UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Making obsolescence obsolete

A practical study of obsolescence management theory in the context of a truck OEM.

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Abstract

Truck manufacturers are facing unprecedented technological disruptions from electrification, digitalization and automation. When disrupted, sustainment-dominated industries such as the trucking industry, face increased risks of component and system obsolescence, which might lead to skyrocketing costs and diminishing aftermarket service. Building on existing theory of obsolescence and insights from other disrupted industries, the purpose of this thesis is to investigate how a truck OEM can effectively manage obsolescence issues caused by disruptive technologies. In order to reach substantiated conclusions of this research question, four supporting research questions were formulated to understand the OEM's current disruption and obsolescence management situation, what insights and learnings can be gathered from other relevant industries, what early warnings the OEM can use to assess when to manage obsolescence issues, and finally how the OEM can develop strategies to better manage obsolescence.

The thesis applied a multi-method framework to investigate the research questions and fulfil the purpose. First, a case study review of relevant industries (aviation, cars, defense, electronics, energy, ICT, lighting, music, maritime, rail and space) was conducted. Second, semi-structured interviews were held with employees from a specific truck OEM, experts within the field of obsolescence; and experienced professionals from disrupted industries (cars, music, lighting and rail). The case study review generated a knowledge platform from which the second method, qualitative interviews, could gather deeper and more applied insights and knowledge.

The thesis concludes that, in order to successfully manage obsolescence issues from disruptive technologies, the truck OEM should continuously improve their existing reactive obsolescence management approaches and additionally develop a strategic and proactive framework including early warning indicators to preemptively assess and monitor potential developments leading to obsolescence. Furthermore, five different areas were identified, in which the OEM should implement strategies to develop more effective proactive and strategic obsolescence management: management, knowledge, design considerations, supplier management and innovation. The detection of early warning signals was deemed as critical for management of challenges caused by disruptive technologies.

The thesis has concluded concepts and insights that primarily fall within the existing contemporary field of obsolescence management. The main contribution of the thesis is instead focusing on adding and extending the existing knowledge by synthesizing practical and empirical depth of obsolescence management from real-life situations.

Key words: *disruption, disruptive innovation, disruptive technologies, obsolescence, obsolescence management, truck OEM, trucking industry*

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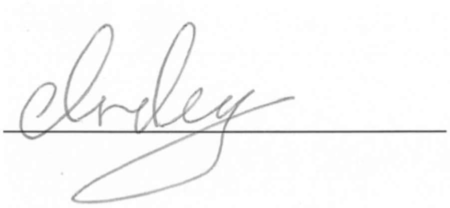
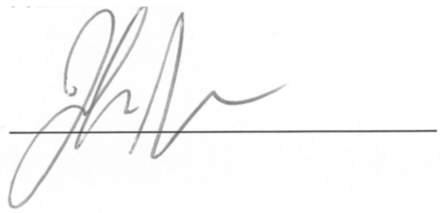


Jonatan Norman



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Glossary

Last-time-buy (LTB): If a supplier sends a PDN (Product Discontinuance Notice) of a necessary component, often an OEM buys enough of these components before the last order date so that they are able to support manufacturing or maintenance until the expected end-of-production for the product

Obsolescence: Materials and components that become non-procurable. This is caused by them no longer being produced by the original manufacturer, or technical assistance being withdrawn.

Obsolescence Management: Managing the complications caused by obsolescence. Involves taking into account the lifespan of all subsets in a system and formulating a plan to replace obsolete parts as they age.

Original equipment manufacturer (OEM): An ambiguous term, but in this thesis, it refers to the producer of the end-product, in other words the company who sells directly to the end consumer.

PDN (product discontinuance notice): Sent out by suppliers to inform buyers that they will stop manufacturing and providing certain components. In these, you also inform buyers of a last order date, allowing them to make an eventual last-time-buy or bridge buy if needed.

1

Introduction

1.1 Background

Industries are constantly evolving, and the accelerating pace of technological evolution is making it increasingly difficult for companies to adapt to developments that might affect their operations. Through technological advancements, changes in customer behaviors and global developments, actors who adapt will thrive while those who miss the mark are rendered obsolete. A key driver to an industry's development is innovation. At the forefront, innovation pushes established boundaries and allows for new ways to create, deliver and capture value (Goffin & Mitchell, 2017). This generates additional growth and usually creates ripple effects of indirect innovations. While innovation can occur regarding business models and organizational structures, one most commonly might think about innovation in terms of technological developments.

In the last decade, innovative technologies such as electric and autonomous vehicles, 5G, wireless technology and drone deliveries have all challenged the way customers will receive value and consequently how industries function (Schilling, 2020). Advancements such as these might be incremental developments and easier to manage, where technologies are improved and made more efficient. They can also be disruptive, where the technology is able to deliver value in such a new way that it turns an industry on its head.

An industry that is currently on the verge of facing many disruptions is the trucking industry. Companies holding the largest market share in this industry include Daimler AG, PACCAR Inc., and AB Volvo. According to Coffmann, Ganguli, Brown & Iyer (2019), the trucking industry as a whole is facing multiple disruptive trends: electrification, autonomous driving, technology convergence, and new entrants. In the short- to medium term, electrification will be especially impactful as it changes the whole architecture of the truck and the OEM's operations.

Granted, such a disruption poses challenges for actors within the industry. They need to be fleet-footed in order to develop and survive. OEMs (Original Equipment Manufacturers), who create and assemble the final truck, are put in a critical position to transition. They need to develop an appealing proposition using the new technology, find suppliers that can deliver required parts, and develop a customer base to provide the new offer for. Furthermore, the trucking industry is sustainment-dominated, which means that the costs of maintaining the system in the aftermarket exceeds its original development or procurement costs (Singh & Sandborn, 2006). What this means in practice for a truck OEM is that they have a long aftermarket (commonly 15-20 years) where service is provided to end customers, along with maintenance and spare parts. Whereas other industries without similar aftermarkets could transition quicker and more completely into a new technology, a truck OEM therefore needs to manage the new technology while simultaneously making sure that the old, "legacy" technology is sustained throughout the expected period of service.

The challenge is that other value chain actors might not share the truck OEM's incentives to stay with legacy technologies. This leads to a decreasing number of available suppliers and increasing costs of retaining spare parts and services. This increases the risk of a component or spare part becoming obsolete. The management of these susceptible parts, called obsolescence management, can be divided into strategic, proactive or reactive measures (Bartels, Ermel, Pecht, & Sandborn 2012). Reactive measures occur after the fact that a company realizes a spare part is being discontinued (and thus obsolete), whereas proactive and strategic measures tries to identify and analyze developments of a technology to manage the issue before it becomes too late. Here, early warning signals from the industry and technology developments play a central role.

In short, while innovation and technological advancements are the fuel that drives an industry to develop and thrive, the transition is not evident for all actors. Truck OEMs need to manage both the future, the present and the past of their industry, which is an intricate balance. By taking active measures, they can prevent ending up in a situation where they either risk failure in providing aftermarket services or face skyrocketing costs as a result of parts becoming non-procurable. Truck OEMs who are able to manage this correctly can prepare for new technologies while still effectively serving their aftermarket customers.

1.2 Purpose

The purpose of this thesis was to provide a better understanding of how truck OEMs can effectively handle issues of obsolescence caused by technological disruptions, what can be learned and operationalized from other industries that have undergone similar transitions, what early warning indicators can be identified to identify the need for affirmative actions, and what strategies can be developed to mitigate obsolescence challenges.

1.3 Research questions

In order to fulfill the purpose of the thesis, a total of five research questions have been formulated: a main research question (RQ) and four supporting research questions (SQ).

> *RQ: How can a truck OEM effectively manage obsolescence issues caused by disruptive technologies?*

The main research question was formulated in line with the requests of a specific truck OEM, from which this thesis was enquired. Many suppliers that have specialized in legacy technologies will have difficulty adjusting to the new technological landscape. Those who are able to make this transition will increasingly disregard their production of old parts and components, even though they are still needed by large truck OEMs to effectively serve their aftermarket. For a truck OEM, these issues need to be handled effectively to ensure operational and financial performance in the upcoming years.

> *SQ1: How is the truck OEM affected by disruptive technologies and what are they doing to mitigate obsolescence issues today?*

The first supporting research question (*SQ1*) aimed to create a better baseline understanding of the nature of the truck OEM's operations and what actions they are already taking to handle issues of obsolescence and disruptive technology. This is important to understand in order to effectively find obsolescence management strategies that are suitable yet currently novel for the truck OEM in question.

> *SQ2: As a truck OEM, what can be learnt and operationalized from other companies in industries that have gone through similar technological transitions?*

The second supporting research question (*SQ2*) was formulated to create a better understanding of how other industries have been impacted by similar industry transformations, and how they have managed it successfully and unsuccessfully. This is valuable to understand since predicting the future of an industry can be difficult, and in many cases, history is the best teacher. If the specific truck OEM can gain and interpret knowledge from other industries that have gone through similar changes, they can create strategies that allow them to be agile and flexible when dealing with them.

> *SQ3: As a truck OEM, what early warning indicators and insights can be implemented to handle obsolescence issues before they become a liability?*

The third research question (SQ3) focuses on the affected technologies, aiming to determine what early warning indicators could be used to detect changes in the external or the operational environment. Understanding these indicators can enable a proactive approach to make obsolescence issues less of a liability during times of rapid change and can help OEMs manage potentially disrupted suppliers and technologies at an early stage.

SQ4: As a truck OEM, how can strategies and operations be developed to manage obsolescence issues?

Finally, the fourth (SQ4) supporting research question was formulated to investigate how the truck OEM can work to reach a holistic and effective strategy of obsolescence management. This is important to investigate since the road to strategic and proactive obsolescence management is hard and time consuming. Understanding how a trucking OEM can manage such a journey, and what challenges there might be along the way, is an important part in answering the main research question.

1.4 Delimitations and scope

Next, the scope of the thesis is defined. The scope has been sectioned into inclusion and exclusion of certain industries, geographical areas, technologies, value chain actors and time frames.

The scope of this thesis has been limited to only include findings from industries relevant to the specific truck OEM. Even though it possesses a business portfolio spanning across multiple industries, the scope merely includes findings applicable to the production and maintenance of trucks. Other operations, such as buses, construction equipment and marine systems were thereby not considered part of the thesis' main focus.

The scope for data gathering was limited to 11 industries, all of which were researched through a multiple case study review. Four of these industries have also been investigated further through semi-structured qualitative interviews.

Given that the truck OEM operates on a global scale, the market and geographical scope of the thesis was made global. In practice, this means that a global strategy for handling these scenarios can be produced and distributed throughout the organization while remaining accurate and relevant. In this thesis, this meant that cases and interviews were gathered globally, and recommendations were made accordingly.

Since the truck OEM and the authors wish to produce tangible strategic support for large parts of the organization, no specific technological segments of the organization's truck manufacturing operations were excluded. However, throughout the thesis the disruption will often be exemplified by vehicle electrification since it is the most potentially impactful disruption in the trucking industry over a 15-year period.

As the company is an OEM, they have both suppliers and customers to consider. Both stakeholder groups will likely be affected by obsolescence. However, the large majority of obsolescence challenges for the truck OEM exist in relation to suppliers and their ability to provide required materials and components. The customers are not dealing with obsolescence challenges to the same degree but are instead primarily facing the consequences. Given that this thesis wants to investigate and provide insights on the core problem of obsolescence, suppliers were the primary focus while customers were excluded.

The time frame used for strategy development is 15 years into the future. This was determined as suitable since there is general acceptance that many technologies related to the megatrends (electrification, connected vehicles) are years away from having significant impact on the industries that the specific truck OEM is operating within. Problems of obsolescence in relation to suppliers will continue to exist further into the future, but the intent of this thesis is not to provide recommendations that can be followed strictly for decades to come. It is rather to serve as a platform on which the truck OEM can base and continually improve their own strategies. Furthermore, for data collection the time frame was 20 years in the past. The intent was to keep the findings on obsolescence management and disruptive technologies relatively contemporary, to ensure that key insights and strategies would still be applicable to a modern industry landscape of the truck OEM.

1.5 Disposition

Moving forward, this thesis consists of five additional chapters.

Chapter 2 - Theoretical Framework, focuses on providing the reader with the relevant conceptual insights required for understanding the thesis: disruptive technologies, obsolescence and obsolescence management.

Chapter 3 - Method, introduces the reader to the research study and design, and the two research methods (case study review (SLR) and qualitative interviews) used in the study.

Chapter 4 - Results, presents the results from the conducted study. Here the case study review will be presented from the perspective of the 11 analyzed industries and the interviews will be presented according to the three actor groups interviewed: truck OEM employees, experts and experienced professionals from benchmark industries (the latter being presented according to industry).

Chapter 5 - Analysis, will then take all the previous insights and results (from theoretical framework, case study and interviews) and analyze them to answer the thesis' research questions and consequently its purpose.

Chapter 6 - Conclusion, finally wraps the thesis up and summarizes what has been studied and what the results of the study has been, provides a discussion on implementing obsolescence management and suggests further research.

2

Theoretical framework

This section of the thesis will provide a theoretical foundation from which the thesis will be conducted and key concepts will be understood. The information has been gathered through the University of Gothenburg academic databases. The theoretical framework consists of three main subsections. The first subsection gives a brief introduction to technological disruption by highlighting innovation, disruptive technologies and S-curves (2.1). The second subsection focuses on obsolescence and its related challenges (2.2). The third subsection is regarding obsolescence management (2.3).

2.1 Technological disruption

As industries grow and develop, the dynamics of the industry change: new actors enter and new capabilities are needed (Marsili, 2001; Tripsas, 1997). A crucial component of technological evolution and development is innovation. No matter if one looks at it from an architectural, technological, business or organizational level, innovation is a motor for technological development, incentivizing companies to target new technologies, ventures or markets.

Innovation is a widely discussed subject in terms of what it entails and how it should be defined. An important distinction for technological advancements is between incremental and disruptive innovations. Norman & Verganti (2013) define incremental innovation as continuous improvements of the current technological base. To contrast this, highlights the systematic impact of the industries they generate by requiring new competencies, actors and ecosystems (Christensen & Bower, 1996; Christensen, Raynor & McDonald, 2015). The authors claim that disruptive innovations must emerge from segments of the market other than the main segment. This is due to these segments being overseen by the incumbent actors who, in a mature market, are focusing on to the main segments where the business is more stable and profitable. Another important factor to disruptive innovation is that it sprouts a new market or a new offer to the same market, that the incumbent actors cannot offer - either through lacking capabilities or that it might cannibalize on their current market. As such, a company that emerges from the lower segments can quickly claim market shares of the disruptive technology.

Another framework that can describe the evolution of technology is what Goffin & Mitchell (2017) refer to as S-curves (*Figure 2.1 - S-curves*). The S-curve can be used by companies to analyze developments of individual components and systems.

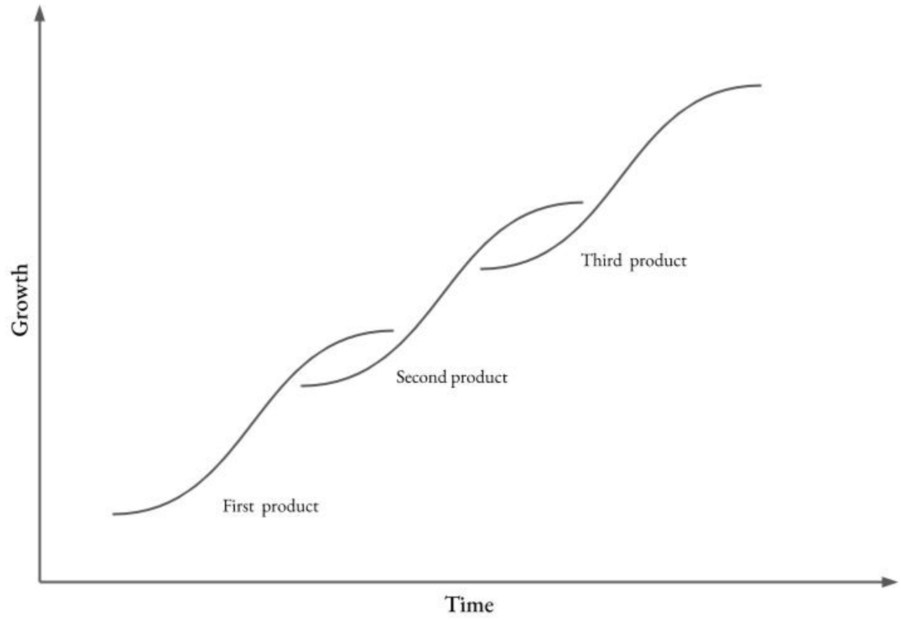

Figure 2.1 - S-curves, adapted from Goffin & Mitchell (2017)

The S-curve is divided into an initiation phase, a growing phase, a decline phase and a mature phase. In the two latter stages, there is an increasing risk for technologies to be surpassed by other (disruptive) technologies. Depending on how initially successful the technology is, it has a longer or shorter growing phase, and finally the growth declines once again before finally being discontinued. As such, the use of an S-curve in this thesis is looking at how new components and products come to replace previous ones, which is depicted by the subsequent curves in Figure 2.1. This shows how continuous developments of components drive the growth of a larger structure.

2.2 Obsolescence

Obsolescence, as used in this paper, refers to materials and components that become non-procurable (Sandborn, 2013). This is caused by components or materials no longer being produced by the original manufacturer, or technical assistance for them being withdrawn (Abili, Onwuzuluigbo, & Kara, 2013). As materials or components become obsolete, the procurer is inevitably faced with a shortfall in supply since their demand for the specific part cannot be satisfied and there are no alternative parts available (Atterbury, 2005; Rogokowski, 2007). Bartels, Ermel, Pecht, and Sandborn (2012) list four different forms of obsolescence, characterized by the source of the obsolescence problem (*Table 2.1*).

Obsolescence Forms	Descriptions
Functional Obsolescence	The product still operates as intended and is manufacturable, but the product requirements have changed, making the function, performance or reliability of the product obsolete. Often caused by changes in other parts of the system.
Technological Obsolescence	More technologically advanced components become available. This becomes an obsolescence issue when suppliers of older parts move on to newer components, and no longer supports older ones.
Functionality Improvement Dominated Obsolescence	Suppliers become unable to maintain market share unless they evolve their products to keep up with competition. They are thus forced to change their products by the market or other forces.
Logistical obsolescence	The loss of ability to procure the parts, manufacturing or materials necessary to manufacture or support a product for other reasons.

Table 2.1 - Forms of obsolescence, adapted from Bartels, et al. (2012)

With a competitive landscape increasingly characterized by rapidly shortening product life cycles (PLCs) of components, there is a growing risk of obsolescence in almost all product sectors (Le Mens, Hannan and Polos, 2015). However, the longer the life of the main products are, the more instances of obsolescence will generally occur (Rio and Sampayo, 2014). This is due to the subcomponents having shorter life cycles than the main product. Some industries are characterized by long product life cycles and are thus susceptible to component obsolescence. Some examples of such industries are military, railway, aerospace, automotive industries, telecommunication industries, and nuclear energy (Pugh, 2015).

The event that truly put obsolescence on everyone’s radar occurred in the early 1990s, when Intel and Motorola abruptly terminated their military semiconductor businesses (Baca, 2010). This affected nearly every military program in the U.S. and led to significant issues of obsolescence since a vast number of components become non-procurable.

2.2.1 Sources of Obsolescence

There are a number of possible reasons for component obsolescence. In order to develop a strategy that can effectively mitigate and combat the issue of obsolescence, it is of vital importance to understand the nature and source of it (Lafontaine & Slade, 2007). Thus, a more detailed description of various sources of obsolescence is given in *Table 2.2*.

Obsolescence Sources	Description
Technological Evolution	A new generation of a specific technology makes its predecessor increasingly obsolete. Typically, the newer generation has improved performance and functionality at lower cost.
Technological Revolution	A new technology displaces its predecessor completely and abruptly.
Supplier (Original Component Manufacturer, OCM) Withdrawal	The supplier, or OCM (original component manufacturer), disappears from the market as a result of i.e. bankruptcy or industry exit.
Market Forces	Demand for component or technology decreases, causing manufacturers to find it uneconomical to continue production.
Environmental Policies and Restrictions	Directives, rules and other forms of legislations imposed by governments can cause obsolescence of components or technologies.
Allocation	Long product lead times result in temporary obsolescence, usually categorized as short-term supply chain disruption.
Planned Obsolescence	Involves artificially limiting the durability of goods to simulate increased consumption. Often implies purposefully designing products that wear out or become out-of-date after limited use.

