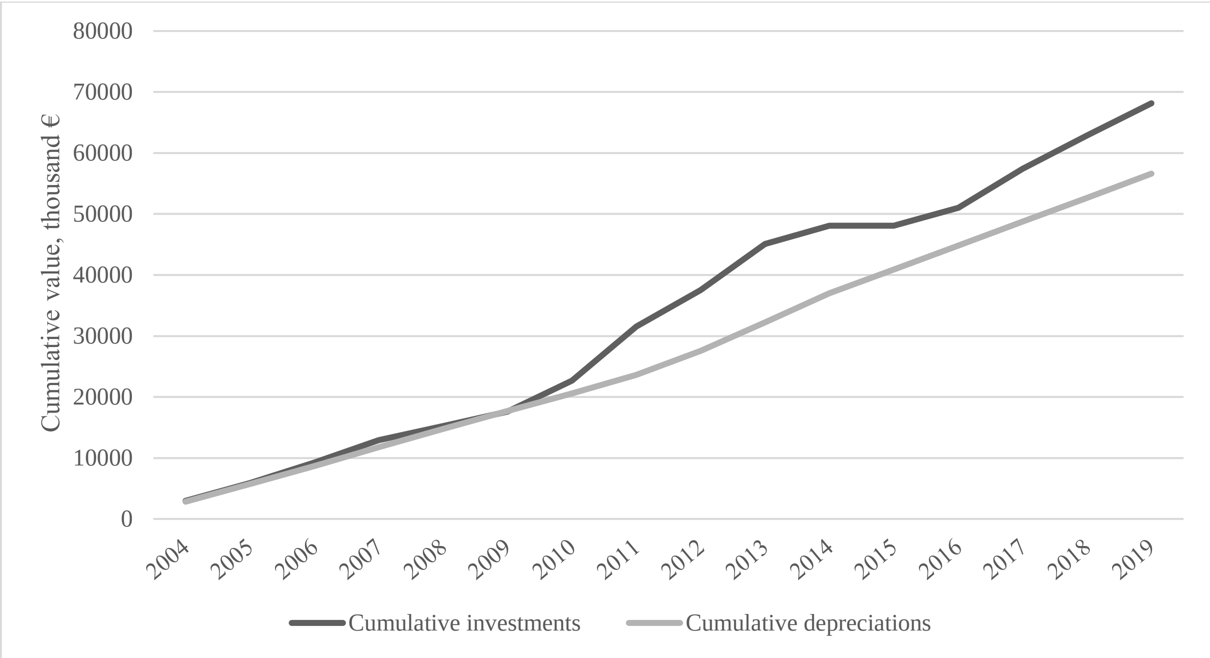

Figure 21. Cumulative investments and depreciations (Vaasa Water)

In the Stora Enso case analysis, several factors influencing balance sheet values and thus results of these evaluations were presented and discussed. These factors include asset sales and transfers into another company, which cause a decrease of fixed asset value that isn't reported through depreciations. In this case this effect was notable, as the amount of investment evaluated utilizing the presented formula notably produced a negative investment for the year 2015 and had to be manually adjusted. In the 2020 annual report Vaasa Water details yearly investment expenses from 2019 until 2016 (2020, p. 7), which matched the evaluated investments quite well. The differential is inspected in Table 5.

Table 5. Differential between reported and evaluated investment expenses in fixed assets. Vaasa Water. 2019-2016.

	2019	**2018**	**2017**	**2016**
Reported investments (M€)	5,28	5,41	6,29	3,76
Evaluated investments (M€)	5,30	5,44	6,39	2,94
Differential (M€)	0,02	0,03	0,10	0,82

While outliers such as the year 2015 affect the results, there were no other major exceptions. It can be stated that from a balance sheet value perspective Vaasa Water experienced greater investments than depreciation and thus a positive differential. However, whether the net positive of 14,8 M€ means that there are no assets containing maintenance debt is another question. It should be noted that Vaasa Water does inspect maintenance debt internally at some level. In their 2017 annual report (p. 1) Vaasa Water states a calculated target level of 3,5 M€ a year in its network refurbishment investments, which if reached would stop the growth of maintenance debt in its networks. At the time investments were reportedly 1 M€ short of target.

The experienced maintenance debt (or network refurbishment debt) becomes apparent from e.g., leakages in both household and wastewater. These leakages are measured in the amount of unbilled water. For household water the amount is around 20 % whereas for unbilled wastewater the amount is approximately 30 %. With continuous network refurbishment the amount of leakage has decreased, which has lowered operating costs in both networks and plants. (Vaasa Water 2020, p. 7)

5.3 Review of cases

Overall, the cases provided opposing stories, as Stora Enso experienced a deficit or a maintenance debt of roughly 1,2 billion € whereas Vaasa Water yielded a surplus of 11,5 million €. The results represent the fact that from a balance sheet value standpoint Stora Enso has experienced larger depreciation than investment, while Vaasa Water has experienced larger investment than depreciation.