Table 2.2: Sources for obsolescence. Compiled from Bartels, et al. (2012); Lafontaine & Slade (2007); Sandborn (2008); Atterbury (2005), Feldmann & Sandborn (2007).

2.2.2 Operational factors contributing to obsolescence

Beyond the primarily external sources of obsolescence listed in *Table 2.2*, there are a number of operational factors that have been shown to increase the vulnerability to obsolescence issues. One such factor involves a lack of system subdividing (Livingston, 2000). This term describes a situation where replacing a component or part of equipment will affect the larger system as a whole. Mitigating issues related to lacking system subdividing (ability to be handled on subsystem/subcomponent level) requires proactive obsolescence management measures. This includes taking the entire system into account and subdividing it so that portions of the system are replaceable without affecting its entirety (Xiaozhou, Thornberg and Olsson, 2012).

Another factor that contributes to obsolescence issues is extensive usage of commercial-off-the-shelf (COTS) parts bought in an open market, rather than commissioning custom-made solutions (Anon, 2019). COTS products are commoditized and standardized products that are easily accessible. Usage of COTS parts increases the risk of obsolescence caused by market forces since there is no formal partnerships or contractual obligations. Consequently, using COTS results in a limited ability to work out agreements with the supplier regarding how obsolescence issues should be handled if they arise and how long the component should remain in production (Atterbury, 2005).

2.2.3 Sustainment-dominated systems

A *system* can be defined as a stand-alone assembly of multiple individual parts operating singularly or interoperating with various other systems in a specific system-of-systems design (Arnold and Wade, 2015). Sustainment-dominated systems are those systems whose lifecycle sustainment costs related to maintenance exceed the system's original development or procurement costs (Singh and Sandborn, 2006). In this specific context, sustainment implies keeping an already existing system operational while also upholding the ability to manufacture versions of the system satisfying original requirements (Sandborn & Lucyshyn, 2018).

Technological obsolescence is a common and significant problem that many sustainment-dominated systems face (Gravier & Schwartz, 2009). These systems are characterized by many of the products making up the system having short lifecycles than the overall system itself (Singh & Sandborn, 2006). Therefore, planning for obsolescence in these systems has become a critical aspect of their life cycle planning (Singh & Sandborn, 2006).

2.3 Obsolescence management

Obsolescence management involves taking into account the lifespan of all subsets in a sustainment-dominated system and formulating a plan to replace obsolete parts as they age, primarily *before* they are non-procurable (Porter, 1998). There are a number of obsolescence mitigation strategies that are commonly used to manage obsolescence once it occurs. These include last-time-buys, emulation, aftermarket sources, part replacement, reengineering, salvaging and design refresh (Stogdill, 1999). These will be elaborated upon in this subsection.

A majority of these mentioned strategies are *reactive* in nature, focusing on minimizing the costs of resolving the problem after it has occurred (Porter, 1998). Reactive measures are unquestionably important, but ultimately, higher payoffs in the form of larger sustainment cost avoidance is possible only through the implementation of a more *proactive* as well as *strategic* obsolescence management approach (Sandborn et al., 2011). Within companies who strive to effectively mitigate problems related to obsolescence, a customized obsolescence management plan should be formulated and improved continually, in order to ensure effective selection, implementation and tracking of obsolescence management activities (Sandborn, 2008). A large part of contemporary obsolescence management involves measuring and forecasting component-level obsolescence and, in extension, developing various models that assess the total costs of different options (Sandborn et al., 2011).

As mentioned, the main approach to manage obsolescence traditionally has been reactive in nature. Consequently, managers have historically focused on optimization techniques such as minimizing the cost of resolving problems related to parts going out of production (Singh & Sandborn, 2006). However, increasing costs generated by extensive reliance on such optimization (involving primarily reactive approaches) has prompted increasing efforts to develop sophisticated strategic and proactive obsolescence management approaches as complements to reactive measures.

2.3.1 Obsolescence and product life cycles

The current procurement status of a product, as well as its future development, can often be described and predicted by the PLC stage that it is currently in (Pecht & Das, 2000). In obsolescence management, awareness of a product's current life cycle stage is often used as a basis for forecasting the eventual obsolescence date for that part (Sandborn et al., 2011).

	Product life-cycle stages					
Characteristic	*Introduction*	*Growth*	*Maturity*	*Decline*	*Phase-out*	*Obsolescence*
Sales	Slow but increasing	Increasing rapidly	High	Decreasing	LTB	Sales from aftermarket, it at all
Price	Highest	Declining	Low	Lowest	Low	Not applicable
Usage	Low	Increasing	High	Decreasing	Decreasing	Low
Part modification	Periodic die shrinks and possible mask changes	Periodic die shrinks	Periodic die shrinks	Few or none	None	None
Manufacturing fab	High-tech, low volume	Standard, high volume	Standard, very high volume	Sub-standard, high volume	Outmoded, low volume	None or aftermarket fab
Competitors	Few	High	High	Declining	Declining	Few
Manufacturers profit	Low	Increasing	High	Decreasing	Decreasing	Decreasing
BCG-matrix	Question mark	Star	Cash cow	Poor dog		

Table 2.3 - Characteristics of different PLC stages, adapted from Pecht and Das (2000).

Unlike the traditional PLC, the model used in obsolescence management includes the stages of "phase-out", where the product is approaching end-of-production (EOP) as well as obsolescence, where the product is no longer produced and thus is hard to procure (Pecht and Das, 2000). To illustrate what the characteristics of different stages within the model above can imply for obsolescence management, consider the tendency of many firms to conduct a lifetime buy (LTB; purchasing the projected amount of parts needed to support the system until its discontinuance) in the phase-out stage of a part. Looking at the aspect of price in *Table 2.3*, the price is still low in the phase-out stage. This is a result of the maturity of associated operations and the potential for a sell-off of existing stock by the seller. However, once the product enters the 'obsolescence' phase, the price is either inapplicable (because the product is non-procurable) or very high, since one must buy it from pricy aftermarket sources (Pecht and Das, 2000).

2.3.2 Implementation of obsolescence management

To ensure consistent qualitative performance, an obsolescence management plan should be improved continually (Kidd and Sullivan, 2010). Sandborn (2008) argues that a critical aspect of effectively handling obsolescence is to address it on three separate levels of management: reactive, proactive and strategic. All approaches are needed.

Sandborn et al. (2011) argue that key steps to implement reactive, proactive and strategic methods of obsolescence management are:

- Taking obsolescence management options into consideration in the process of part selection
- Introducing proactive systems of information sharing and standardization to improve predictive capability
- Formulating strategic procedures to define, design, acquire and use (maintain) products
- Maximize component obtainability by identifying, utilizing and supporting available resources for procurement of components meeting the requirements
- Lifting the focus beyond single parts or components, thereby enabling management above the part level
- Proactively design the lifecycle management of systems. Involves choosing the optimum mixture of design refreshes and reactive mitigation to effectively manage obsolescence.

Unexpected events causing obsolescence issues will never cease to exist, thus organizations need to have a strategy in place to deal with arising challenges systematically and effectively. A good way to do so is to follow the Plan-Do-Check-Act (PDCA) cycle proposed by Singh and Sandborn (2006; *Figure 2.2 - Plan-Do-Check-Act (PDCA)*). This PDCA process for managing obsolescence involves *planning* for obsolescence on a strategic level, *designing (doing)* for obsolescence in a proactive manner, *checking* for obsolescence continuously, and lastly acting as *planned* when problems occur potential risks are detected.

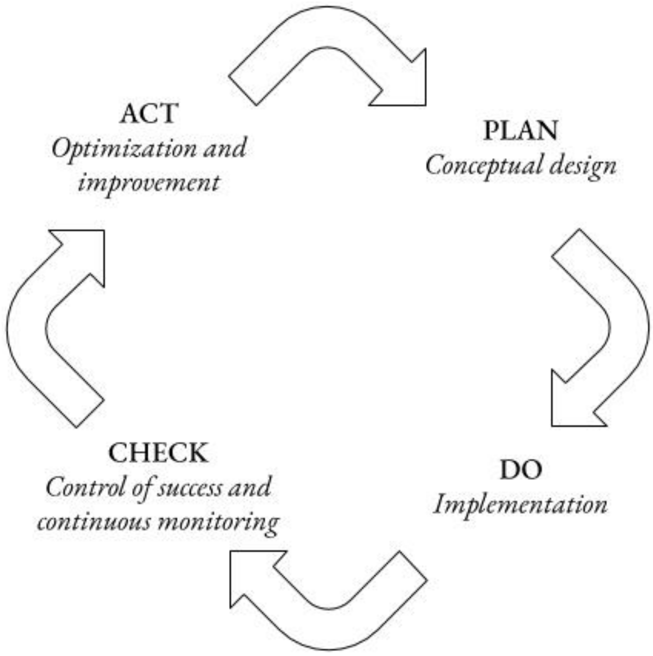

Figure 2.2. Plan-Do-Check-Act (PDCA) cycle, adapted from Bartels, et al. (2012).

2.3.3 Reactive obsolescence management

In those instances where management have not developed any proactive or strategic approaches to manage obsolescence, obsolescence problem identification often comes from suppliers providing end-of-life (EOL) notices. These proclaim that a supplier's product(s) are about to become obsolete, and thereby non-procurable by the OEM within a near future. Often, the part is still procurable for a limited time after this EOL notice has been provided, Reactive obsolescence management then involves finding immediate solutions to these components becoming obsolete and documenting the actions taken (Sandborn, 2008).

There is a tendency within obsolescence management to rely too heavily on reactive measures (Kidd & Sullivan, 2010). Continuous and holistic management involving hundreds, perhaps thousands of different components with varying lifecycles poses a daunting task for an organization to handle. Therefore, many managers adopt a reactive posture, developing solutions primarily when problems have been identified (Rojo, Roy and Shehab, 2009). This approach has proven ineffective, since identifying obsolescence in an exclusively reactive manner leads to failure in planning for software and hardware replacements, which has a negative impact on total costs. An overreliance on reactive approaches has therefore been shown to generally generate higher cost in the long term (Kidd & Sullivan, 2010).

Bartels, et al. (2012) list the most common reactive management approaches, which are listed in *Table 2.4*.

Approach	Description
Lifetime buys & Last-time buys	Often when a supplier issues an EOL notice, the part is still procurable for a limited time in order to give customers a chance to buy parts one last time and meet the systems' forecasted lifetime requirements (Lifetime buys). Last-time-buys are stock purchases of parts which serve to cover the time necessary to select new suppliers from which to source parts.
Bridge buys	A bridge buy is intended to meet demands until the next time when the system is redesigned or modified. At this point, the obsolete part is replaced with another non-obsolete one.
Buying from aftermarket sources	The aftermarket is made up of the period after the original supplier has phased the part/component out of production. As such, the function of aftermarket sources is to satisfy continued demand for parts discontinued by the original supplier. There are three categories of aftermarket sources: Approved aftermarket sources remanufacturing parts, approved aftermarket sources providing finished parts and lastly unapproved aftermarket sources for finished parts (brokers).
Alternate parts	Involves finding alternate parts (parts with same or greater performance) which can be provided by another supplier. These parts can then be used instead of the obsolete part if the functionality is equivalent, the mechanical characteristics are the same and the quality is equally as good.
Uprating	Is a special form of component replacements. It involves evaluating a parts ability to fulfill performance and functionality requirements of applications where it is necessary to utilize the part outside the specification range of the manufacturer.
Emulation	Mainly applicable for electronic parts. Involves creating unavailable electronic components from their slash sheets, datasheets, and other information.
Harvesting	Involves salvaging used parts that have a remaining useful life. When the parts in need of salvaging are identified, source of reclaimable parts are searched in order to find parts that can be reused. These include systems that are beyond economic repair, retired assets, excess stock and spares that are stocked for discontinued systems.

Table 2.4 - Common reactive obsolescence management approaches

2.2.4 Proactive obsolescence management

A multitude of researchers highlight that proactive methods to manage obsolescence are required during the development of systems and components (Rojo, Roy & Shehab (2009; Bartels et al. 2012; Sandborn et al. 2011). In proactive obsolescence management, the objective is to track life cycle information on selected, critical parts in a proactive manner. This will prevent risks related to obsolescence, such as production stops or costly redesigns (Bartels, et al., 2012). Doing so requires the ability to accurately forecast and analyze the obsolescence risks of different parts.

Such parts should be systematically identified and managed prior to becoming obsolete. Most corporations do not have the resources required to proactively manage all parts in their systems. Therefore, parts must be ranked in order of importance and managed accordingly. An important aspect of proactive obsolescence management involves handling of bills of materials (BoM) for critical and potentially obsolete components. It also involves the process of articulating, updating and reviewing the system-level obsolescence status (Sandborn, 2008). The ultimate outcome of proactive obsolescence management is an effectively health measurement of different critical systems.

One method of proactively managing obsolescence is usage of design refresh planning. According to Singh and Sandborn (2006), it is an effective approach to strategically plan for obsolescence, by determining the best timing for design refreshes and the optimal mixture of actions to take when those designed refreshes are needed. For this method to be effective, accurate forecasts of parts obsolescence must be obtainable.

2.3.5 Strategic obsolescence management

Strategic obsolescence management involves leveraging obsolescence data, technology forecasting, logistics management inputs, as well as business trends to allow for lifecycle optimization, strategic planning. This enables long term obsolescence case development, in order to effectively support systems. The high costs of relying on reactive measures to handle obsolescence occurrence are mitigated by implementing strategic solutions at the design stage and over the entire life cycle of the product. To strategically manage issues of obsolescence, plans and process guides must be developed, which describes the infrastructure and processes to be followed in product design, manufacturing and support.

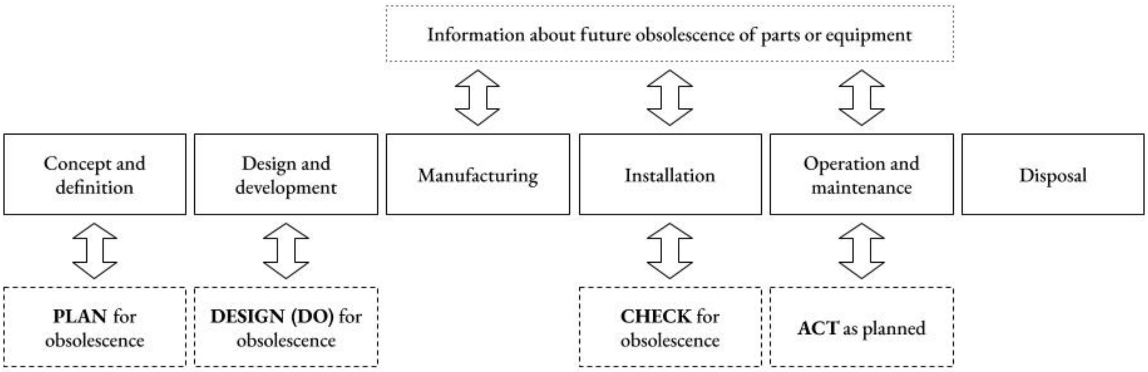

Figure 2.3 - Strategic obsolescence management during PLC, adapted from IEC-62402 (2004)

The model in *Figure 2.3*, shows how strategic management of obsolescence is carried out during the entire product life cycle. It is an adaption of the plan-do-check-act (PDCA) cycle, in this case illustrating how a life cycle view of obsolescence can be implemented throughout the entire company to better manage issues of obsolescence. As shown in *Figure 2.3*, it is possible to implement an obsolescence management plan in all life cycle phases of a product. As previously stated, it is more effective if management of obsolescence issues are initiated in the product development process; in the creation of the product's conceptual design (Tomczykowski et al., 2000). This is based on the most effective way to minimize the obsolescence cost and risks is to facilitate rapid replacements and maintenance of components (Baker, 2013). If a flexible design is achieved, the ability to manage part obsolescence is likely to be improved.

One major objective of strategic obsolescence management involves efforts to achieve such a flexible condition. However, to reach this goal it is necessary to plan long term and cooperate at all different levels of the intra-organizational as well as external supply chain. Sondermann (1994) has created a framework for reaching such a level of obsolescence management of strategic obsolescence. It involves four different stages:

1. *Initiation stage:* The initiation stage is used to analyze the current situation and build a knowledge base regarding obsolescence. This involves auditing and raising awareness.
2. *Planning and design stage:* In this stage preliminary obsolescence management plans are developed to detect weaknesses, risks and causes of obsolescence. Much of this involves designing products to avoid issues of obsolescence and analyze processes to enhance their ability to support products.
3. *Execution stage:* This stage involves strategically operating, performing and leading the obsolescence management system. Forecasting the product life cycle when developing a new product, to determine the suitable obsolescence avoidance strategy; including scheduling of redesigns and refreshes of the system. Optimizing the parts selection process to avoid obsolescence issues. Effective supplier management to deal with their input: parts, materials and services. This demands suitable supplier selection, development and integration. Another strategic aspect that needs to be dealt with effectively is contractual language. Effective contracts with suppliers ensure that information from original part manufacturers (like PDNs and PCNs) arrive in time, ensuring that appropriate actions can be taken to deal with it. Furthermore, effective contracts mitigate the risk of obsolescence and help evaluate the probability of obsolescence occurring. Lastly, this stage involves design refresh planning (described more in 2.5.2) optimization.
4. *Monitoring and controlling stage*: This stage involves defining, analyzing and evaluating the different costs of obsolescence management.

2.4 Theoretical summary

In this chapter, theory relevant to answer the formulated research questions has been presented. Starting off, an explanation of *technological disruption* (including related concepts like disruptive innovation and S-curves) was provided. This is a key concept to grasp in order to how answer how a large truck OEM can effectively manage obsolescence issues caused by disruptive technologies. The reason for this is that technological disruption is the source of many occurrences of *obsolescence* which was the next concept described in the literature review. Obsolescence can lead to increased costs and operational problems, all of which are challenges to the company in question.

Fortunately, there are established practices to deal with these issues, grouped under the name *obsolescence management.* These practices can be divided into three groups, *reactive, strategic* and *proactive* obsolescence management, all of which intended to mitigate the detrimental effects of obsolescence by targeting different areas of potential action. Reactive measures aim to manage problems that have already occurred, for example when a PDN (product discontinuance notice) has been received. Proactive measures involve proactively identifying parts at the risk of becoming obsolete and finding solutions to reduce the risk and impact of such occurrences. In this category, *design refresh planning* is found, detailed in its' own chapter subsection. Strategic measures target the problems of obsolescence at an even more holistic level, involving measures not directly related to specific parts or occurrences, but the general processes and operations of the company.

In summation, the chapter has shown how challenging technological developments can be for sustainment-dominated systems, but also that there are effective ways to mitigate and manage the potential impacts a sustainment-dominated company might face.

3

Method

This chapter will provide the reader with a detailed overview of the research strategy (3.1) and research design (3.2) that have been implemented to effectively answer the formulated research questions. It will elaborate upon the choices made to conduct a multi-method study consisting of a case study review (3.3) and qualitative interviews (3.4), as well as a justification for why these specific choices have been made. Finally, the selection method for participants is detailed, and the process for gathering data is discussed.

3.1 Research strategy

3.1.1 Inductive approach

Since the research conducted was aimed to primarily generate new learnings related to a specific industrial context, the nature of the study was primarily inductive. This approach was decided upon after carefully considering the purpose of the research, as well as the methods best suited to either test a hypothesis or explore a new area of research. Following the thesis' purpose, the study was mainly concerned with the generation of new theory emerging from the gathered data and finding new learnings by looking at a previously researched phenomena from a practical perspective (Bryman & Bell, 2011; Esaiasson, Gilljam, Oscarsson & Wägnerud, 2012).