There were factors influencing the results of the evaluations using the balance sheet value method. Most of these factors stemmed from the way that investments in fixed assets were evaluated utilizing formula 1, where changes in fixed asset values other than depreciations were assumed to be investments. Because of this, other changes in asset values affect the evaluated yearly investment and ultimately the resulting differential. If not for outliers, such as an evaluated result of negative investment adjusted to zero, evaluating the cumulative differential this way represents the exact change in balance sheet value of assets. However, doing the evaluation this way allows one to look at the data on a closer, yearly basis.

For Stora Enso other depreciations were experienced on several years e.g., following the year 2008. In addition, the company’s announced asset strategy had the strategic goal of reducing the amount of tied-up capital and improving the productivity of their assets, including asset forfeitures and other methods that lowered asset values outside of planned depreciation. Because of this, investments in fixed assets we’re likely larger in reality than as represented by the evaluation.

For Vaasa Water there were two main factors of interest that affected the results: the asset transfer of the stormwater network to the municipality in 2015 and the major investment in the wastewater processing plant of Pått starting in 2010. The asset transfer resulted in a negative evaluated investment, adjusted to a year with no investment, which is not accurate of the reality. In addition, it should be noted that a major investment in a new asset doesn’t reflect the condition of existing assets. However, in this evaluation method there is no distinction made between the different types of investments. It would be beneficial for the accuracy of the evaluation to separate the normal, operational level of investment from the major, strategic investments and asset transfers that show as positive and negative spikes in the graphs.

Ultimately with the outlying factors in mind, the evaluation results represent the change in the value of fixed assets in both companies. For Stora Enso, a drastic decrease from 2 billion in 2003 to 800 million € in 2019 and for Vaasa Water an increase from 23,6 to 34,6 million €. Yet one cannot necessarily say that Stora Enso's assets are in poor condition, or that Vaasa Water's assets are in great condition.

It would be interesting to analyze cases where the total value of fixed assets didn't see such strong variation as seen here, as well as with accurate investment data that doesn't need to be estimated from financial statements. Access to better and more precise data would improve the overall accuracy of the results as well as allow distinctions to be made e.g. between different kinds of investments.

6 CONCLUSIONS

6.1 Summary of results

The focus of this thesis is maintenance debt in Finnish infrastructure and industry as well as its classification and how it can be evaluated. While there is certainly a lack of academical research about maintenance debt, there are a few reports by governmental agencies or the ROTI report by the Finnish Association of Civil Engineers that have documented and estimated the amount and development of maintenance debt in Finnish infrastructure.

The verdict from these reports is that crucial infrastructure assets such as buildings, the transition network and civil engineering assets are aging and developing maintenance debt due to an insufficient level of investment. The same development has been observed in other developed countries such as the US. While similar macro-level reporting in terms of industry doesn’t exist, it can be stated that in Finland industrial investments have been lower than depreciation for several years after 2008. It is estimated that the total yearly bill caused by the existing maintenance debt in Finnish infrastructure amounts to 3,4 billion euros a year, or 1300 euros per household. It causes a yearly decrease of 2 % in GDP and jobs (approximately 37 000 jobs) and reduces company turnover by 57 billion euros over 10 years. To conclude and reach the objective of the thesis, the three research questions are presented and answered below:

Q1: What is the classification of maintenance debt?

In this thesis the following classification is proposed. Maintenance debt is classified in to 3 sub-categories: operational maintenance debt, refurbishment debt and improvement debt. The basis for the classification comes from maintenance standards, be it the definition of maintenance or the key elements of the maintenance realization process that include a similar 3-part split of maintenance tasks and objectives: maintain, restore, and improve.

Operational maintenance debt represents the smaller day-to-day maintenance tasks that accumulate the first category of maintenance debt when neglected. These tasks represent the smaller maintenance tasks in budget, scope as well as timeline. Operational maintenance tasks have the potential to maintain or restore an asset’s condition up to the optimal level (e.g., 75 %). Accumulating operational debt is gradual as small maintenance tasks have little effect on the current value of an asset initially. However, if routine maintenance is neglected and operational debt is accumulated over a long period of time it is possible to develop more serious faults and failures.

Refurbishment can be defined as bringing used products up to a certain, pre-determined, quality standard. It involves the replacement of worn and critical parts, and aesthetically making the product look like new. Refurbishment tasks have the potential to restore an asset’s condition level up to good-as-new (90-100 %). Refurbishment debt is accumulated from neglecting medium-sized maintenance tasks and projects that are done once a year or less frequently.

Improvement is the combination of all technical, administrative, and managerial actions, intended to better the reliability, maintainability, or safety of an item without changing the original function. Improvement debt represents the largest tasks in scope, budget and length. Improvement maintenance tasks bring an asset’s condition above good-as-new (100 % or higher).