One central reason for choosing an inductive approach relates to the objective of the truck OEM. Their main strategic concern for this particular thesis project was the generation of new learnings on obsolescence through benchmarking industries that have undergone similar disruptive challenges and transitions. While theories related to obsolescence management and obsolescence caused by disruptive technologies there already exists, a void exists in the literature when it comes to the specific context and nature of this thesis. A new perspective on obsolescence is provided as a result of the company-specific context of the truck OEM as well as the method of benchmarking to gain insights into historically successful strategies of handling technology obsolescence. Thus, the chosen method needs to reflect an exploratory way of researching the situation of a truck OEM as well as other industries that have undergone similar challenges (Bryman & Bell, 2011).

An inductive approach is generally associated with the usage of qualitative research as the primary research strategy, which is also the case for this thesis (Bryman & Bell, 2011; Esaiasson, et al., 2012). A major reason why a qualitative research strategy was deemed appropriate for this thesis was once again the nature of the study's purpose. An argument can be made that a quantitative approach could be applied to analyze the tendencies of obsolescence within the case (i.e. through statistical analysis or surveys). However, the specific truck OEM had already analyzed certain developments of components on a quantitative level and wanted to inquire the qualitative and pragmatic implications of obsolescence to their operations.

The usage of an inductive approach involves continuously jumping between theory and data in an ongoing process. At first, theory might be collected, followed by gathering a certain amount of data. This data might thereafter prompt collection of some additional theory, and linkages between the two are formed gradually (Bryman & Bell, 2011; Esaiasson, et al., 2012)

3.1.2 Multi-method study

Given that a qualitative approach was decided upon, it was furthermore deemed suitable to apply a multi-method qualitative study. This was due to the challenge of generalizing the insights on a grander scale. As such, by utilizing multiple methods to study the same developments, it allowed for the insights to be triangulated and confirmed from multiple points of view (Bryman & Bell, 2011; Esaiasson, et al., 2012). In parallel, the two methods (a case study review and semi-structured interviews) acted to gather different levels of information. Brewer & Hunter (2006) argue that different methods within qualitative research have different and specific strengths in relation to the different levels that exist within that area of research. It was assumed that the case study review would generate more general knowledge across the field of obsolescence, whereas the interviews would verify or challenge that knowledge, as well as deepen the insights on a case specific level. Thus, in line with the inductive nature of the study, the qualitative interviews provided an ability to facilitate the creation of novel insights contributing to existing knowledge, whereas the case study review formed a solid foundation of knowledge upon which these novel learnings can be applied, integrated and validated.

Furthermore, interviews were held with different actors to gather a variety of perspectives needed to answer the research questions. In total 3 interviews were held with employees of the specific truck OEM, 3 were held with obsolescence experts (one of which also counted as a benchmark interview) and 7 were held with experienced professionals from benchmark industries.

Finally, a multi-method approach combines multiple methods of data collection in a research study (Creswell, et al., 2007). The reason behind this choice was that a narrow data gathering process often leads to misleading conclusions. It was therefore more likely to gain a broad yet accurate result by combining multiple different approaches and perspectives (Brewer & Hunter, 2006).

To summarize, the inductive, multi-method research framework aims to gather a variety of data and answer the research questions as depicted in *Table 3.1*.

	Research questions				
Method	*RQ*	*SQ1*	*SQ2*	*SQ3*	*SQ4*
Case study review	X	X	X	X	X
Truck OEM interviews	X	X			X
Expert interviews	X			X	X
Benchmark interviews	X		X	X	X

Table 3.1 - Overview of methods and research questions

3.2 Research design

Given the objectives and prerequisites of the research, the research design chosen for this thesis was a case study approach as described in Bryman & Bell (2011; Esaiasson, et al., 2012). A case study approach is a research design commonly used in business research, which entails the detailed exploration of a specific subject: an individual, group, location, event, phenomenon, or organization (Stake, 1995).

A case study is furthermore characterized by its concern for the complexity and specific nature of the case in question. Bryman and Bell (2011) argue that a case study is an appropriate research design in those instances when you wish to gain highly concrete, in-depth knowledge about a specific, real-world subject. In this instance, that real-world subject was the handling of obsolescence and disruptive technologies. Rather than challenging the theories of obsolescence management, this case study aims to expand on these theories and models by uncovering new concepts and ideas that need to be incorporated into the existing literature on this topic. More specifically, this involves providing specific examples of suitable obsolescence management strategies based on lessons learned in other industries over the last 20 years.

The selection of cases was done on the basis of the formulated problem statement and research questions. This generated the following criteria to include a case:

1. Their perceived potential to provide new insights into the subject matter of effective obsolescence management within the organizational context of a large truck OEM
2. Their ability to profoundly challenge existing assumptions on these matters

3. Their capability to generate viable courses of action to solve the problems related to such obsolescence issues
4. Their potential to open up new directions for future research, for both the company and the academic field overall

Additional case study review inclusion and exclusion criteria are listed in *Table 3.3*, found in the next section.

Starting off with the first criteria for case selection: the perceived potential of cases to provide new insights into the subject matter. This criterion involved finding cases which possessed both enough similarities to the company-specific context of the large truck OEM to remain applicable to their situation. The cases also needed to provide enough novel and new information to formulate a greater understanding of alternative courses of action that have been used when effectively managing obsolescence issues. A variety of industries were deemed as suitable cases based on their similarity to the trucking industry. These industries were chosen based on the following dimensions:

1. Companies within the industry experienced problems with obsolescence as a result of technological disruptions
2. The operational context somewhat resembles that of a large truck OEM:
    a. Products sold have long service market
    b. Relatively low volumes create difficulties controlling suppliers' operations
    c. Products sold are technically complex and composed of a large number of components and materials

Regarding the remaining case criteria (2, 3 and 4), there also had to be enough similarities to remain applicable, yet sufficient amounts of novelty to provide fresh perspectives and insights. Beyond complementing the context of the specific truck OEM, the multiple cases chosen also had to complement each other, and each be able to bring something of value to the mitigation of obsolescence issues for the large truck OEM.

3.3 Case study review

The first stage of the research was identifying and investigating cases from industries that have gone through similar obsolescence challenges and transitions as the heavy truck industries, and how the issues were managed. As such, a multiple case study review using a Systematic Literature Review methodology was conducted. This formed a multi-case study review of 90 cases from 11 different industries (see *Figure 4.1*).

The reasoning to utilize a Systematic Literature Review (*SLR*) method was due to it being a method aiming to bring structure and objectivity to gathering cases. An SLR does so by establishing a structure for conducting the review, including revision and pilots to test the hypotheses of the researchers, as well as early establishing and challenging criteria for relevance (Kitchenham, 2004; Brereton, et al., 2006). Furthermore, the structure and revision allow for researchers to distance their own interpretations from the results. Finally, an SLR reports the framework and data gathering in greater detail than an ordinary review, which increases the transparency and consequently the repeatability of the study. As such, an SLR contributes to both the reliability and validity of the study (see section *3.5 Reliability and Validity*).

As a method, an SLR serves to gather, synthesize and analyze relevant cases. As previously mentioned, the thesis applied a multi-method approach to triangulate knowledge, achieve knowledge on different levels, and aggregate more current and applicable knowledge. A case study review can contribute further to synthesizing such insights from a broad range of sources. Furthermore, there are additional reasons why an SLR is a relevant framework for the study. Petticrew & Roberts (2007, p. 21) provides a list when and why an SLR is beneficial. From this list, a number of reasons were applicable to this research. First of all, in order to answer and understand obsolescence issues, a broad understanding needs to be established. Second of all, there are historical developments that needs to be understood when generating a new company strategy.

The case study review conducted in this thesis is based on SLR methods provided and explained in Kitchenham (2004), Brereton et al. (2006) and Petticrew & Roberts (2007). Overviewing these frameworks, they are quite similar in their structure and phases. For the purpose of this study, the case study review will be structured around the framework provided in Brereton et al. (2006) and developed and analyzed by insights from Kitchenham (2004) and Petticrew & Roberts (2007). The framework consists of three separate phases: Planning (1), Conducting (2) and Documenting (3) the review. These phases are then broken down into separate, individual stages. The interpretation and application of these stages can be visualized in line with the understanding of Brereton et al. (2006) in *Figure 3.1*.

The first phase (Phase 1) is focusing on establishing a clear platform for the case study review with a case study review specific research question, review protocol (inclusion/exclusion criteria and questions to assess the review), and a test (case study review pilot). This is important in order to standardize and separate the authors from the study, thereby reducing risk for bias. Conducting the review (Phase 2) is then related to gathering all the cases according to the review protocol. Finally, documenting the review (Phase 3) is showing the results of the review. *Table 3.2* provides a detailed description of how the case study review was conducted in this thesis.

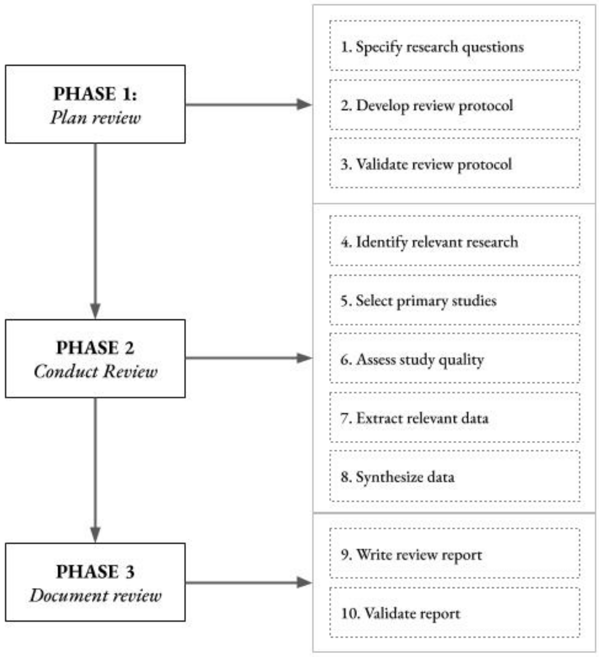

Figure 3.1 - The Systematic Literature Review process, adapted from Brereton et al. (2006)

Phase 1 - Plan Review	
Stage 1: Specify Research Questions	Since the purpose of the case study review was to gather insights and cases from obsolescence issues in other industries, the following review questions were formulated: - Review questions: Which other industries have gone through similar disruptions and obsolescence issues as the trucking industry will face? What trends and patterns are there? What can be learnt from these cases?
Stage 2: Develop Review Protocol	Two instruments were created for the review protocol: A set of inclusion/exclusion criteria (Table 3.3) and a number of review questions. The review questions were as follows: - Are the cases relevant to the truck OEM's context (based on the case criteria)? - When was the case published? - When was the case conducted? - Who published the case? - Are the sources described or listed? - Does the publisher have a stake in the case? - Is there any dependency to other studies or actors? - Has diversity been taken to consideration where needed?
Stage 3: Validate and challenge review protocol	The case study review was validated and challenged through an initial pilot that gathered cases on the databases of University of Gothenburg (ub.gu.se). This pilot found 33 cases, out of which 19 were deemed highly relevant. From these 19 articles, key words were gathered, and the main case study review was refined and conducted.

Table 3.2 - Summary of case study review method (pt. 1)

Phase 2 - Conduct Review	
Stage 4: Execute review	The review was conducted by combining key words (gathered and refined in Phase 1) of the theories, industries and delimitations. These formed a search sling following *[keywords: all] + [industry: industry-specific] + [delimitations: all]* which were used to search for cases in academic databases and general online searches. A full list of these keywords can be found in *Table 3.4*.
Stage 5: Select case studies	After the search was conducted, 90 case studies across 11 industries were found and deemed relevant to the thesis.
Stage 6: Assess study quality	An additional analysis was made based on the review protocol questions. As the questions had been used continuously when gathering the cases, no new cases were excluded from the study.
Stage 7: Extract data	This was simply done through downloading and categorizing the case studies according to industry.
Stage 8: Synthesize data	All cases were then synthesized and summarized per industry. The results of which can be found in *Figure 4.1*.
Phase 3 - Document Review (*See Chapter 4*)	

Table 3.2 - Summary of case study review method (pt. 2)

	Inclusion	**Exclusion**
Case delimitation	Included benchmark industries were those who had (1) faced disruption, (2) had operational contexts similar to the truck OEM including (a) long aftermarket, (b) relatively low volumes and (c) technologically complex products.	Excluded benchmarked industries were those who differ from the inclusion criteria or those who are within the industries that the truck OEM are active in.
Time	Included were cases that are conducted as recent as possible (20 years; around the 2000's).	Excluded are cases that are older than 20 years.
Accreditation	Included were cases that were: - **Academic**: had other accreditation (i.e. university accreditation) - **Other**: released by companies or organizations with a clear publisher	Excluded are cases that were blog posts, non-accredited, or publications that had no clear publisher.

Table 3.3 - Inclusion and Exclusion criteria for the case study review

Key words	**“obsolescence”** OR “obsolescence management” OR “obsolescence mitigation” OR “obsolescence prevention” OR “obsolescence strategy” OR “technological obsolescence” **“disruption”** OR “disruptive innovation” OR “technological disruption” **“case”** OR “case study” OR “business case” OR “white paper”
Industries	**“aeroplane”** OR “aeroplane industry” OR “aero” OR “aero industry” **“car*”** OR “car industry” OR “vehicle industry” OR “personal vehicle industry” OR “automotive industry” **“defense”** OR “defense industry” OR “defense” OR “defense industry” **“electronics”** OR “electronics industry” **“energy industry”** OR “solar power” OR “solar power industry” **“ICT industry”** OR “telephone industry” OR “communications industry” **“lighting industry”** OR “outdoor lighting industry” **“maritime industry”** OR “navy industry” OR “boat industry” **“music industry”** OR “physical music industry” **“rail industry”** OR “train industry” **“space industry”** OR “spacecraft industry”
Delimitations (time, availability)	Setting publication date to: “Last 20 years” (PD >= 2000) Setting availability to “Full text availability”

Table 3.4 - Components of case study review search slings

3.4 Qualitative interview study

3.4.1 Interview design

In combination with the desktop research a series of semi-structured interviews were conducted. 12 interviewees were chosen: three internal employees within the truck OEM, three experts on obsolescence management and six experienced professionals in industries that were deemed suitable to benchmark. Semi-structured interviews are centered around an *interview guide* that is utilized to standardize interviews across different interview subjects, while allowing follow-up questions (Bryman & Bell, 2011). This approach allows the interviewer some degree of flexibility in how to acquire the data while keeping a clearly defined purpose (Bryman & Bell, 2011).

A decision was made to conduct separate yet overlapping semi-structured interviews with different actors. The different actors that were included in the interview part of the thesis were experts, actors within the truck OEM’s operations, and actors in the benchmarked industries. Bryman & Bell (2011) highlight that it is beneficial to standardize the interview guides as much as possible, which is especially true when having multiple categories of respondents. For this thesis, the interview guides were therefore standardized as much as possible, but still slightly altered based on the different knowledge and forms of unique insights that separate respondent groups possessed. These interview guides and how they were constructed are explained under each individual segment below (3.4.2 - 3.4.4).

For all interviews conducted, certain elements remained constant. One central similarity for all interviews was related to recording and transcription. The interviewees were always asked if they wanted to be recorded or if they preferred note taking. From a researcher standpoint, recording would always be preferable. According to Bryman & Bell (2011), recordings would allow for more accurate reproduction and analysis of an interview. Therefore, with the approval of the interviewees, the interviews were recorded and transcribed in the original language and word-by-word.

Another similarity across the interview segments was related to open-endedness and open-mindedness. Some initial understanding had been formulated through research before the interviews were conducted. However, it was deemed that this should not influence the interviews more than guiding and framing the interview guides. As a consequence, two actions were taken. First of all, the interview guides were constructed in a way where the questions were formulated in an open-ended and exploratory manner. While being open-ended, they could still have different characteristics of i.e. follow-up questions, probing questions, specifying questions or indirect questions (as can be found in Bryman & Bell, 2011, p. 478). This would allow the interviewees to introduce their own perspectives in the interviews, which would either strengthen or contradict other interviews and data sources (both of which would be interesting outcomes). Second of all, the role of the interviewers was equally as important. According to Bryman & Bell (2011), the interviewer is a critical factor to both creating a trustworthy interview setup, and consequently acquiring relevant insights. Thus, focus was put on properly introducing the context and not forcing any opinions.

A final similarity of the different interview segments was related to providing the interviewee with the questions before the time of the interview. This was done in all cases. Bryman & Bell (2011) claim that sending the questions beforehand allows the interviewees to reflect upon these, which generates more relevant insights. Furthermore, it would allow for any potential misunderstandings to be discussed and clarified beforehand. One such example that emerged in this interview study was the various definitions of "disruption". While not being a central point to the interviews, it was still raised as an ambiguous term. Thereby, the authors were able to clarify their definition of the term, minimizing the risks of misunderstandings.

3.4.2 Truck OEM interviews

The first segment of interviewees were employees from within the specific truck manufacturing OEM. These interviewees are employed within a variety of business functions. One selection criterion that was consciously used to screen potential employees was their professional and personal experience in dealing with issues of obsolescence. For this "experience" screening, the authors were given assistance by multiple senior managers within the company who possessed a better grasp of whom within the organization would be fruitful to interview.

Another criterion that was kept in mind was the ability of interviewees to sufficiently complement each other in terms of divergent experiences, while also retaining the ability to triangulate the findings from different interviews. As a result, an attempt was made to interview multiple individuals from each chosen business function (in order to validate findings), but simultaneously the authors tried to find interviewees from multiple functions of the corporation to gain a broader understanding of the issues the truck OEM is facing. In order to further strengthen the validity of findings from truck OEM interviews, the questions were kept the same regardless of what function the interviewee worked within.

3.4.3 Expert interviews

Expert interviews were conducted throughout the process of data collection parallel with internal interviews at the truck OEM, as a conscious effort to establish a solid academic and practical foundation from which further exploration into the subject matter could be conducted. All experts interviewed are published and accredited authors of both books and articles within the field of obsolescence management. They were deemed valuable to interview based on how relevant their publications were to the company-specific context of this thesis, as well as how constructive their publications were in helping the authors gather relevant theory to answer the stated research questions.

There was also a conscious effort made to find experts who complemented each other, either in their industrial background or their specific sub-field of expertise. Regarding their industrial background, one selection criteria was that the industries in which an expert had their eventual expertise had to conform with the selection criteria for industries suitable for cases (explained in section *3.2 Research design*).

3.4.4 Benchmark interviews

The last set of interviews were conducted with experienced professionals within industries that were chosen as suitable to benchmark. The suitability of industries to benchmark was determined through data gathered in the truck OEM and expert interviews. Hence, those categories of interviews were carried out before benchmarking interviewees were found. In this way, the company-specific context as well as the collective knowledge on the concept of obsolescence was combined to determine industries that had most to offer as benchmarking industries for a large truck OEM.

Since the interviewees in this category were more heterogeneous in terms of their professional background, their field of expertise and their company’s industry, it was deemed disadvantageous and ineffective to develop an interview guide broad enough to apply to every interviewee in the benchmarking category. Hence, an effort was made to balance the objectives of specificity (attaining useful and specific data) with that of standardizing and validity (triangulating and validating the obtained data) when constructing the interview guides and booking interviews. Without specificity, the interview guide risked becoming too broad, resulting in blunt and substandard data. Without validity, the data gathered (and by extension conclusions drawn) risked becoming skewed by the specific perceptions and opinions of a singular interviewee.

To balance validity and applicability, one outcome was that interviewees were grouped into a number of industries that were deemed suitable to benchmark. Thereafter, at least two interviewees from different companies in an industry were identified and reached out to in each industry (See *Table 3.5*). The one exception to this was the car industry, where only one interview was conducted.

#	Interviewee	Group	Date & Location	Interview Duration	Role	Interview Language
1	Employee A	Internal	2020-03-26	1 hour and 14 minutes	Quality Assurance at Uptime.	English
2	Employee B	Internal	2020-03-27	58 minutes	Manager Uptime EMEA Powertrain	English
3	Employee C	Internal	2020-03-12	59 minutes	Purchasing Director	Swedish
4	Bartels, Bjoern	Expert, Benchmark - Railway	2020-04-23	1 hour and 13 minutes	Founder AMSYS GmbH.	English
5	Ermel, Ulrich	Expert	2020-03-26	1 hour and 11 minutes	Director at PULS Group.	English
6	Sandborn, Peter	Expert	2020-02-19	57 minutes	Director, Maryland Technology Enterprise Institute	English
7	Alexandersson, Frida	Benchmark - Lightning	2020-04-02	38 minutes	CEO at Westal	Swedish
8	Antonov, Katriin	Benchmark - Music	2020-04-01	41 minutes	CEO Digibox	English
9	Bryntesson, Peter	Benchmark - Cars	2020-04-22	1 hour and 3 minutes	Senior Advisor at FKG	Swedish
10	Börjesson, Jan	Benchmark - Lightning	2020-04-03	58 minutes	Director of foreign accounts at Zumtobel Group	Swedish
11	Tydal, Thomas	Benchmark - Railway	2020-04-01	1 hour and 7 minutes	Founder of Tydal Systems	Swedish
12	Uggla, Måns	Benchmark - Music	2020-03-18	46 minutes	CEO Naxos Sweden	Swedish

Table 3.5 - Summary of interviews

3.4.5 Interview guides

Across all interviews, interview guides were constructed. These varied slightly across group and interviewee, and can be found in *Appendix A*. All interviews started with an introduction to the subject and thesis, followed by an introduction by the interviewee. Then came an investigation into the subject at hand. For the truck OEM employees, the focus was the OEM's situation, for the experts there was a focus on contemporary obsolescence management and for the benchmark industry, there was a focus on their company, the disruption they had faced and how the company managed it. Finally, if suitable, snowball sampling was applied if more data was needed from other interviewees.

3.4.6 Interview data processing

The interpretation and processing of data is an essential aspect of qualitative research (Bryman & Bell, 2011; Flick, 2006). The data gathered throughout this thesis therefore underwent a thorough thematic analysis, as the researchers leveraged an empirical approach to view the material (Widerberg, 2002). In order to properly categorize and find themes in the qualitative interviews, coding was used. This involves attaching labels to certain lines of text, in order for the researcher to be able to group or compare related pieces of information (Bryman & Bell, 2011). Using this approach, themes were identified from the empirical material. This entails the conduct of a detail-focused analysis of certain parts of the data, which were thereafter combined with broad classifications and summaries of other parts of the interview material (Flick, 2006). This results in a high degree of internal validity in the study, where the material is presented as a whole, but where the primary focus lies on those aspects that are deemed most deserving of a deeper analysis.

During the data analysis, these themes (together with themes found in the case study review) were subsequently grouped and merged into a number of main themes, which all assist in answering the formulated research questions. These themes were contextual based on the actor segment, but generally focused on (1) the situation, (2) challenges and (3) solutions (for an example, see *Appendix B*). These were thereafter coupled with the theory found in the theoretical section in order to deepen the analysis further.

3.5 Reliability & Validity

Reliability is regarding the repeatability of the study (Bryman & Bell, 2011; Esaiasson, et al., 2012). Being that this thesis uses multiple common methods with a focus on qualitative data, the study can be repeatable. However, looking at the different data gathering techniques, there might be different challenges arising.

Starting with the case study review, it can be seen to be repeatable as each stage of the process is described. Still, some subjective interpretations exist. For example, the case study review could go on and cases could be gathered for a long time. Due to the time restraints of the thesis (20 weeks), the data gathering had to be limited to a shorter amount of time (about 2 weeks).

Another researcher might find more cases depending on time put in. Furthermore, what cases are included and excluded might also vary. In this study, it has been made as structured and transparent as possible (see section *3.3 Case study review*), but it might still vary.

As for the interviews, they can themselves be repeated in terms of interview guide, but the responses might vary. Furthermore, some of the interviewees are anonymous. As such, if another researcher would be interested to repeat the results, it would either have to be shared under confidence or be done with other interview subjects. Ultimately, due to the interview guide and interviewee selection being thoroughly accounted for, the methods and results are deemed repeatable.

Finally, being that the thesis uses multiple methods that exchange and build on each other, the validity is deemed as high. A mixed methodology allows for outcomes to emerge in more than one instance (i.e. both in interviews and the case study review). While not all methods always overlap, there is almost always multiple methods helping in answering a research question (see *Table 3.1*). This strengthens the validity of the results as outcomes are authenticated by multiple separate sources and methods. However, a second point of view highlights the fact that the methods to some degree builds on each other due to the nature of the research question and research strategy. The case study review will act as a steppingstone for the interviews. As such, there could be built-in biases that start from the initial data gathering and is reproduced throughout the research. Thus, in order to ensure the results are valid, this has to be taken into consideration as the research is conducted. An example of how to overcome this is to formulate an open interview guide that does not has built-in biases but allows the interviewees to reflect their own point of view.

4

Results

This chapter will present the results from the case study review (4.1) and the qualitative interviews (4.2). The results chapter is structured to firstly provide the results of the case study review, as these form a foundation on which to apply the empirical findings of the qualitative interviews. The case study review will be presented through a summary of cases for each industry, as well as general findings (situation and solutions). Thereafter, the results of the qualitative interviews are presented. These are structured according to the previous argument of first understanding the OEM situation and thereafter providing relevant supplementary views from benchmarked industries. The qualitative interview results will be presented systematically within each interviewee group (truck OEM employees, experts and benchmark industries) through summaries of transcribed and coded interviews.

4.1 Case study review

The first subsection in this results chapter will focus on the case study review. Each case has been summarized based on the obsolescence intervention or mitigation strategy, as well as a summary of the article itself. In total, 90 cases were retrieved and analyzed from 11 different industries (see *Figure 4.1 Number of cases per industry*).

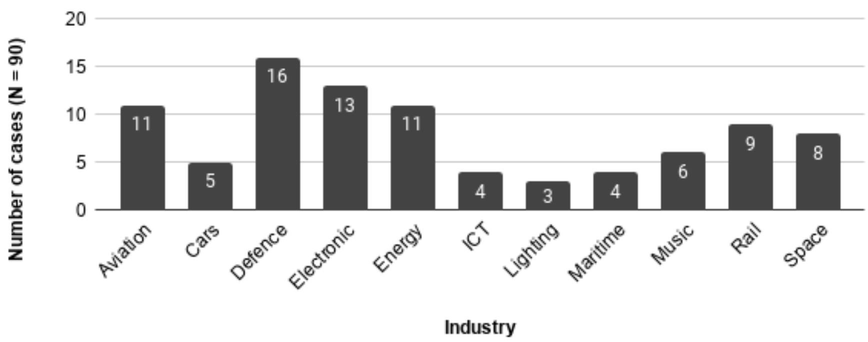

Figure 4.1 - Number of cases per industry

Additionally, an overview has been provided of what sources the cases were from. As can be seen from *Figure 4.2*, about a third of the cases came from academia, a third from companies and a final third from a mix of other sources.

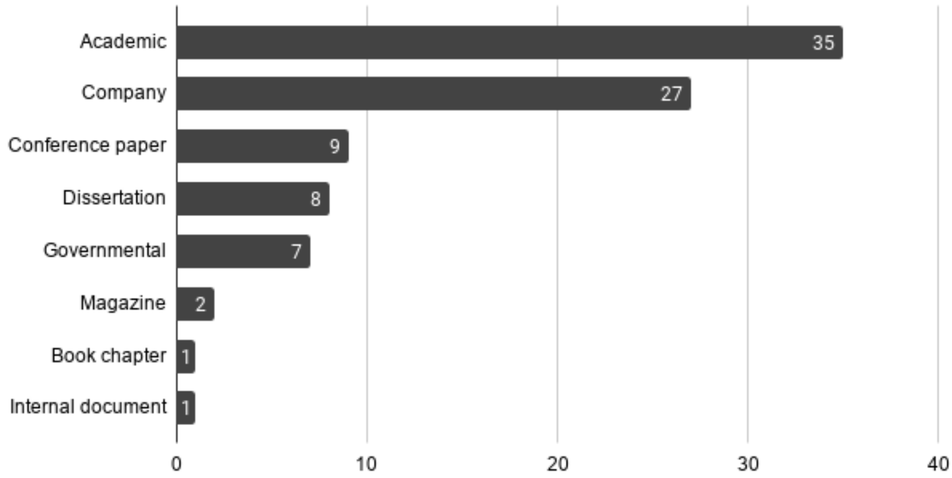

Figure 4.2 - Overview of case study review source type

4.1.1 Aviation industry

The aviation industry has faced multiple forms of obsolescence issues (Boeing, 1998; Wilkinson, 2015). This is especially true when taking into account the increasing level of electronic components in an aircraft (Durugbo & Erkoyuncu, 2014). Many aircrafts are already obsolete by the time they leave the drawing table and enter manufacturing (Sandborn, Lorenson & Geiser, 2002). The cases indicate that there are multiple different tendencies of technological disruption, but these are mainly derived from electronic (i.e. ECUs or Full Authority Digital Electronic Controller (FADEC)) and physical obsolescence issues (i.e. power supplies and rotors).

In order to mitigate and reduce risks of these obsolescence issues, the cases provide a range of strategic, proactive and reactive alternatives. Many of the cases emphasize the importance of collaborating and sharing information between different actors within and outside the company borders (Boeing, 2001; Durugbo & Erkoyuncu, 2014; SiliconExpert Technologies, 2008). Furthermore, Boeing (2001) highlights the importance of establishing an obsolescence management team to steer and monitor obsolescence efforts in an effective way, (which also CMCA.uk (2017) and Muñoz, et al. (2017) emphasize as important).

As for efforts to resolve obsolescence issues, the cases highlight a number of approaches to revolve obsolescence: LTB, redesign and finding an alternative component. However, the cases also provide successful examples of additive manufacturing and utilizing open system architecture in the design of aircrafts (Boeing, 1998; Boeing 2012; Sandborn, Lorenson & Geiser; 2002; Togwe, Eveleigh & Tanju, 2019).

Name	Type of publishing	Intervention/ Strategy	Summary
Bayruns & Koenig (2002)	Conference paper	Open System Architecture	This article focuses on the development of a helicopter system and trying to avoid obsolescence issues. The OEM decided to utilize open system architecture from previous aircrafts, as well as COTS components in order to mitigate obsolescence issues. This led to reduced life cycle costs and support in the ecosystem.
Boeing (1998)	Company	Redesign LTB	This article looks into the case of components and cost-based differences between redesign and LTB. Redesign being the more expensive and time-consuming alternative brings benefits in terms of significantly extending the life of the component. LTB on the other hand extends the life until the next component becomes obsolete, while being easier and more streamlined to commit to. As such, there is a cost-based decision (NPV, Breakeven) that needs to be made. The case shows that when there is only one component, LTB might be preferred, but when there are multiple a full redesign might be preferred.
Boeing (2001)	Company	Task force Monitoring Cooperation	This article focuses on electronic obsolescence in the aerospace industry, that really started disrupting the industry in the early 2000's. Boing committed a number of strategies and actions to mitigate the obsolescence issues. First was to create a operating group to stay updated with standards, second was to look into the design of the components to stay on top of developments, finally was to cooperate with all relevant parties.
Boeing (2012)	Company	Alternative LTB Redesign	This document is a Boeing internal order of action when components become obsolete. It outlines three strategies (and outlines) for handling obsolescence issues. Prioritized action is finding an alternative (preferably by the Seller), moving to a last-time-buy (which the Seller should own), and finally a redesign by the Seller if necessary (which is not preferred due to costs).
CMCA.uk (2017)	Company	Monitoring	This publication provides a case of Safran Electrical & Power that works with aerospace equipment. They had spread their obsolescence actions and information across the company and centralized their monitoring efforts in the same database/system. This allowed them to improve their monitoring across the portfolio.
Durugbo & Erkoyuncu (2014)	Academic	Information sharing Partnership	This article focuses on how information sharing can be a factor in mitigating obsolescence in different industries (mostly avionic and space). Information sharing and partnerships can according to the article greatly improve how companies reduce risk in obsolescence. The authors also indicate the not only formal relationships are important (i.e. formal partnerships and shared databases), but that companies also should nurture individuals with informal relations, platforms and networks within the industry.
Muñoz, Shebab, Weinizke, Fowler & Baguley (2017)	Academic	Monitoring	This article tries to understand what drives (software) obsolescence issues in the aerospace industry through interviewing experts and reviewing literature. The article finds that monitoring a range of obsolescence drivers is the best way to mitigate obsolescence issues. The article also provides a list of drivers that needs to be monitored.
Sandborn, Lorenson & Geiser (2002)	Academic	Redesign	This article analyzes how an aviation manufacturer can learn when the optimal point of a redesign is. By combining life cycle assessment, net present value (cost analysis) and component data, this framework (MOCA) tries to minimize the window of design refresh. The case focuses on a Full Authority Digital Electronic Controller (FADEC) and successfully and preemptively implemented plans for design refresh activities.
SiliconExpert Technologies (2008)	Company	Forecasting Information sharing Partnerships	This publication looks into the current and possible obsolescence mitigation efforts utilized by aero OEM's at the time. They claim that the most important effort to obsolescence mitigation is to correctly forecast when a component becomes obsolete - for which you need to have the correct information. The information can be found in different databases and different actors gather and track such databases.
Togwe, Eveleigh & Tanju (2019)	Academic	Additive Manufacturing	This article highlights a case where additive manufacturing is used to mitigate spare parts management (obsolescence) issues. Additive manufacturing can be used both to print simpler spare parts, but also bridging spare parts where the forecast has come short. However, the case shows that additive manufacturing is not perfect yet and is currently not cost efficient.
Wilkinson (2015)	Government	Governmental support	This governmental publication focuses on companies and how the government can aid them in mitigating obsolescence issues. The publication is full of different examples of current and potential mitigation efforts. As a government body, their efforts should focus on facilitating best practices, reducing costs, improving life cycle planning processes. This can be achieved through sharing issues across industries, establishing standards, aiding existing R&D and using COTS IP.

Table 4.1 - Case study review summary: Aviation industry

4.1.2 Cars industry

The car industry has been rapidly developing in the 21st century, with additional electrical parts, shorter lifecycles and the advent of technologies such as electronic engines, automation, sensoring and digitalization (Boissie, et a., 2018; Mulcare, 2016). This has posed significant challenges for car OEMs and caused ripples in the industry value chain, creating significant obsolescence issues (for both electronic and physical materials).

In order to solve and mitigate these obsolescence issues, the cases provide a range of alternatives. An important fact to realize is that the car industry is currently going through the mentioned technological disruptions. As such, there might be a significant increase in cases in the near future. However, cases provided here still cover a range of mitigation and resolution efforts to reduce the risks and impact of obsolescence. For proactive and strategic mitigation, the cases (similar to aviation) promote partnerships and information sharing among actors within and outside the company borders (Brooks, 2018; Mulcare, 2016; van der Zijl, 2019). Additionally, there are some proactive measures taken. Firstly, analyzing long term storage feasibility enables an OEM to better evaluate whether LTB is a feasible option (Boissie et al., 2018). Second, Khalil & Wahba (2009) gives an example of including obsolescence early in the design of parts and whole systems. While requiring lots of foresight, this enables an OEM to limit risks. The same goes for the case of XYT and their modular cars (Vanderseypen, 2018). Including a modular design could enable an OEM to access and maintain cars, and reuse/refurbish components.

As for reactive efforts, the cases include additive manufacturing and 3D printing, which are showing promising developments (van der Zijl, 2019). Finally, Khalil & Wahba (2009) also describe the use of finding alternatives which might lower the obsolescence risk.

Name	Type of publishing	Intervention/ Strategy	Summary
Boissie, Addouche, Zolghadri & Richard (2018)	Conference paper	Long Term Storage Feasibility (LTSF) modeling	The article finds, through a literature review and analysis of 573 automotive materials, that automotive manufacturers tend to use last-time-buy and storage for components that run the risk of being obsolete. The article provides a storage feasibility mapping model to optimize warehouse compliance operations and mitigating risks of long-term storage.
Brooks (2018)	Company	BMI: Servitization Information sharing	In the need to reduce obsolescence issues, the author suggests three solutions: (1) maximizing product uptime through new business models, (2) optimizing inventory management through data and management systems and (3) making data actionable through gathering, analyzing and sharing data.
Khalil & Wahba (2009)	Academic	Design Alternatives	This article focuses on the electronic parts in cars has rapidly increased in the 21st century, and how especially ECUs run the risk of being obsolete quicker. Due to this fact, the authors suggest that using FPGAs (Field Programmable Gate Arrays) instead of microcontrollers) will lead to fewer ECUs inside the car and thus less obsolescence issues.
Mulcare (2016)	Company	Partnership	In the advent of many new technologies and changing markets, automotive OEMs must change their assembly lines to be more adaptable and energy efficient, which renders traditional machinery obsolete. Changing the machinery fully might be costly and lead to downtime, but at the same time it might be hard to keep older machines going when components are obsolete. However, the automotive industry has seen trends of using trusted partners in acquiring the right component to ensure consistent machine uptime.
van der Zijl (2019)	Company	Monitoring Information Sharing AM	Based on insights from two car manufacturers, this article suggests that the industry needs to think differently in how to do business for the better and mitigate obsolescence issues. Three measures to mitigate obsolescence issues can be identified: (1) Blockchain and machine learning analysis, (2) Information sharing in the supply chain, and (3) utilizing additive manufacturing solutions where possible.
Vanderseypen (2018)	Dissertation	Design: Modularity	This dissertation identifies and analyzes a wide arrange of obsolescence solutions. As for technological component obsolescence, a case study is given for modular design of vehicles through the French company XYT. The company has designed cars with only 600 easily accessible components, instead of 10 000 in an ordinary car.

Table 4.2 - Case study review summary: Cars industry

4.1.3 Defense industry

The defense industry (along with electronics) is one of the industries that historically has faced most obsolescence issues. Being that machinery in the defense industry has long development cycles, systems might experience obsolescence already when entering manufacturing (similar to the aviation industry). Furthermore, systems in the defense industry often have 30-40-year life cycles, during which many components become obsolete (Moore, 2014; Rajagopal, Erkoyuncu & Roy, 2014; Rostker et al., 2014). As such, when looking at the whole industry, there is no single technological disruption, but rather a wide array of different disruptions, that need to be handled based on their context. Granted, some disruptions have been more significant and found in other industries as well (i.e. semiconductors, ECUs, controls, etc.).

The cases provide a broad picture of how companies and organizations have tried to mitigate obsolescence issues. As for the more proactive and strategic measures, cases suggest a working group being key to navigate obsolescence issues (Mitsdarffer, 2014; Meyer, Pretorius & Pretorius, 2012) especially when combined with monitoring and forecasting efforts (Feldman & Sandborn 2007; Moore, 2014; Rojo, Roy & Shehab, 2009), as well as information sharing (Mitsdarffer, 2014; Meyer Pretorius & Pretorius, 2012; Rojo, Roy & Shehab, 2009; Özkan & Bulkan 2019). Since products might already be obsolete as they commence manufacturing, another mitigation effort is to consider obsolescence issues in the design of the system architecture (Jibb & Walker, 2000; Rajagopal, Erkoyuncu & Roy, 2014; Underwood, 2011; Özkan & Bulkan, 2019).

As for more reactive approaches, the cases provide a number of examples. Eiband (2013), Redling (2004), Rojo, Roy & Shehab (2009), Tomczykowski (2003) and Weaver & Ford (2003) all suggest that acquiring, reusing and refurbishing components that are already out in the market can save lots of costs and time if the channels are there. It also brings an added benefit of reducing costs for waste. Moore (2014), O'Boyle (2012), Rostker et al. (2014) & Weaver & Ford (2003) all give success cases for LTB, as well as finding alternative parts. In contrast, Rojo, Roy & Shehab (2009), Tomczykowski (2003) and Weaver & Ford (2003) show how redesign might be a valid alternative to LTB or finding alternatives in the market. However, they claim that there needs to be cost advantages, which are reached when the scale of purchasing existing components is too big or that storage would be too costly. Finally, there are some decision-making methods and tools that are described in the cases. The first example is Feldman & Sandborn (2007) who describe Mitigation of Obsolescence Cost Analysis (MOCA) as a tool to establish when the best time to make a design refresh is. The second example is Özkan & Bulkan (2019), who describe Multi-Criteria Decision Making (MCDM), which includes a broad range of factors to decide upon different obsolescence management strategies.