Q2: How can the amount of maintenance debt be evaluated?

While there is a distinct lack of standardization and academic documentation of maintenance debt and especially its evaluation methods, in this thesis the following 4 evaluation methods are presented. The evaluation methods were often documented by municipal, or groups closely linked to municipal entities.

Firstly, in 2009 the ERANET Maintenance Backlog Model was developed and reported by an international consortium consisting mainly of national road administrations. The project developed the first guidelines for evaluating maintenance debt in the road network. The model defines maintenance debt first in non-monetary and then in monetary terms. While the model doesn’t provide exact formulas, it provides guidelines and steps for grouping assets into sub-groups, assigning performance factors and targets, and measuring functional (non-monetary), and ultimately monetary maintenance debt based on the amount below the targeted limit.

The second evaluation method is the replacement cost model, where maintenance debt is defined as the difference between an assets current and optimal condition as a percentage of an asset's replacement cost. A main principle in this model is that at the beginning of an asset's life cycle the condition is at 100 % from which point the condition will deteriorate. The optimal condition can be a strategic choice and set manually, e.g., at 75 % of asset value. The optimal condition represents the limit to which the condition level of the asset can deteriorate to without it accumulating maintenance debt. Current condition is the second crucial variable. It can be approximated by physical measurements, by completely theoretical models, or by a hybrid model that combines both methods.

The third evaluation method is the technical value model, which shares many common characteristics with the replacement cost model. This model separates from other evaluation methods by one main factor. It separates maintenance debt, need for basic refurbishment and need for basic improvement maintenance. Maintenance debt is accumulated once asset condition deteriorates below 75 % and up to 75 %, while need for refurbishment and improvement maintenance are evaluated once asset condition drops below 60 %, and up to 90 % and 120 % respectively.

Finally, the fourth evaluation method is the balance sheet value model, which defines maintenance debt as the negative differential of investments and depreciations. This evaluation method is used in the empirical part of the thesis to analyze maintenance debt in Stora Enso as well as Vaasa Water based on financial statement data.

Q3: What are the results and lessons from the case evaluations of maintenance debt based on financial statement data?

Evaluations were done utilizing the balance sheet value method. To evaluate investments in fixed assets, a formula was proposed that estimated investments based on asset value change when removing the effect of depreciation from the equation. The evaluation results showed that within the timespan (2003 – 2019) Stora Enso experienced larger depreciation than investment, yielding a deficit or maintenance debt of 1,2 billion €. Within the same timespan Vaasa Water yielded a positive differential of 11,5 million €, indicating no existing maintenance debt.

Due to the way investments were evaluated based on fixed asset value change when removing the effect of depreciation, factors such as asset forfeitures, company restructuring due to asset strategy and other forms of value change that don't occur through depreciation affected the results, resulting in lower evaluated investment sums. Examples of these were the forfeiture of the Vaasa Water stormwater network to the municipality in 2015, and Stora Enso's overlying asset strategy that had the strategic aim of divestment of less competitive and non-core production assets.

Moreover, the balance sheet value method defines maintenance debt as the negative differential between investments and depreciation. It is important to note, that as one cannot separate between different kinds of investment, major investments e.g. in the new wastewater management plant for Vaasa Water increase fixed asset values drastically and thus have a significant impact on the investment-depreciation evaluation over the whole timespan. Dividing investments into strategic and operational could be a future area of development for the evaluation using balance sheet value model.

While changes in asset value often indicate a change in the productive capacity of a company, it doesn't necessarily reflect the condition of older assets. The same principle can be applied inversely to Stora Enso, where the drastic decrease in asset values can be the result of multiple factors including asset strategy.

The balance sheet value method estimates maintenance debt as the cumulative gap between investments in fixed assets and depreciations. This method provides a clear formula for estimating the amount of maintenance debt without requiring knowledge of asset specific conditions, replacement values or repair costs.

The weakness of this method may be that the 'investment gap' does not directly represent maintenance debt, but a decrease or increase in the productive capacity of a company. Evaluating maintenance debt from an 'investments-depreciations' perspective might work better on a larger scale in either timeframe or the number of companies or industries analyzed. Estimating the situation of fixed assets based on financial statement data would also benefit from additional information on asset transactions and the ability to separate different kinds of investments.

6.2 Suggestions for future research

It is evident that there is a lack of research and standardization when it comes to maintenance debt, be it its very definition and what constitutes maintenance debt in addition to how it is evaluated. While maintenance debt as a topic is difficult to define in uniform terms, and even the preliminary lessons achieved by this thesis show that there is no ‘one size fits all’ evaluation model, there are benefits to be achieved from progress in this area. More case studies using different evaluation methods on different industries are needed, as they would increase general understanding as well as contribute to methodological expertise of maintenance debt evaluation.

Researching maintenance debt through its classification into operational, refurbishment, and improvement debt or by some other distinction allows for a more comprehensive definition of a complicated concept. In addition, while there may not be one evaluation method that is suitable to all situations and assets, developing standardized evaluation principles for homogenous infrastructure groups or common principles for certain types of industrial assets may be achievable. The main benefit of common principles is the comparability of the research and results achieved, allowing e.g. comparative studies of maintenance debt in different countries to be made.

Moreover, technological advancements in availability, accuracy, and detail of asset data (IoT etc.) may enable more accurate evaluations to take place that include more real-time physical measurements and data. Advanced theoretical models may predict non-linear accumulation of maintenance debt, perhaps according to asset failure patterns discussed in chapter 3.2.

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Depreciations and fixed asset values by year, Stora Enso. Data gathered from Voitto+ database. Thousands €.

Year	Planned depreciation	Other depreciation in non-current assets	Buildings and structures	Machines and hardware	Other tangible assets	Prepayments and uncompleted acquisitions	Total fixed assets
2003	227000		426000	1398000	211000		2035000
2004	247000		420000	1383000	122000		1925000
2005	263000		402000	1302000	109000		1813000
2006	248000		386000	1188000	108000	37000	1718000
2007	359000				1558000		1558000
2008	345000				1374000		1374000
2009	161000	383000	280000	510000	48000	34000	872000
2010	125000	143000	258000	596000	41000	48000	942000
2011	128000		243000	562000	34000	82000	920000
2012	128000	-85000	227000	648000	30000	54000	959000
2013	131000	217000	184000	465000	25000	28000	702000
2014	103000	48000	156000	415000	23000	98000	692000
2015	126000	0	189000	648000	25000	75000	937000
2016	141000	4000	179000	640000	24000	52000	894000
2017	123000	7000	115000	526000	21000	120000	782000
2018	159000	0	143000	538000	18000	121000	819000
2019	115000	3000	156000	644000	15000	49000	864000

Evaluation of maintenance debt, Stora Enso. Thousands €.

Year	**Investments (formula 1)**	**Depreciations**	**Change**	**Cumulative change**
2004	137000	247000	-110000	-110000
2005	152000	263000	-111000	-222000
2006	153000	248000	-95000	-317000
2007	199000	359000	-160000	-477000
2008	161000	345000	-185000	-661000
2009	42000	544000	-502000	-1163000
2010	338000	268000	70000	-1093000
2011	107000	128000	-21000	-1114000
2012	81000	43000	38000	-1076000
2013	91000	348000	-257000	-1333000
2014	142000	152000	-10000	-1342000
2015	371000	126000	245000	-1098000
2016	102000	145000	-43000	-1141000
2017	17000	130000	-113000	-1253000
2018	196000	159000	38000	-1215000
2019	163000	118000	45000	-1171000
Total	2452000	3622000	-1171000	

Depreciations and fixed asset values by year, Vaasa Water. Data gathered from annual reports. Thousands €.

Year	Depreciations	Buildings	Solid structures and equipment	Machines and hardware	Prepayments and uncompleted acquisitions	Total fixed assets
2003	2942	2218	21181	256	0	23655
2004	2829	2101	21427	274	0	23802
2005	2901	1921	21519	348	0	23787
2006	2960	1913	21184	333	775	24205
2007	3067	2903	21575	365	0	24843
2008	2985	2732	21051	383	0	24166
2009	2929	2077	21079	402	0	23558
2010	2903	1918	21025	321	2494	25757
2011	3068	3963	22926	253	4414	31556
2012	3905	7387	26012	228	0	33626
2013	4675	7099	28865	312	254	36530
2014	4808	6432	27183	292	800	34708
2015	3864	5828	23138	464	835	30265
2016	3934	5301	23432	414	120	29266
2017	3928	4817	26004	439	471	31731
2018	3911	4439	27918	403	504	33264
2019	3950	4336	28270	465	1545	34616

Evaluation of maintenance debt, Vaasa Water. Thousands €.

Year	**Investments (formula 1)**	**Depreciations**	**Change**	**Cumulative change**
2004	2977	2829	148	148
2005	2885	2901	-16	132
2006	3378	2960	418	550
2007	3705	3067	638	1188
2008	2308	2985	-677	511
2009	2321	2929	-608	-97
2010	5102	2903	2199	2102
2011	8866	3068	5798	7900
2012	5975	3905	2070	9970
2013	7579	4675	2904	12874
2014	2986	4808	-1822	11052
2015	0	3864	-3864	7188
2016	2936	3934	-998	6190
2017	6393	3928	2465	8655
2018	5444	3911	1533	10188
2019	5302	3950	1352	11540
Total	**68157**	**56617**	**11540**	