Name	**Type of publishing**	**Intervention/ Strategy**	**Summary**
Eiband (2013)	Dissertation	Reuse Refurbish	The article analyzes the reuse of legacy defense material (hardware) from eight different cases from different parts of the U.S. defense system (air, navy, etc.). The article describes that the quality and quantity of the hardware was misjudged. Similar was the cases for subject matter knowledge and integration costs. As such, only 3 of the 8 cases were successful in hitting the targets. In order to improve, better knowledge is needed in how to estimate quality, knowledge and costs of integration.
Feldman & Sandborn (2007)	Conference paper	Forecasting Refresh planning (MOCA)	This article focuses on the issues of knowing when to trigger a refresh planning (and update a product). This case uses a forecasting hierarchy based on large databases and then MOCA (Mitigation of Obsolescence Cost Analysis) to narrow down the refresh window as good as possible.
Jibb & Walker (2000)	Conference paper	System architecture	The article addresses system architecture design as an approach to obsolescence management. A carefully designed system architecture can provide a stable structure within which COTS components and processes can be accommodated with reduced risk from obsolescence

Meyer, Pretorius & Pretorius (2012)	Academic	Task force Information sharing	The article provides a process with several stages: 1. Planning activities must be established. 2. Component Obsolescence Teaming Group (COTG) must be formalized 3. Notice of obsolescence needs to be sent 4. Project team established 5. Obsolescence Management Plan implementation 6. Identification of most cost-efficient solution 7. Total obsolescence cost calculated
Mitsdarffer (2014)	Magazine	Working group Collaboration	This article highlights a case where microwave tubes had to be exchanged in almost all of DoD weapon systems. The problem was that the chemical components needed was in incredibly high demand and very rare. Through a working group and (governmental) collaboration, they managed to solve the obsolescence issues to a higher degree.
Moore (2014)	Company	Forecasting Partnership LTB	This article highlights a case of semiconductors of defense materiel. There are issues in forecasting how much will be needed to sustain the full 30-year life cycle of the machine, when a semiconductor might be outdated after 3 years. In this case, they combined forecasting methods with experts in the field. This allowed the companies to better finetune the forecasts.
O'Boyle (2012)	Company	LTB "The grey market" Redesign Partnership	This article brings forth a case with a number of solutions for obsolescence management issues in the Military/Aero industries. LTB is a simple solution, but with lots of forecasting issues. The "grey market" (buying alternatives) comes with a lot of risks and testing period. A new design might also come with costs and long testing periods. All of these, the case claims, can be improved through a partnership.
Rajagopal, Erkoyuncu & Roy (2014)	Company	Barriers to obsolescence management	The main problem in identifying the key cost drivers of software obsolescence is: Unavailability of the data related to Software Obsolescence. Inadequate design documentation and configuration. Unavailability of historic cost data associated with Software Obsolescence. Unavailability of Software obsolescence Management plan and strategies
Redling (2004)	Academic	Retrofitting	The article shows that careful consideration must be given to the physical characteristics of the aircraft, its mission profiles, and interaction with existing legacy systems that will remain on the aircraft after the retrofit has been completed. Finally, consideration must be given to system flexibility and its ability to grow to meet future requirements that have not yet been defined.
Rojo, Roy & Shehab (2009)	Academic	Mitigation Resolution Forecasting	This article is a literature review of a wide range of efforts to improve obsolescence issues. The authors separate between mitigation strategies (prevention) and resolution approaches (reactive). All ways to mitigate obsolescence issues is based on some kind of forecasting of type of component, complexity, maturity, number of suppliers, market trends and changes in laws and regulations. Mitigation: Supply chain (LTB, partnering agreements); Design for obsolescence (Modularity, Multi-sourcing, Transparency); Planning (Monitoring, forecasting, Risk assessment, Road mapping). Resolution: Same component; Replacement; Emulation; Redesign. Forecasting (type/complexity of component, maturity, number of suppliers, market trends, changes in laws and regulations)
Rostker et al. (2014)	Book Chapter	Rapid acquisition	The article describes when the U.S. Department of Defense formed a Rapid Equipping Force (REF) and other similar task forces in order to find the correct components (both new and old) quickly and safely. However, there were some issues in the groups, as acquiring the technologies too quickly might lead to some things being lost in the process - i.e. training material and knowledge of the product.
Tomczykowski (2003)	Academic	Alternatives LTB Bridge Buy Emulation Redesign	This article provides three cases of defense systems to reduce DMSMS issues. Some identified practices are using existing stock, reclamation, alternatives, substitution, looking into the aftermarket, LTB or bridge buy, emulation and redesign. There have been incorporated in different defense programs called AFMC Resolution Guide, DMEA Product Managers Handbook and EIA Bulletin.
Underwood (2011)	Academic	Data Preventative planning	The article highlight that it is critical to maintain a complete Bill of Materials (BoM) for each weapon system in the USAF inventory. DMSMS prevention must begin before equipment is purchased and delivered.
Weaver & Ford (2003)	Academic	Alternatives Harvesting LTB Bridge technologies	The article describes that in the past decade the DoD has chosen to combat test system obsolescence by offloading TPSs to standardized test platforms like the Navy's Consolidated Automated Support System (CASS). Some important cases in the articles is: continuous maintenance of the same component (which is ineffective), finding alternatives (in primary or secondary market), Harvesting, LTB and finding bridge technologies that can sustain a redesign.
Welch (2016)	Dissertation	Management Supplier collaboration	This article focuses on a number of barriers that a company needs to be aware of to truly succeed in obsolescence management. Three major barriers and themes were studied in this article: management commitment, lack of details in the statement of work and vendor management.
Özkan & Bulkan (2019)	Conference paper	Standards Partnerships Multi-Criteria Decision Making.	The article highlights the risks of not having secure options in software obsolescence. Due to being tested and certified, COTS software solutions might be preferred in terms of security, but also run a higher risk of being obsolete. The article then provides three levels of solving these potential obsolescence issues: Nation level mitigation (standards), Management level mitigation (adhering to security organizations), Multi Criteria Decision Making (mapping costs, security, efficiency).

Table 4.3 - Case study review summary: Defense industry

4.1.4 Electronics industry

The underlying factor of disruption in the electronics industry is Moore's Law, which claims exponential growth over time in the number of transistors in an integrated circuit (O'Boyle, 2012; Zheng, Terpenny, Sandborn & Nelson, 2012). What this means is that electronics are developing quickly, and electronic components' life cycles are becoming shorter. This has forced electronics OEMs to invest a lot in R&D to stay at the forefront, while also having to cater to the longer life cycles of customers (manufacturers of larger products, i.e. aeroplanes and cars).

Given that obsolescence has been an issue in the electronics industry, there are also many efforts to mitigate these issues. In terms of proactive efforts, the cases highlight a number of examples. Chemigraphic (2018) and Yali, Guang, Wai & Wei (2012) emphasize the importance of partnership and information sharing as ways to learn more about potential obsolescence risk. As this might generate obsolescence data, there are a number of examples that highlight the use of forecasting, life cycle analysis and simulations to improve the understanding of the risks (Godenes, 2017; Ma & Kim, 2017; Sandborn, Mauro & Knox, 2007; Xiaozhou, Thornberg & Olsson, 2012). However, Xiaozhou, Thornberg & Olsson (2014) also emphasize that data uncertainty is a critical factor that might impact the analysis and that companies need to gather the correct data.

As for reactive resolution efforts, similar examples to previous industries have been highlighted. Multiple cases provide success cases for LTB and redesign (Thiébaud, Hilty, Schluep, Widmer & Faulstich, 2017; Tulkoff & Caswell, 2012; Xiaozhou, Thornberg & Olsson. 2012; Xiaozhou, Thornberg & Olsson, 2014). Godenes (2017) takes it one step further in recommending modular redesign, which would improve harvesting and maintenance of a component. The discussion between LTB and redesign comes up in many articles across the industry. A different take from previous industries is Prabhakar & Sandborn (2012), who analyze total cost of ownership (TCO) to understand when to use LTB and when to use redesign. An example is given by Ericsson and the case indicates that, choosing more expensive parts with a later obsolescence date is more preferable than choosing less expensive parts that will be obsolete sooner (and probably will lead to redoing the analysis and mitigation practices).

Name	**Type of publishing**	**Intervention/ Strategy**	**Summary**
Chemigraphic (2018)	Company	Partnership	This article describes a case where partnerships were used to reduce the risks and knowledge gaps of obsolescence risk. The article claims that for OEMs to partner with i.e. an Electronics Manufacturing Supplier (EMS) they can both stay better up to date regarding information, but also reduce the risk of counterfeit components in the market.
Godenes, 2017	Company	Modular (re)design Management software	This article looks into the risk of obsolescence that data centers (with servers, power supply, memory, etc.) face. In their 10-15-year lifespans, the IT systems that data centers use will be severely obsolete if they are not updated. In order to solve these issues, the case provides two options. First is modular (re)design, meaning to structure the data centers modularity, so that replacing a component/product is easier and more flexible. The other was to install a management software to improve the monitoring and control of the units in place.
Ma & Kim (2017)	Academic	Forecasting	This article describes how forecasting (in terms of time series modelling and Box-Cox transformation) was used to predict obsolescence of memory units' microprocessors. Some learnings of the life cycle forecasting were that the newer memory units were estimated to have shorter lives and that the forecasting gave advanced warning to conduct strategic obsolescence management.

National Instruments (2019)	Company	Test systems	This article suggests using long term test systems as a means to mitigate obsolescence issues and thereby improving the decision-making process for obsolescence mitigation. These test environments can be improved through information sharing, modularity, implementing standards and training.
Prabhakar & Sandborn (2012)	Academic	Total Cost of Ownership (TCO)	This article provides a case for analyzing Total Cost of Ownership for an OEM. An example is given from Ericsson and the case indicates that, choosing more expensive parts with a later obsolescence date is more preferable than choosing less expensive parts that will be obsolete sooner (and probably will lead to redoing the analysis and mitigation practices).
Sandborn, Mauro & Knox (2007)	Academic	Forecasting: Data mining	This article looks into obsolescence of memory modules and flash memory chips. In order to understand when they become obsolete to a higher degree, the authors conducted a data mining forecasting framework to understand the history of vendors' components that have become obsolete. The goal for the forecasting was to narrow down the optimal "window of obsolescence" within which different mitigation efforts could be made. This was argued to be determined as a fixed number of standard deviations from the peak sales year of the part.
Solomon, Sandborn & Pecht (2001)	Academic	Life cycle analysis Forecasting	This article aims to provide a system for forecasting obsolescence of memory units. The authors conduct the life cycle forecasting through capturing market trends (market and technological attributes as memory density, voltage, packaging), statistical analysis of sales data as well as computing an overall risk factor, such as component risk, manufacturer market share and part life cycle information.
Thiébaud, Hilty, Schluep, Widmer & Faulstich (2017)	Academic	Long term storage	This article analyzes 10 different electrical equipment, their service lifetime, how they are affected by storage and different disposal pathways. The authors suggest that type of electronic equipment needs to be considered and that storage time is a significant factor in obsolescence issues.
Tulkoff & Caswell (2012)	Academic	LTB Long Term Storage	This paper provides a case of last-time-buy and the effects of long-term storage on quality. The authors mean that there is an unconsidered factor of quality deterioration that needs to be considered then doing LTB. In order to prevent these issues, a management system can be considered. The authors suggest including asset security, component inspection, product origin and condition, storage environment, data management, assured supply and potential reliability issues to be considered in the system.
Xiaozhou, Thornberg & Olsson (2012)	Academic	Life cycle analysis Forecasting LTB Redesign	This article provides a case for analyzing life cycles of electronic components and consequently minimizing costs of managing these obsolescence issues. The mathematical model takes LTB and redesign into consideration and suggests different alternatives depending on the component. In the case, LTB is preferred when interest and investment is low, and redesign as the interest grows.
Xiaozhou, Thornberg & Olsson (2014)	Academic	LTB Redesign Data uncertainty	This article provides a proactive obsolescence management model to decide between LTB or redesign in mitigating obsolescence issues. Looking into a range of 7 different electronic equipment, the model varies between the mitigation efforts, but mainly suggests LTB to be minimizing costs. The authors also suggest that data uncertainty is a factor that needs to be considered.
Yali, Guang, Wai & Wei (2012)	Governmental	Information sharing Open architecture	This article provides two cases for obsolescence management of electronic parts. The first within an avionics system and the second within a command and control system. In order to solve the avionics system, the case describes a high degree of knowledge sharing among their large user base. This would reduce costs and better understand the readiness of the system. For the other case with control systems, the case describes the use of open architecture. This reduced obsolescence issues downstream as there was better understanding throughout the value chain.
Zheng, Terpenny, Sandborn & Nelson (2012)	Conference paper	Design refresh planning	This article analyzes how ECUs (Electronic Controlling Units) become obsolete and require a design refresh - both for hardware and software. In order to properly know when this design refresh should be triggered, different planning and forecasting efforts were made through Porter's Model (Net Present Value and real options) and simulations on the Bill of Materials (MOCA). The article also highlights that software obsolescence is more problematic as it needs immediate attention, or it might become a security risk. Hardware obsolescence on the other hand can wait until next design refresh.

Table 4.4. - Case study review summary: Electronics industry

4.1.5 Energy industry

The energy industry is quite broad - ranging from wind to coal to nuclear energy systems and beyond. As for obsolescence issues, a significant share of cases came from the nuclear industry, which has been and still is facing obsolescence issues. Greenway (2007) and others claim that some nuclear issues have been impacting components that are 30 years old or older. An especially impacted part is Control and Instrumentation (C&I) equipment (Greenway, 2007; IAEA; 2004). Apart from nuclear, the cases also provide cases from oil and gas companies, and general energy companies.

Similar to previous industries, preventative measures focus on monitoring and forecasting (Al-Qahtani, Lourido, Dabbousi & Al-Shahrani, 2010; Electric Power Research Institute, 2013; Greenway, 2007; IAEA, 2004; LeCompte, 2017). Similarly, creating obsolescence teams, and acquiring and sharing the correct knowledge and information is seen as critical (International Atomic Energy Agency, 2004; Taberner, 2015). Cole (2013) provides a case that shows the benefits of co-locating actors around the power plant to combat obsolescence.

As for reactive measures, LTB, redesign and refurbishment are the most prominent (Bodine, 2015; Greenway, 2007). Additionally, Salman & Dagres (2018) provide a case for reverse engineering an obsolete part from the BoM, 2D and 3D blueprints. While being a quite expensive effort late in an obsolescence chain, it still proved successful and of high quality.

Name	Type of publishing	Intervention/ Strategy	Summary
Al-Qahtani, Lourido, Dabbousi & Al-Shahrani (2010).	Conference paper	Monitoring Forecasting	This article provides a case from an obsolescence management program in a large energy company (oil and gas). Following International obsolescence standards, the company aimed to gather as much information from sites, vendors and equipment databases as possible. Based on this information they created a scoring and ranking framework for which components needed to be prioritized.
Baker (2011)	Academic	Early planning Monitoring (FMECA) Risk analysis (FMECA)	This article provides a case form subsea and offshore energy companies. It argues that it is critical to implement obsolescence planning when designing a subsea platform, since it will have a decade long lifecycle. Furthermore, the case suggests that an obsolescence management plan needs to have risk analysis, here called "failure modes, effects and criticality analysis (FMECA)" to monitor and assess obsolescence issues.
Benjaminsson & Johansson (2016)	Dissertation	Waste management	This publication focuses on the case of Solar Sweden AB (who among other products provide energy systems) and what happens when forecasts have gone wrong and a company needs to manage obsolete products. The authors find alternatives in returning to the supplier, discounted sales, supplier deals and scrapping. However, they also identify the need for a more strategic and lean approach that mitigates this risk beforehand. This is something that requires transparency and cross-functionality.
Bodine. (2015)	Company	Upgrading/ Redesign	The article highlights a case where valves in nuclear power plants have gone through significant developments in the 2000's. The valves have significantly improved the performance of valves (i.e. isolation) as well as leading to millions of dollars in savings.
Cole (2013)	Academic	Partnerships (colocation)	This article focuses on the nuclear revival in the U.S. and the challenges of power plants requiring updates and having obsolescence issues. The author describes many potential mitigation practices (LTB, other vendors, alternatives, COTS components that fit standards and safety, etc.). However, the provided case called AREVA Solutions Complex in Lynchburg, which focuses on partnerships and even establishing a common physical location. This ensures that a common ecosystem can be developed to sustain each other.
Electric Power Research Institute (2013)	Academic	Monitoring Forecasting	This article highlights the case of the CENG program and their proactive approach to nuclear obsolescence. The successful program had two main focuses. First, identification and prioritization of obsolescence issues, and second, data modelling and data forecasting. Then, the program shared the insights to benefit multiple plants across the U.S..
Greenway (2007)	Conference paper	Monitoring LTB Redesign Refurbishment	This article focuses on Control and Instrumentation (C&I) equipment in nuclear power stations in the UL. These might be over 30 years old and are commonly facing obsolescence issues. To mitigate these issues, the British Energy agency first of all monitored these components closely to track any safety concerns. Then, they also varied between LTB, upgrade/redesign, and repair/refurbishment (depending on availability and cost).
IAEA - International Atomic Energy Agency (2004)	Governmental	Knowledge management Risk analysis Monitoring Task force	This article from IAEA provides an extensive view on how nuclear power plants can work with aging Control and Instrumentation (C&I) units. They form a very holistic approach and emphasize the need to adapt to a case-by-case approach. Some overall efforts they recommend is gathering the correct knowledge, analyzing the risks of a component being obsolete, monitoring internally and externally, and establishing a task force to continuously handle these issues.
LeCompte (2017)	Internal document	Monitoring	This internal document from Nuclear Utility Obsolescence Group (NUOG) provides (among others) an outlook on how to minimize obsolescence impact. Their list focuses on identification of models and new technologies, prioritizing among those, levering solutions and finally maintaining critical spare parts.
Salman & Dagres (2018)	Company	Reverse engineering	This article provides the case of a nuclear power plant in Western Europe that failed to find an existing spare part for a pump. This led to them sharing blueprints in terms of BoM, 2D and 3D solid models, from which a company could reverse engineer a replacement part. After some safety testing, this was then put into practice and the problem was solved.
Taberner (2015)	Academic	Cooperation Information sharing Data science	This article highlights two solutions to obsolescence management: Information sharing and Forecasting. The information sharing case highlights where nuclear component suppliers are working closely together to mitigate the obsolescence of parts becoming old. They also added data services and reverse engineering as a solution. The forecasting case is from Rolls Royce who created Proactive Obsolescence Management System (POMS) to collect information (BoM, inventory, work orders, maintenance) from all members to forecast and analyze which components might be obsolete.

Table 4.5 - Case study review summary: Energy industry

4.1.6 ICT industry

The ICT industry has faced multiple disruptions during its lifetime. However, due to the industry being a short-term consumer market, it has not faced very significant obsolescence issues. Instead, consumers just move on to the next phone. This does not mean that they have not faced any obsolescence issues. The cases show disruptions for ICT infrastructure and use of the electronic aspects of the phones as a factor for obsolescence.

Since phones can be easily exchanged (and thus do not have a long aftermarket), the cases show mostly preventative measures. Risk analysis and forecasting algorithms is the most prominent effort against obsolescence risks (Jennings, Dazhong & Terpenny, 2016; Sodhi & Lee, 2007). Using their machine learning algorithm framework, Jennings, Dazhong & Terpenny (2016) managed to identify active and obsolete cell phones to an accuracy as high as 98.3 percent. Furthermore, knowledge management and information sharing through partnership was also seen as key to prevent obsolescence issues (Victorian Auditor-General's Office, 2012). In this case, these partnerships were made within a larger governmental structure. Finally, Hacklin, Raurich & Marxt (2015) suggest business model innovation as a key to navigating obsolescence issues. While requiring a lot of work and time, this was deemed to be exceptionally effective in the ICT disruption of the early 2000's.

The cases only give one example of reactive measures in finding alternatives (Victorian Auditor-General's Office, 2012). Given that the products of the industry easily can be exchanged, this solution sounds very reasonable as there probably are similar ICT product to use when one breaks or gets outdated.

Name	**Type of publishing**	**Intervention/ Strategy**	**Summary**
Hacklin, Raurich & Marxt (2015)	Academic	Business model innovation	This article looks into the period when two technologies (one disruptive and one disrupted) exist and operate at the same time. There is a case given of an anonymous incumbent firm that needed to innovate a new business model that cannibalized on their existing business, just to be able to be disruptive, rather than disrupted.
Jennings, Dazhong & Terpenny (2016)	Academic	Risk Analysis (Machine Learning) Forecasting (Machine Learning)	This article looks into how machine learning models can be facilitating life cycles and obsolescence risk management. There is a case given from the cell phone markets and data gathered from 7000 unique models. The used algorithm identified active and obsolete cell phones to an accuracy as high as 98.3 percent. For lice cycles, they managed to predict obsolescence dates within a few months of the actual obsolescence dates.
Sodhi & Lee (2007)	Academic	Risk analysis (General)	This article establishes what risks exist for an ICT company such as Samsung. They identify obsolescence as a risk that can lead to financial risks, inventory risks (as with Compaq in 2000), and sourcing risks. As such, companies need to be aware and monitor said risk, so they not face surprising costs.
Victorian Auditor-General's Office (2012)	Governmental	Knowledge management Alternatives Information sharing Partnerships	This article looks into ICT obsolescence in a governmental organization. A main takeaway is that obsolescence is highly dependent on local expertise and solved on case-by-case basis and not systematically. Two cases are given, one from education and one from the juridical system. In the schools, alternatives were used to solve obsolescence issues. In the juridical system, transparency and cooperation generated a positive outcome.

Table 4.6 - Case study review summary: ICT industry

4.1.7 Lighting industry

The lighting industry has faced some different disruptions, but one large disruption reflected by the cases is when LED became effective and cheap enough to disrupt the previous technologies (Beccali, Bonomolo, Ciulla, Galatioto & Lo Brano, 2015; Nunes & Downes, 2015; Rahman, Kim, Lerondel, Bouzidi & Clerget, 2019). LED is a technological development that existed since the 1970's. However, it took until the late 1990's and early 2000's before it started to disrupt the industry. The reason why is according to Nunes & Downes (2015) due to it becoming cheap and effective enough, but according to Beccali et al. (2015) it was also because of legislation from the European Union started to enforce lighting OEMs to pivot. As such, the technology came first, but the disruption was also base on legislative developments.

All of the interventions in the cases are preemptive. Similar to ICT, this might be due to the flexibility of the lighting systems - once they decide to switch, it is easier than many other industries. Similar to other industries, the cases give success examples of forecasting (cost and performance), monitoring and acquiring the correct knowledge (Beccali et al., 2015; Nunes & Downes, 2015). Interestingly, two of the cases also emphasize the purpose of sustainability being a key to mitigating obsolescence and fueling a transition (Nunes & Downes, 2015; Rahman et al., 2019). This connects to the environmental focus of the EU legislation.

Name	**Type of publishing**	**Intervention/ Strategy**	**Summary**
Beccali, Bonomolo, Ciulla, Galatioto & Lo Brano (2015)	Academic	Cost analysis Performance analysis	This article provides a case for inefficient and obsolete lighting in cities in South Italy. Even though there have been governmental efforts (EU, Italy) to modernize outdoor lighting with more energy efficient LED systems, it has still lagged behind. Looking into the city of Comiso, the authors suggests mitigating obsolescence issues (and breaking the status quo) through installing more efficient alternatives based on a cost and energy analysis.
Nunes & Downes (2015)	Company	Monitoring Knowledge Management Purpose driven	This article provides a case for Philips' transition to LED lighting. The case claims that the management and engineers of the company listened to the Haitz's Law of increasing LED performance and decreasing LED price to start switching over to LED lighting. In order to do so, the company benefited from technological knowledge, a sustainable purpose and investing in armature companies.
Rahman, Kim, Lerondel, Bouzidi & Clerget (2019)	Academic	Modularity Purpose driven: Eco-design	This article focuses on the issue of obsolete LED products not being able to be completely recycled and reused. This leads to waste, when it could help mitigate obsolescence in a secondhand market. The authors claim that, in line with a circular perspective, that value could be retained if products are eco-designed to be used again when nearing its life cycle end.

Table 4.7 - Case study review summary: Lighting industry

4.1.8 Maritime industry

The maritime industry has, similar to some previous industries, faced a broad range of disruptive tendencies from technologies. The cases give examples of both electronic, but also physical component issues.

As for mitigation efforts, the cases provide mostly strategic/proactive and some reactive efforts. On the proactive side, monitoring, risk assessment and forecasting is prominent (Josias, 2009; NAVSEA, 2014). The forecasting in this case comes in the form of Net Present Value and real option analysis (Josias, 2009). Aside from these frameworks, information, knowledge and management is also seen as critical (NAVSEA, 2012; NAVSEA, 2014; NAVSEA, 2015).

NAVSEA (2015) also gives an example of process mapping in the form of a flowchart. While being utilized in many other articles (as part of monitoring and management), this case emphasizes the importance of visualizing the process. Finally, the reactive measures focus on using existing components in the market (LTB, reclamation, refurbishment, etc.), finding alternatives or substitutes, and redesign (NAVSEA, 2012).

Name	Type of publishing	Intervention/ Strategy	Summary
Josias (2009)	Dissertation	Risk assessment Monitor Forecasting	This article provides a case of anonymous company "ABC" that has combined a quite traditional obsolescence mitigation strategy with real options analysis and forecasting. This allows the company to properly analyze which paths might be used to reach the most desirable path.
NAVSEA (2012)	Company	Task force Information sharing Existing components Alternatives Redesign	This document provides a strategy for resolving obsolescence issues in the navy. Proactively, a task force with senior individuals is formed, and they are partaking in industry exchange programs. In terms of resolution, three resolution options are preferred: using existing material out there (LTB, reclamation, refurbishment, etc.), finding substitutes or redesign. This is decided on a case-by-case level.
NAVSEA (2014)	Company	Monitoring Management system	This document looks into a case from NAVSEA and how they developed a system to monitor obsolescence issues through their application OMIS. The system monitors development both on a component (BoM) and systematic level (i.e. vendor surveys). This enables them to be more proactive on their measures.
NAVSEA (2015)	Company	Information sharing Task force Process mapping	This document takes a more holistic view of how a navy OEM can mitigate obsolescence issues. The key efforts are to interact and share information within and outside the company (where possible), form teams, monitor market developments (surveys, industry trends) and propose cost-effective solutions. To facilitate these complex issues, they follow the SEA21 DMSMS Process, which is a flowchart to ensure an obsolescence issue is correctly handled.

Table 4.8 - Case study review summary: Maritime industry

4.1.9 Music industry

The music industry is an interesting industry to compare to a truck OEM. The products are more of a consumer product than trucks, but the technological disruption they have faced is of an immense scale. The (printed) music industry has faced multiple disruptions in its time, but the most recent and relevant disruption is that of digital music from printed (Fairchild, 2015). This disruption significantly reshaped the industry, mighty fell and new actors emerged.

In this disruption, numerous factors were critical for a company to survive the obsolescence and even transition to the new technologies. Similar to many other cases, monitoring and forecasting is a critical conduct for obsolescence (Hunt & Melicker, 2008; Moreau, 2013; Myrthianos, et al., 2014). From an organizational point of view, Urbinati, et al. (2017) and Verspreet (2013) highlight the importance of managerial actions (in restructuring and direction), as well as having an ambidextrous organization that can juggle both present and future technologies. Furthermore, they also highlight the importance of getting the best information through partnerships and information sharing. Urbinati et al. (2017) suggests open innovation as a measure to reduce obsolescence issues. Open innovation is a way for a company to loosen the grip on its IP and allow outside actors to give input and ideas (and offers) for how to improve things. One thing that this might lead to (among other things) is the solutions that Fairchild (2015) and Moreau (2013) highlight: business model innovation. Especially for this specific transition from physical to digital, companies needed to transition into a digital delivery of music. Granted, this generated a need for new business models, partnerships and organizational restructuring.

Name	Type of publishing	Intervention/ Strategy	Primary outcome
Fairchild (2015)	Academic	Business model innovation	This article describes the transition to the digital age of music and how it created not just a disruption of an industry but a driving force for a reconstruction of the underlying dynamics of that industry. In this brutal reconstruction, many companies found new business models to survive in a new reality.
Hunt & Melicker (2008)	Academic	Monitoring	This article provides detailed description of the industry's technological history. The author suggests that careful monitoring of the technological developments and sales is key. This becomes especially apparent in recent times of technological obsolescence.
Moreau (2013)	Academic	Monitoring Business model innovation	This article describes the impact that digital technology has had on the music industry. It focuses on how many incumbent firms failed to realize the shift and thus faced significant costs and accept the need for rethinking their business model.
Myrthianos, Vendrell-Herrero, Parry & Bustinza (2014)	Academic	Business model innovation Forecasting	This article provides a case on companies' transition in the digital disruption. The article focuses on profits as a link between changing industry dynamics and survivability, and the larger firms has better adaptability for innovating their business models.
Urbinati, Chiaroni, Chiesa, Franzò & Frattini (2017)	Academic	Ambidextrous organization Partnerships Knowledge management Open innovation	This article focuses on the organizations' roles in adapting to disruption and consequently obsolescence issues. Four enabling success factors are examined for incumbents: ambidextrous organizations, partnerships, knowledge management (acquisition of external capital and innovative solutions) and open innovation.
Verspreet (2013)	Dissertation	Management efforts Partnerships Restructuring	This article describes the case of the record company EMI and how they navigated the digital disruption of the music industry. Not reacting properly in the beginning, they lost lots of market shares and faced decreasing turnovers. However, through strict management efforts of restructuring, initiating partnerships and protecting their IP, they managed to transition into the digital future (finally being bought by Warner Bros. in 2013).

Table 4.9 - Case study review summary: Music industry

4.1.10 Rail industry

The rail industry is an industry that has faced different types of obsolescence issues. This is mainly due to the operational lives of rolling stock (trains) of more than 30-40 years. Similar to other industries, the rail industry has faced some technological disruption here and there, which has led to obsolescence issues, for example when updating the standard train sets (X2000 or Regina; Tilière & Hulten, 2003). However, Tilière & Hulten (2003) also highlights a current ongoing disruption with a new safety standard called European Rail Traffic Management System (ERTMS). This system is an EU common initiative to standardize the safety signal systems. Being that this is a current and ongoing disruption, not all of the cases reflect this disruption, but also present other cases in electronic and physical obsolescence.

On the preemptive side of the efforts, monitoring and risk assessment, information sharing, and early planning are at the core (Broadbent, 2020; CMCA.uk, 2020; DB Fahrzeuginstandhaltung, 2018; Jenab, Noori and Weinsier, 2014; Macaulay, 2010). In addition, Upton (2018) suggest that preemptive maintenance also can be a key to reduce obsolescence risk.

Janson & Norman (2020)

Some reactive measures to resolve obsolescence issues in the rail industry cases are LTB, substitution (alternatives), refurbishment of old parts, redesign and harvesting components from old trains (DB Fahrzeuginstandhaltung, 2018; Macaulay, 2010). Additionally, two success cases for additive manufacturing is given. Global Railway Review (2018) gives a case between a train OEM, a consultancy firm and a 3D printing provider, where they printed obsolete parts directly to the OEM. The other case is by van den Bogaard (2019) and focuses on Castlab that 3D prints the casts for components, allowing for OEMs to cast and recast pieces. A quite investment costly process, but cheaper to upkeep.

Name	**Type of publishing**	**Intervention/ Strategy**	**Summary**
Broadbent (2020)	Company	Risk assessment Monitoring: Information sharing	This article introduces obsolescence from the view of the rail industry, which has operational lives of rolling stock (trains) of 30-40 years. Two general approaches are recommended: proactive obsolescence management (starting in product design, BoM checks, dual sourcing, technology transparency, etc.) and information sharing.
CMCA.uk (2020)	Company	Early obsolescence planning	This article shines light on the need for initiating obsolescence planning early in a new project. The case highlights the new high-speed train system in the UK called HS2, which is currently in the making, and how different actors are coming together to negotiate proper contracts - including obsolescence.
DB Fahrzeuginstandhaltung (2018)	Company	Risk analysis LTB Alternatives Refurbishment Reconstruction/ redesign Additive manufacturing Old parts management (harvesting)	This article provides insight to how the German public railway actor Deutsche Bahn works with obsolescence management issues. Rather than giving a one size fits all solution, they work with a wide arrange of tools such as risk analysis, EOL stockage (or LTB), substitution, refurbishment, reconstruction/redesign, and old parts management (i.e. harvesting).
Global Railway Review (2018)	Company	Additive manufacturing (3D printing)	This article provides a case for an additive manufacturing, which is an obsolescence mitigation strategy that is recently gaining ground. In this article, they show success in manufacturing interior components that has been rendered obsolete from other suppliers and through 3D printing being delivered.
Jenab, Noori and Weinsier (2014)	Academic	Monitoring	This article focuses on issues of hardware/software obsolescence in signaling systems on rolling stock. The authors develop a new forecasting model ("Markovian model") to assess and forecast hardware and software obsolescence. The result is that the signaling systems are more prone to become obsolete due to software obsolescence issues.
Macaulay (2010)	Company	Design Planning Risk management Monitoring	The article provides a case from Trantech, who apply a proactive obsolescence management process, which has allowed them to stay ahead of the "obsolescence window". The key to their strategy is to develop an obsolescence management process that runs parallel to the product life cycle phases. For each of the four stages (Concept, Design & Development, Production and Operation and Maintenance), there are corresponding obsolescence measures (Plan for obsolescence, Design for minimal obsolescence, Check BoM for obsolescence risk, Continuous monitoring).
Tilière & Hultén (2003)	Conference paper	Standards	This case focuses on the emerging security standard in Europe called ERTMS, which has rendered previous security systems more or less obsolete.
Upton (2018)	Magazine	Predictive maintenance	This article provides a case from SNCF France and how they limit the issues of obsolescence on rolling stock with a life cycle of 35 years. They have applied a data scientific approach of predictive maintenance. While providing improved uptime, this also allows SNCF France to assess whether any components run the risk of being obsolete and from there take action.
van den Bogaard (2019)	Company	Additive manufacturing	This article provides a case from Castlab. This company creates casts from 3D models of obsolete components. From these casts, they can create the components even though the original suppliers have stopped producing them.

Table 4.10 - Case study review summary: Rail industry

4.1.11 Space industry

The eleventh and final industry - space - has faced multiple technological disruptions and is in some cases operating on products that are more than 20 years old. Additionally, the space industry is facing similar issues to the defense industry in that it takes 5-15 years to develop and manufacture the products (i.e. spacecrafts). This leads to risks such as components being obsolete when they are finally produced. A final issue that the space industry is facing is regarding their machinery that is in orbit (satellites and spacecrafts). This brings two issues in that they are hard to access for maintenance, and that it is very costly to send new components to serve when it has to (Djoukuimo, 2019; Dubos, 2011; Dubos & Saleh, 2010).

Being that it is hard and expensive to solve obsolescence issues reactively, the space industry relies heavily on proactive and strategic efforts against obsolescence. A lot of these efforts are focusing on the design against obsolescence (Concini & Toth, 2019; Dubos, 2011). If a spacecraft operator or OEM can implement design solutions that reduces the risks for obsolescence, they would minimize the times they need to serve in-orbit machinery. In order to better understand the design choices and potential risks, many cases have implemented forecasting, monitoring and simulations (Djoukuimo, 2019; Dubos, 2011; Dubos & Saleh, 2010; Geng, Dubos & Saleh, 2016; ECSS, 2017). Different frameworks are suggested, among them Markovian models, NPV and machine learning-based algorithms (i.e. Neural Networks, k-Nearest Neighbors and Random Forests). In order to conduct such simulations, the correct data and data management systems is needed, as mentioned by ECSS (2017). Finally, many of the cases also emphasize the importance for establishing an obsolescence management team that can lead the efforts and monitor the risks with the correct mandate (ECSS, 2017; Heiskanen, 2018; NASA, 2012).

However, there are instances when reactive approaches need to be used to solve an obsolescence issue. In these cases, NASA (2012) suggests LTB, design refresh and finding alternatives. Finally, similar to some of the other industries, Concini & Toth (2019) provide a success case for the promising developments of additive manufacturing as a solution. While being early and quite costly, it still shows a promising development as an obsolescence mitigation effort.

Name	Type of publishing	Intervention/ Strategy	Summary
Concini & Toth (2019)	Governmental	Design Additive manufacturing	This article takes a broad view of technological developments and disruptions in the space industry. Obsolescence, the authors claim, is one of the most significant issues for the space industry in the long run, since developing products takes 5-15+ years. To solve these issues, the authors suggest looking at complexity costs (non-value-adding costs) of a product and aim to design it with lower costs. Then, they also discuss the advent of additive manufacturing as a promising development.
Djoukuimo (2019)	Dissertation	Forecasting Monitoring Simulation (Machine learning)	This article looks at obsolescence issues at the International Space Station (ISS). The author claims that a mix of machine learning-based algorithms (Neural Networks, k-Nearest Neighbors and Random Forests) and cost saving analysis is a promising model to forecast and schedule obsolescence planning efforts.

Dubos (2011)	Dissertation	Design Early obsolescence planning Simulation	This article looks into obsolescence issues for spacecrafts and space systems (i.e. satellites) in orbit. Being that these systems are hard serve and maintain after launch, it is critical to plan and establish an obsolescence plan before launching them to space. In order to do so, two analytical and simulation modules were used, facilitating designers' ability to explore the impact of different design decisions.
Dubos & Saleh (2010)	Academic	Simulation (Markovian models)	This article focuses on simulating and analyzing the risk of space assets being obsolete. This is an issue as updating spacecrafts that are in orbit requires expensive and riskful operations. As such, the authors created two simulations that together can help to better understand when a spacecraft is obsolete.
ECSS (2017)	Company	Task force Knowledge management Monitoring Data management	This handbook for obsolescence management provides a holistic view of how a space OEM can understand and manage obsolescence issues. Some key initiatives to take away is to establish an obsolescence team (with a mandate), establishing both proactive and reactive approaches, acquiring the correct knowledge, and keeping an obsolescence management database through monitoring and inquiries. A case is given when REACH (EU chemical legislation) was implemented, which forced many actors to change their current manufacturing.
Geng, Dubos & Saleh (2016)	Academic	Design forecasting (NPV) Design simulation (NPV)	This article uses Net Present Value (NPV) analysis to investigate different design options for spacecrafts, focusing on time to obsolescence and obsolescence intensity (impact). This would allow the design teams to make value informed decisions for the spacecraft's design before it is manufactured.
Heiskanen (2018)	Governmental	Task force Risk assessment Contracts Monitoring	This presentation for the European Space Agency (ESA) focuses on when REACH (EU chemical legislation) was implemented and how that impacted actors within the space industry, which is using many chemicals. In order to mitigate the obsolescence issues, a 7 step management plan was created; (1) identify all stakeholders, (2) identify all sources of information for obsolescence, (3) define a risk threshold, (4) include contractual requirements (5) detail an update schedule, (6) risk assessment and mitigation plans, and (7) monitor and follow-up
NASA (2012)	Governmental	Task force Risk analysis Cost analysis LTB Refresh Alternative Monitor	This article looks into 24 increasingly obsolete product groups in space crafts. In order to mitigate the impact of this development, NASA suggests establishing an obsolescence management team, proactively analyzing risks and costs for obsolescence, mitigating (LTB, refresh, alternatives), monitor and report.

Table 4.11 - Case study review summary: Space industry

Case study review overview

In total, 90 cases were analyzed from 11 industries. All cases were gathered from around the year 2000 until present day. The frequencies of identified cases can be found in *Table 4.12 - Case study review: frequency of obsolescence management efforts*.

Strategic and proactive measures		Reactive measures	
Intervention	**Number of cases**	**Intervention**	**Number of cases**
Monitoring	23	LTB	17
Forecasting	16	Redesign	13
Partnership/Cooperation	14	Alternative	10
Information sharing	13	Additive manufacturing	6
Risk analysis	13	Refurbish	6
Design (early planning)	11	Design refresh	3
Task force	10	Bridge buy	2
Knowledge management	6	Contracts	2
Business model innovation	5	Harvesting	2
Simulation	5	Reverse engineering	1
Cost analysis	3	Waste management	1
Data management	3		
Open architecture	3		
Ambidextrous organization	2		
Purpose	2		
Standards	2		
Life cycle analysis	1		
Open innovation	1		
Predictive maintenance	1		

Table 4.12 - Case study review: frequency of obsolescence management efforts

4.2 Qualitative Interviews

Findings from the 12 qualitative interviews have been grouped into the overarching interviewee categories (internal employee, expert or benchmark interviewee). Within the benchmark category, findings have been furthered divided into the different industries within which interviewees are active. Furthermore, findings within each benchmark industry have been grouped into sections about industry situation, challenges and strategies for resolution. (N.B. Sources using interviews will be noted as "p.c." for "personal communication".)

4.2.1 Truck OEM employees

Disruption in the trucking industry

OEM employees all agree that the situation of the trucking industry is changing on multiple fronts, from electrification of engines, to digitalization of trucks, to autonomous drive. While all these trends will impact the industry, the interviewed employees all argue that electrification will impact the most and the soonest. Employee C (p.c. 2020) claims that, without a doubt, the most exposed technology is the combustion engine. "I see a large risk in that there are so varied groups of technology that can be affected" (p.c. Employee C, 2020). Employee C (p.c. 2020) then gave an example of diesel engine filters, which require scale economies to be profitable.

If they are disrupted and volumes drop, it will generate ripple effects of costs and risk in the industry.

According to Employee A (p.c. 2020) and Employee C (p.c. 2020), electrical disruption is driven primarily by legislation, and not technology (unlike many other disruptions, i.e. mobile phones). Employee C (p.c. 2020) claims that, while electric vehicle technology exists, it is not yet mature. Legislation from the European Union has therefore started a technological transition into the unknown, prompting commitment from the truck OEM to offer fossil free alternatives to all their trucks by 2030 (p.c. Employee A, 2020). All respondents were unanimous that even though many disruptions are happening quite far in the future - within 10-20 years - the truck OEM needs to start acting now and setting up a more strategic approach.

Another technological risk is automation. Employee A (p.c. 2020) claims that, while full automation of a truck is quite far into the future, there are still disuption risks that many are unaware of today. Employee A gives the example of an autonomous test platform that the company has, which lacks windows, seats and steering wheels. In a future where autonomous trucks are more broadly available such components might also be disrupted.

A final disruptive tendency of the trucking industry is digitalization. There is an increasing velocity for which digital solutions and technology, such as ECUs (Electrical Controlling Units) are developed and disrupted (p.c. Employee B, 2020; p.c. Employee C, 2020). Employee A (p.c. 2020) highlights the increasing importance of electrical equipment for a truck. Consequently, Employee B (p.c. 2020) mentions experiencing increased obsolescence issues from electronic components (both software and hardware) in recent years.

Truck OEM situation

As a truck OEM, the employees describe that they have the obligation to provide any spare parts and services for 15 years after a product sale (p.c. Employee A, 2020; p.c. Employee B, 2020; p.c. Employee C, 2020). Consequently, they claim that obsolescence issues will be critical to handle, as they might need to access an important spare part for a truck produced 10 years ago, even though the part is not used in the current manufacturing.

If the truck OEM is not able to provide a spare part, it can lead to significant risks. Employee B (p.c. 2020) claims that disruptions might lead to shortages of material (components and parts) and that the truck OEM has no ability to supply necessary parts. Employee B (p.c. 2020) continues that the risks might lead to them being very dependent on a small range of suppliers to deliver the component. Employee C (p.c. 2020) highlights the increasing costs that might come from not having an available spare part and being reliant on a few suppliers. Another large risk highlighted by the interviewees is damaging the company brand, which is one of the truck OEM’s strongest assets (p.c. Employee C).

Employee A (p.c. 2020) and Employee B (p.c. 2020) reflect on the time obsolescence issues take from the segment leaders. Employee A (p.c. 2020) claims: “it is the most time consume part of the job to be honest. If you ask any of my team members, they will tell you that it starts off as a single problem, but that single problem can perhaps take 75 percent of the working day."

Supplier situation

The employees also highlight the challenge that suppliers will face. Starting with the current situation, Employee C (p.c. 2020) mentions that some of the bigger suppliers of the truck OEM are already facing liquidity problems due to technological disruption. Employee A (p.c. 2020) mentions a couple of occasions when suppliers have gone bankrupt, creating obsolescence issues for OEMs related to affected components and parts.

Additionally, depending on the readiness of the suppliers, all interviewed employees expect many suppliers to either start divesting their dying technologies ("no one wants to bet on a dead horse"; p.c. Employee C, 2020) or go bankrupt, making their services unavailable. However, Employee A (p.c. 2020) and Employee B (p.c. 2020) are positive that many suppliers will be creative in the coming transitions. This can be through diversifying their portfolio into new technological areas, while utilizing their old capabilities and infrastructure to keep their operations for obsolete products running (p.c. Employee A, 2020). Another potential scenario raised by Employee A (p.c. 2020) and Employee C (2020) is the field of suppliers consolidating into a more duopolistic-like structure. Employee C (p.c. 2020) claims that this might lead to decreased bargaining power and increased costs for the truck OEM.

A final development for suppliers involves emergence of new actors. These might be startups with new business models aiming to mitigate obsolescence (Employee B, p.c. 2020). Another scenario involves actors from other industries, with relevant capabilities and infrastructure, diversifying into manufacturing spare parts where demand exists (Employee C, p.c. 2020).

Truck OEM's strategic and proactive obsolescence measures

Being that the trucking industry is facing disruptions impacting the whole value chain, some obsolescence measures have already been implemented by the truck OEM. All employees agree that there is no systematic plan for managing obsolescence. Employees mention that some related strategic initiatives are in place (i.e. risk analysis and risk management groups), but no company-wide strategies to mitigate obsolescence. However, there are some existing efforts that can be categorized as proactive or strategic.

- *Business and product knowledge.* Both Employee A (p.c. 2020) and Employee B (p.c. 2020) highlight the importance of business acumen and product knowledge as key to mitigating obsolescence issues. Similarly, Employee C (p.c. 2020) specifies that the knowledge and actions of the segment leaders and account managers is key.
- *Contracting*. Employee B (p.c. 2020) describes that they formulate contracts with suppliers where "we expect the supplier to supply the parts for minimum 15 years after

production". While this is not always the final outcome, it can still be utilized in negotiations, according to Employee B (p.c. 2020).

- *Financial monitoring*. Employee C (p.c. 2020) explains that the truck OEM has a number of parameters that they aim to follow and monitor. These parameters generate a scoring where 3 is the highest performing score, but where suppliers should not go under 2. If they do, the "alarm goes off" and they initiate quarterly follow-ups. Employee C (p.c. 2020) also details some issues in financial monitoring since many suppliers are not listed on a stock exchange. This might make it harder to gather specific financial data, especially in cases where the supplier is not willing to share such data. Such a case, Employee C (p.c. 2020) states, could involve a supplier having financial problems and not wanting to risk losing the business with the truck OEM.
- *Standardization*. Employee A (p.c. 2020) describes that one of the truck OEM's brands currently has 420 part numbers for seats. "Do we really need to have 420 seats available in the aftermarket or the service department?" (p.c. Employee A, 2020). The truck OEM can be proactive in the design phase and rationalize how many variations are needed. However, Employee A (p.c. 2020) also states that this brand is a premium brand, where seat customization might be expected, so a balance is needed.
- *Dialogue.* A final strategic measure that Employee B (p.c. 2020) mentions is continuous and open dialogue. Employee B (p.c. 2020) claims that exchanging developments and comparing technological road maps can only strengthen the relationship between the actors, as well as mitigate significant obsolescence risks.

Truck OEM's reactive obsolescence measures

All respondents claim that the OEM's efforts to mitigate these issues are mainly reactive and contained in solving issues in the daily work of their employees. A reactive measure is, according to Employee A (p.c. 2020), generally triggered in one of two ways. It can either happen when they receive an order of a part they have not had in a while. When they then go to their tier 1 supplier, they might not still have it available, and the tier 1 supplier need to go to a tier 2 supplier, and so on. The other way is when they receive a PDN (Process Discontinuance Notification). If such a notice is sent, the product owners will initiate efforts to mitigate the changes. The truck OEM's currently applied measures are listed below.

- *LTB.* While commonly used, all employees highlight that LTB also comes with some issues. Employee B (p.c. 2020) highlights that there are risks in forecasting remaining lifetime. It is impossible to be completely accurate in how many components are needed, which might result in either buying too many component (which will be scrapped) or buying too few components (leading to additional reactive measures at a later stage). Another issue with LTB is that it might be very costly to store the components for a longer period of time (p.c. Employee A, 2020).

- *Alternatives and Harvesting*. Employee A (p.c. 2020) mentions that finding an alternative is a commonly used strategy when components are discontinued. These might be from other suppliers, which the Employee C (p.c. 2020) calls a “supply switch”. Usable parts can also be found in scrapped trucks, which Employee B (p.c. 2020) refers to “harvesting”. No matter which of these alternatives is used, Employee A (p.c. 2020) and Employee B (p.c. 2020) mention the risks and costs that comes with finding an alternative. These components need to reach a certain standard and quality and testing these components can take time and resources from the truck OEM.

- *Additive manufacturing (3D printing).* Employee B (p.c. 2020) discussed this development to a larger extent and described that, while being a promising development, it is still only in its cradle as an operational technology. “Since people can print at home or in school, they think that we can do that for the truck. But then you need to realize that 3D printing is not mature enough to produce a specific complex component in a specific material” (p.c. Employee B, 2020). However, the truck OEM has started initiatives to utilize additive manufacturing as a way to mitigate certain obsolescence issues and all interviewed employees see this as a promising development for lesser complex components and parts.

4.2.2 Experts

Process of implementing an effective obsolescence management strategy

The experts Bjoern Bartels, Ulrich Ermel and Peter Sandborn all agree that the best process on implementing effective obsolescence management is a contextual matter and depends on a number of factors specific to the company. Industries characterized by high investment costs, and products that need to be maintained for long periods of time typically require more robust obsolescence management approaches (p.c. Ermel, 2020; p.c. Sandborn, 2020). Another factor that influences the process of obsolescence management is qualification requirements. Sandborn (p.c. 2020) highlights that industries like aerospace and automotive, products are security relevant and obsolete parts might cost millions since solutions need to be extensively tested.

What solutions a company develops and implements to manage obsolescence depends on the alternatives available, in other words what reactive and proactive measures are you able to execute (p.c. Bartels, 2020). Does the supplier allow for a last-time-buy, do you have ways to execute a system redesign, are there alternative parts available in the aftermarket that are usable as replacements? It also depends on the situation that the company is in. This comprises considerations like when the end of useful life (EOL) is for the part. If EOL is near, you might want to do a last-time-buy. If EOL is far away, you might be more inclined to find other solutions, since storage will cost more (p.c. Ermel, 2020). Another consideration is how many other parts are obsolete in your system. If these are many, you might want to execute a system redesign to mitigate obsolescence throughout the entire system. Lastly, suitable measures depend on how many products the specific item is used within, since this determines the total impact of the component's obsolescence (p.c. Bartels, 2020; p.c. Ermel). So, actors in different industries, and even within the same industry, will find different solutions to obsolescence, depending on their specific situation (p.c. Bartels, 2020).

The experts were unanimous in the need to initiate obsolescence issues by creating a robust and well-functioning reactive process. Reactive strategies will always be needed, and the cost-to-benefit equation is very favorable, meaning that you can cut extensive amounts of cost for relatively small investments by strengthening your reactive processes (p.c. Ermel, 2020; p.c. Sandborn, 2020). Bartels (p.c. 2020) exemplifies the value of a strong reactive process by describing a project that he conducted for the with The Swiss Federal Railway. Just with a robust, centrally coordinated reactive process, this organization was able to cut costs of obsolescence by 3,9 million dollars in just seven months, with very little investment.

After focusing on strengthening the reactive process, companies should start rolling out proactive approaches to complement these. The ability to deep dive into the system's configuration (which manufacturers typically have, while operators do not) is required to do an effective proactive analysis (p.c. Ermel, 2020). Understanding system configuration provides information of the system, without which you are unable to understand what it comprises of, let alone how it should be managed. As a result of this, Sandborn (p.c. 2020) claims that more and more companies are experiencing problems with obsolescence, since technologies are becoming more and more complex, and software (which is highly complicated to understand at a granular level) is increasingly integrated into product's systems.

Here, multiple experts point out many companies' lack of high-quality data, which complicates the process of accurately monitoring, forecasting and designing for obsolescence (p.c. Bartels, 2020; p.c. Ermel, 2020). In 90 percent of the cases, companies are required to go through a process of 'data cleaning', to sort and refine the data (p.c. Bartels, 2020). Beyond this initial challenge, proactive approaches to obsolescence is described as quite hard to execute. Many companies try to become proactive through purchasing a database, which they use to forecast the likelihood of products becoming obsolete (p.c. Bartels, 2020). This is not sufficient however, because "the forecasted likelihood of the item becoming obsolete is only one part, you also have to consider its' impact" (p.c. Bartels, 2020). This is an element which many companies forget, using data to figure out the company-specific impact of an item becoming obsolete, and thereby finding the best course of action.

When moving from reactive to proactive, multiple experts point out the need to shift the responsibilities and processes of obsolescence management to not only fall on the departments responsible for aftermarket or maintenance phases (which is typical), but to also include the design and R&D departments (p.c. Ermel, 2020). This shift includes "designing for obsolescence", which implies keeping risks of future obsolescence in mind when developing new products. "Obsolescence management should start during the development of new systems, were you should plan for new technologies and how they will impact the system further on" (p.c. Ermel, 2020). R&D should also only approve new product designs if the product is sustainable from a lifecycle perspective. Sandborn (p.c. 2020) points out that most engineers focus too much on cost and time, aiming to make the product as cheap as possible while designing it quickly. This focus on cost and time has prompted increased usage of COTS (commercial-off-the-shelves) products in systems, which can lead to more problems with obsolescence down the line, since parts are not specifically design to fit into your particular system or be maintainable for 20-30 years (p.c. Bartels, 2020). R&D often reuse components and designs that have been shown to work before, while disregarding the effects that usage of older designs might have in the long term. This way you largely disregard quality, in this case by not designing products that resist obsolescence by using great technology, making customized solutions and constructing modular systems (p.c. Ermel, 2020).

All of this combined creates a need to implement both a top-down proactive and strategic approach, and a bottoms-up approach. In the top-down approach you look less at the individual parts and more at the configuration of the entire system in a proactive manner. In the bottoms-up approach, you focus on the parts themselves, available options and technologies, and how you should communicate better with suppliers to mitigate risks of obsolescence (p.c. Bartels, 2020; p.c. Sandborn, 2020). As for communication with suppliers, Ermel (p.c. 2020) exemplifies how a company can such communication or cooperation through rewarding desirable behavior, whereas typical approaches are more likely to involve disincentivizing undesirable behavior.

Ermel (2020) gives an example of a suppliers' contest, where suppliers who coordinated their efforts most effectively with those of the truck OEM were rewarded through both recognition and publicity. This is applicable to the obsolescence field, where desirable behavior (not discontinuing parts that the OEM uses, helping provide solutions if the parts must be discontinued anyway, assisting the OEM in forecasting and monitoring, and finding strategies to minimize the risks of supply chain disruptions) should be incentivized and rewarded. The company needs to be synchronized with the supply chain, making sure that suppliers prepare for the long-term maintenance phase of the products (p.c. Sandborn, 2020). Furthermore, companies need to monitor their service contracts and customer expectations. This is required to know the maximal period of required maintenance, and how many products will be affected by obsolescence during this long period (p.c. Ermel, 2020).

New developments in the field of obsolescence

Multiple interviewees mention additive manufacturing as a potential future solution to many obsolescence problems. However, they point out that it is not a fully viable solution yet, since it cannot print certain forms of components/parts reliably and safely (p.c. Bartels, 2020; p.c. Ermel, 2020). Another technology with a lot of promise is machine learning, which can assist in the cleaning and utilization of data to allow for better forecasting and monitoring (p.c. Bartels, 2020). Blockchain is another new technology that has the potential to improve obsolescence management, however its' likely use cases are not determined yet. Further new developments include new actors and business models. New actors have been created, who specialize in making lifetime buys and storing the parts for the company who experiences obsolescence issues. There are also companies who have begun specializing in reengineering of parts that have become obsolete (p.c. Ermel, 2020).

Early warning signals

One effective early warning signal is to monitor and detect changes in the relative spending off R&D towards maintenance of old products/systems, versus R&D spending on new products (p.c. Bartels, 2020). Increased usage of R&D resources for maintenance might signal that obsolescence issues have increased in frequency or significance, and thus that there might be a need to look over the proactive and reactive methods used within the company. Another early warning indicator mentioned is the relative growth of aftermarket suppliers within your industry (p.c. Sandborn, 2020). Growth of aftermarket suppliers can signal increased problems of obsolescence within the industry as a whole, since their primary function is to provide solutions to PDNs. Lastly, a more direct approach is to monitor and detect changes in the rate of PDNs within the company, and the aggregated costs of reactive measures (p.c. Ermel, 2020).

4.2.3 Benchmark industries

4.2.3.1 Music

Katriin Antonov and Måns Uggla agree that the music industry faced significant disruption from digitalization of a previously physical product (p.c. Antonov, 2020; p.c. Uggla, 2020). Solutions such as Napster, Spotify and iTunes severely altered the function of the industry in the 21st century.

Challenges

Beyond the lack of demand for physical products, which naturally created issues of profitability for incumbent firms, the lack of scale in production also created problems as production cost per unit went up significantly (p.c. Uggla, 2020). Another major issue was the unanticipated speed of the transition. “Everything went so fast. It was impossible to handle the problems at that rate - there were losses for many years” (p.c. Uggla, 2020). The sense that issues were impossible to handle for incumbents could also be attributed to the lack of effective early warning indicators (or incumbents’ lacking ability to detect these). Both interviewees describe how the transition went very fast and was quite unanticipated. “The big labels closed down quite suddenly, so that put us in a difficult place. There were no warnings that they would close down” (p.c. Antonov, 2020). With proper systems for early warning indicator detection, these changes could possibly have been managed more effectively and actively. Another major issue is the incompatibility of the old medium with new products. “Most computers do not have a place to insert a CD anymore. So even if people buy the product, they cannot do anything with it anymore, because it is not compatible with modern devices (p.c. Antonov, 2020).

Solutions

In order to reduce the problems with decreasing sales/production figures, two different methods were presented by the interviewees. Either you vertically integrate activities, thus taking on more of the activities of the value chain yourself, in order to achieve larger scale of operations by doing more of the work (p.c. Antonov, 2020). Or you look for ways to achieve mass by merging your activities and existing customer base with those of other actors in the industry; in other words, consolidation (p.c. Uggla, 2020). Another solution is consolidation or centralization of specific company units, such as storage. Naxos International removed all their national storage units and centralized this function to one location in Munich, in order to create scale of operations (p.c. Uggla, 2020).

Another approach to handling demand issues is to be more reactive to demand, and not produce too many units beforehand (p.c. Antonov, 2020). Naxos furthermore successfully navigated the changing industry landscape by simultaneously harvesting the profits remaining in the old medium and directing these into initiatives aimed to enhance the new business area of digital streaming. For them, the aim was to harvest profits in the physical market with low costs while investing heavily in the new digital market (p.c. Uggla, 2020). Digibox also focused on changing the management, in order to acquire competencies that were more relevant to handle challenges related to technological shifts rather than maintenance of operations. Lastly, in Digibox case, cost reductions have been achieved through leveraging of new technologies in production (p.c. Antonov, 2020).

4.2.3.2 Railway

Bjoern Bartels, Ulrich Ermel and Thomas Tydal all highlight that the railway industry has faced disruption both from digitalization and standardizations based on legislation, such as ERTMS (p.c. Bartels, 2020; p.c. Tydal, 2020). These changes are both costly and hard to implement due to the longevity of rolling stock (30-40 years).

Challenges

The railway industry experiences significant challenges with obsolescence, mainly due to the nature of the product and the intentions of incumbent actors. The business logic in the industry is to make products affordable and able to run for several decades, a combination that tends to create problems with obsolescence (p.c. Ermel, 2020). Many products in recent years have been modular in their composition, with different modules being supplied by different suppliers. However, some trains, like the Regina model, utilizes a dependent network standard describing how different systems and parts are supposed to interact and communicate with one another (p.c. Tydal, 2020). The train conductor is then able to steer and see the status of all these modules from a smart screen. In Regina's case, this smart screen runs on Window 1995, since updating the operating system might lead to complications for the system as a whole. The challenge is that this network standard, where every system is reliant and interconnected with each other, creates interdependencies where computers and software are now required to use the vehicle.

Another challenge is the nature of transactions in the industry (p.c. Tydal, 2020). When a company purchases a train, they are taking over the responsibility of the maintenance of the train, even though they often have a quite limited understanding of the product's composition and technical specifications. When maintenance or replacement of parts/systems is required, it is common for operators to not hire the services of the original manufacturer, if there are cheaper alternatives available. One interviewee points out that this price-focused decision-making process made sense when trains were analog products, and less complex with longer expected system lifetimes. "When a seller delivers a product, it is still expected that this train will be functioning without serious issues for 30-40 years. And this might have worked half a century ago, when components were not that complicated and you could just follow the maintenance manual, saying 'this component needs to be replaced in 10 years'" (Tydal, 2020). 50 years ago, that component might just have been a cog, but as more and more maintenance issues revolve around software, a company that is not the original equipment manufacturer is less able to fix such issues, since complexity increases. As a consequence, the expected lifetime of a manufactured train has decreased, as products have become more and more digital. This unawareness of differences between modern trains with significant amounts of integrated software and older trains who run on analog systems is a large problem for operators and manufacturers in the train industry, since many incumbents still hold on to the idea of documented instructions (drawings). However, with software, less and less is documented, since the OEM's source code is typically classified. With this in mind, there is an increased reliance on the original manufacturer of products, but the operators who often do not fully understand the products are often unaware of this, and do not see the point of allowing original manufacturers to service the products. Another problem is standards and regulations, which can lead to the need to upgrade the systems of trains, which can cost a significant amount of money (p.c. Ermel, 2020). An example is the previously mentioned ERTMS system, a safety system to allow.

Solutions

There are a number of solutions that would mitigate these challenges. Exemplifying a strategy to mitigate obsolescence in the industry, Ermel (p.c. 2020) details a case where Bombardier, one of the world's largest train manufacturers, offered train operators to buy trains with the inclusion of a service contact spanning the product's total lifetime. In this deal, obsolescence management services performed by the supplier (Bombardier) are included. As a result, operators are able to share the risks of obsolescence with suppliers, and those who are experts on the composition of the product are allowed to manage such problems. On the other hand, managing the issue of system interdependencies and network standards (which was exemplified through the Regina train model), the best course of action is likely to apply a modular design approach, creating less system interdependencies. This way the entire train does not rely on a particular subsystem (like a tablet running Windows 1995) to function.

To handle problems with shortening product lifetimes, there is need to service and monitor the performance of products proactively, and to not expect things to still run for 30-40 years without maintenance intervention (p.c. Ermel, 2020). A solution to problems with servicing the products, which has been advocated by the equipment manufacturers, would be to implement leasing deals (or deals where the OEMs are allowed to service the trains regularly), since they are the ones who understand the product best. Buyer's often do not understand the need of servicing the products until they break down, and so such solutions could allow trains to have a longer expected lifetime, while providing less complications along the way. However, operators would thereby become very reliant on the manufacturers of the original products.

Another potential way to decrease the reliance on original manufacturer for products that integrate a lot of software is to insist on using open source coding. This will allow the operator or other actors than the original manufacturer to have an increased ability to fix things without having access to the classified source code. By using open source, you also solve issues with suppliers going out of business. If the supplier goes out of business, and the operator does not have access to the source code, a company is unable to analyze the problem and find an appropriate solution. So, access to the source code, or alternatively using open source software like Linux, should be considered a safer option (p.c. Tydal, 2020). "When you buy a software product with the source code, or open source coding, it is the equivalent of purchasing an old, analog car. Any repair shop can fix it. With a secret source code, it is more like a new car, where you cannot really fix anything since there is so much you cannot access" (p.c. Tydal, 2020).

4.2.3.3 Lightning

Frida Alexandersson and Jan Börjesson describe that the outdoor lightning industry, much like the automotive industry, has experienced few large-scale disruptions in the past, but especially from LED (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). "Our products have looked pretty much the same since the 70's, but then LED came and overturned the entire industry" (p.c. Alexandersson, 2020).

Challenges

One of the major challenges with the transition towards LED technologies were in R&D and concerned the new specifications and requirements of the products. For example, one major challenge was that products could not be constructed as previously, and keep the same cooling ability, since the diodes would overheat in many products (p.c. Börjesson, 2020). Thus, old systems needed to be remanufactured to account for this. This, coupled with the speed of the required transition (p.c. Börjesson, 2020) created large challenges for actors who were not prepared. This includes suppliers to the interviewees' companies, who have had trouble meeting the increasing demand for components related to LED technology (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). Obsolescence was also discussed as a problem within the industry; however, the risk of part obsolescence is not carried by the seller, but rather by the buyer. "It has happened that companies go out of business, but for us it is not a huge problem. However, it is a problem for the end customer, since they are not able to attain spare parts" (p.c. Börjesson, 2020). There are other companies that serve the delivered products, so even though products have between 25-50 year expected life, and there are problems with part obsolescence, these problems and risks associated with them are carried by end customers and external actors (p.c. Börjesson, 2020).

Solutions

A main thing that was brought up as a facilitating factor to handle technological changes like LED was to be aware of the potential of these new technologies early on (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). Both interviewees mentioned that their organizations had realized the potential of LED early on, and therefore were early to make appropriate adjustments to capitalize from it rather than becoming detrimental to the business (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). The modular nature of the products also created opportunities, since Zumbotel Group were able to take their existing products and insert LED technology directly into them (p.c. Börjesson, 2020). This provided good but not excellent results, however it served as a great solution to firstly serve the increasing demand for LED, secondly show that the company was at the forefront of new technologies, and thirdly attain the loyalty of early adopters. Simultaneously, Zumbotel Group developed new products that were entirely dedicated to the new LED technology. However, these took a while to reach the market, since they required an entirely new design to work perfectly (p.c. Alexandersson, 2020).

Another important factor is to take in feedback on what actors in the industry (customers and suppliers) want, focuses on and are planning for. To respond to challenges of obsolescence and supply chain disruptions, the interviewees stressed the value of creating a robust value chain and leveraging multiple sourcing whenever possible to secure the availability of parts for manufacturing. This was seen as critical, since suppliers often had trouble keeping up with rapid transitions in volume demand, and also being susceptible to disruptive events (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). Also, cooperation and long-term commitment to chosen suppliers was mentioned as beneficial, since this 'key customer'-status allowed Zumbotel Group to purchase parts even in times when the supplier had more demand than they could handle (p.c. Börjesson, 2020). Another final step was to have robust processes for supplier screening and selecting, to purchase (and thus rely upon) those suppliers that are best for the job (p.c. Alexandersson, 2020).

4.2.3.4 Cars

Peter Bryntesson provides a nuanced picture of an industry that has experienced significant disruption in the last decade, and which will continue to do so in the future. Historically, the car industry (much like the heavy-duty trucking industry) has been relatively unfaced by disruption and competency-destroying technology (p.c. Bryntesson, 2020). The interviewee describes this shift from historical stability towards recent disruption by proclaiming: "What we are currently seeing in the automotive industry is the equivalent of Motorola's situation when the iPhone was introduced, or Facit's situation when IBM started making digital computers" (p.c. Bryntesson, 2020).

As a result, we have seen incumbent truck OEMs take unprecedented actions to acquire the resources and competencies required to respond effectively. These actions encompass everything from joint scientific collaborations, mergers and acquisitions and creation of new subsidiaries (p.c. Bryntesson, 2020). A large part of the disruption is caused by the change in business models all over the industry, where consumers are finding it increasingly attractive to attain mobility (the ability to move from point A to point B) rather than owning a car.

Beyond business model changes, there are major technological advancements that are increasingly reconfiguring the landscape of the car industry (p.c. Bryntesson, 2020). The main disruptions for the car industry are electrification, autonomous vehicles, digitalization and AI. Digitalization and AI are on the one hand important facilitators of this new form of mobility, but also create other business implications. The interviewee points out that digitalization will create an entirely new potential source of revenue for both suppliers and truck OEMs, in the form of user data. Digitalization is also an important part of the development of Industry 4.0, the implementation of which is pointed out by the interviewee as a key source of competitive advantage going forward. The interviewee's organization (FKG) estimates that successful implementation of Industry 4.0 features can reduce production costs by more than 20 percent. The same goes for AI, which he mentions as a key to reduce costs and increase efficiency. Thus, he concludes that "those who manage these technologies effectively will survive, and those who cannot will not" (p.c. Bryntesson, 2020).

Challenges

The creation of new business models, as well as modification of existing ones, is described as the hardest challenge for incumbents in the industry to deal with, since it will involve a drastic shift in approach and mindset. Many incumbent actors also appear to be unaware of (or unable to deal with) the challenges that they are facing. In a survey conducted by FKG, a third of the respondents in the automotive industry said that they will not be affected by electrification at all. Another third said that they are unable to adjust to the challenges that electrification brings (p.c. Bryntesson, 2020). The interviewee argues that the unaware group is especially vulnerable, since "there needs to be an understanding of the problem, before you can deal with it effectively" (p.c. Bryntesson, 2020).

The increased importance of new technologies (electrification, AI, digitalization, autonomous driving) will drastically change the competencies required to manufacture and distribute products in the industry, since they represent completely new solutions to mobility (p.c. Bryntesson, 2020). Research conducted by FKG in cooperation with leading automotive firms in Sweden estimates that around 30 000 to 40 000 engineers in Sweden will need to be reeducated, since their expertise lie in technological areas that will not be relevant in the future (p.c. Bryntesson, 2020).

Another potential challenge or facilitating factor for change is the top management of firms. Companies in which executive management is too preoccupied with the daily matters of the firm to fully handle future matters are especially vulnerable to future technological disruption, since they lack foresight to adjust the operations of the business to meet future market needs (p.c. Bryntesson, 2020). Furthermore, incumbent managers in a traditionally stable industry such as automotive might have extensive experience in streamlining existing operations, but likely not in transforming the nature of the business or the company's operations (p.c. Bryntesson, 2020). Thus, the need for new competencies encompasses the entire company, from engineers working in new product development all the way up to top management. Lastly, there is much work to be done in understanding the future nature of the industry's value chain, and your company's role within it (p.c. Bryntesson, 2020). As the systems and components of product's systems will change, so will the role of actors in the supply chain. An electrical motor is composed of much fewer subsystems and components than a typical diesel engine and can be bought in its entirety from companies like Bosch and Siemens. Additionally, new actors like Uber are entering the industry and becoming suppliers of software solutions.

Solutions

After becoming aware of the challenges ahead, the interviewee argues that suppliers and OEMs must find effective ways to deal with them. This involves attaining new competencies required and understanding what the company's knowledge and capabilities can be used for in the future (p.c. Bryntesson, 2020). As an example of how hard it can be to forecast the need for business model change, the interviewee brings up an example of a supplier who manufactures tires for a car. Often, this actor will think "electric vehicles need tires too, so I'm not in any danger" (p.c. Bryntesson, 2020). However, the different qualities of a new or modified product can lead to unexpected component requirements in the future, even if the component itself will in some way be needed. For example, an electric car is likely to make less noise, and thus friction from tires might be the loudest part of the vehicle. Hence, customers might prefer tires that produce less sound, which then becomes a unique selling point (USP) without suppliers being prepared for this. The interviewee also points out that there is a lack of collaborative efforts between OEMs and suppliers in the industry, where they jointly try to find strategies of limiting their exposure to various risks (p.c. Bryntesson, 2020).

A final, but vital, learning from the car industry is the need to focus on functions and attributes of components first, rather than focusing on articles primarily (p.c. Bryntesson, 2020). Currently, many actors are looking at article first (that they need a steering system) and then they look at what it is supposed to accomplish and contain. Moving forward, it will be advantageous to look at function and attributes first - what functions will the article achieve? Currently, most automotive manufacturers achieve one function per article, which is rather ineffective. Instead, incumbents must examine ways to achieve perhaps three functions and two attributes through one article. One example Bryntesson (p.c. 2020) highlights is Porsche, who in their electric vehicles are experimenting with making the trunk into a cooling system, so that cold drinks can be stored there. Furthermore, they have made the trunk area a space where you can charge your electric bicycle. Thereby, they innovatively achieved three functions: storage area, charging station and cooling system, in one article of the vehicle.

5

Analysis

This chapter aims to combine theory and results to provide a foundation for answering the thesis' research questions. The chapter has been divided into five subsections, each aiming to increase the understanding for a respective research question. First, the four supporting research questions (SQ) will be discussed under 5.1-5.4. Finally, in 5.5, the main research question (RQ) will be discussed as a summary of the previous segments.

(N.B. in order to facilitate for the reader, "p.c." for "personal communication" has been added to references referring to the qualitative interviews.)

5.1 Understanding the truck OEM's situation

This section aims to summarize and shine light on situation of the truck OEM, thereby helping to answer the first supporting research question, *SQ1: How is the truck OEM affected by disruptive technologies and what are they doing to mitigate obsolescence issues today?*

5.1.1 What drives obsolescence

The truck OEM is facing a number of disruptions, from electrification, to autonomous drive, to digitalization (p.c. Employee A, 2020; p.c. Employee B, 2020; p.c. Employee C, 2020). According to the interviews with the truck OEM employees, the most impactful and urgent to consider is the transition from diesel propulsion to electrical engines. There might be numerous reasons for this. Looking at the sources of obsolescence (*Table 2.2*) there are numerous potential drivers of obsolescence. In this thesis, disruptive technologies (technological evolution and technological revolution) has been a critical factor that has influenced many industries. However, what can be added to the electrical engine disruption is that it is prefaced by environmental policies and restrictions. According to Bartels, et al., (2012), these are legislations imposed by governments that shifts the current balance of an industry by restricting certain technologies, while allowing others to grow. From the perspective of the truck OEM employees, the combustion engine is what is restricted by EU emission legislations, while the electrical vehicles are preferred. Additionally, according to Employee C (p.c. 2020), the technology for electrical trucks is not yet mature (i.e. compared to personal vehicles), so the truck OEM is working toward an unknown future. So, what can be derived from these facts is that a truck OEM is facing a significant legalization-first disruption from electrical vehicles, which demands a technology that is not yet available.

From an industry perspective, this means that the combustion engine is nearing the end of its lifecycle. Looking at the different product life cycle stages from Pecht & Das (2000; *Table 2.3*) the combustion engine has reached its maturity and is on its verge to decline. This means that the components are currently on the verge to being more expensive (Pecht & Das, 2000) This transition speed will be increased as soon as more electrical trucks reach the market. Employee A (p.c. 2020) highlights the commitment that the truck OEM will deliver (end-of-pipe) emission free trucks by 2030. Thus, indicates that there will be a rapid progression on the technological side in developing offers for electrical vehicles.

Being that the truck OEM is developing and maintaining a sustainment-dominated system, the decline of the combustion engine leads to challenges. Normally in later stages of the life cycle, companies with products in the later stages of the product life cycle would according to Pecht & Das (2000) face decreasing sales, its lowest price, decreasing modifications, lower profits, among other impacts. OEMs with systems that are not sustainment-dominated could in such a situation switch to the newer technology, leaving the declining technology behind. Such were the cases in i.e. the outdoor lighting industry, where incumbent actors switched to deliver LED solutions and saw an increase of new business opportunities. For a sustainment-dominated system such as the combustion engine, which have life cycle sustainment costs in the aftermarket that exceed the manufacturing costs (Singh & Sandborn, 2006), the transition out of an old system is difficult. With a 15-year service commitment, a truck OEM needs to invest both in the future of the electrical vehicles, as well as sustaining their service and uptime in the aftermarket.

Maintaining aftermarket services requires efforts from a truck OEM and the value chain surrounding it, which needs to be able to acquire spare parts and components from suppliers. However, as described in the interviews with Employee A (p.c. 2020), Employee B (p.c. 2020) and Employee C (p.c. 2020), some suppliers are already facing challenges in liquidity and delivering certain components (i.e. fuel filters). Such a supplier situation is a similar development to suppliers of train systems having challenges or even going out of business (p.c. Tydal, 2020). Not being able to deliver on the aftermarket services can generate multiple risks in terms for a truck OEM of increased costs, negatively impacted brand and decreased customers satisfaction (p.c. Employee A, 2020; p.c. Employee B, 2020; p.c. Employee C, 2020). It is not always the truck OEM that carries the risk, which can be seen in the case of outdoor lighting where the buyer carried the risk (p.c. Börjesson, 2020). Another example is that it is not that black and white and that an OEM shares the risk with its operators and suppliers, as exemplified by Ermel (p.c. 2020).

5.1.2 From reactive to strategic

No matter if the risk is carried mainly by the OEM or an actor up- or downstream, the reality is still that the truck OEM will be impacted by technological disruption and obsolescence. In order to mitigate these problems and reduce the obsolescence risks, the truck OEM has implemented a number of efforts. These efforts are a mix of strategic, proactive and mostly reactive measures. As previously mentioned, reactive measures are solutions that occur after the truck OEM receives indication that a component will not be produced any more (through i.e. a PDN or EOL notice). When, in some cases the truck OEM does not receive such a notice, Employee A (p.c. 2020) also mentions that a reactive measure might be triggered when the truck OEM reaches out to a supplier (which might reach out to its suppliers) for a component, after which they get notified that it has already been discontinued. No matter how they are notified, Bartels, et al. (2012) and Stogdill (1999) lists the most common reactive management approaches as *LTB*, finding *alternatives* ("supply switch", finding other aftermarket sources and salvaging/harvesting/refurbishment) and testing *additive manufacturing*. While the first two are quite common, additive manufacturing is only in its early stages and it is also quite costly and complex to develop the spare parts, which is indicated by the case study review (i.e. Concini & Toth, 2019 or van den Bogaard, 2019).

From the case study review there are one common strategy that the truck OEM is currently not applying: redesign (i.e. Bodine, 2015; Dubos, 2011; Greenway, 2017; NAVSEA, 2012; Khalil & Wahba, 2009; Xiaozhou, Thornberg & Olsson, 2012; Xiaozhou, Thornberg & Olsson, 2014). Redesign is a process that requires lots of knowledge and forecasting, as well as the cross-functionality to function. Moreover, the operations of the truck OEM are very complex, and achieving such functionality is therefore hard. These are some likely reasons why redesign is not present today, and they instead rely on other reactive measures.

However, it can be said that the truck OEM is utilizing some proactive approaches. The results show that the truck OEM currently conducts knowledge, contracting, financial monitoring, (attempts at) standardization and dialogue (p.c. Employee A, 2020; p.c. Employee B, 2020; p.c. Employee C, 2020). Contracting is a measure used by many companies. Looking at the case of Bombardier by Ermel (p.c. 2020), it could ensure that spare parts will be available through the intended period of the contract. Furthermore, it can also be used to signal that obsolescence is an issue that needs to be considered during the lifetime of the product (p.c. Employee B, 2020).

The truck OEM has identified the need for standardization of a product line, a strategy that only came up in a few instances in the case study review. The "420 seats" that Employee A (p.c. 2020) mentions could be reduced if there is a risk for obsolescence. However, it needs to be balanced with offering a premium offer (p.c. Employee C, 2020) and that the available seats are designed to be changed from one to another - which examples of modular design and system independence could facilitate (Bayruns & Koenig, 2002; Godenes, 2017; Jibb & Walker, 2000; Rahman, et al., 2019; Vanderseypen, 2018; Yali, et al., 2012).

From the case study review, it is indicated that proactive and strategic approaches are strategic additions that can be done. The cases show successful strategies such as monitoring and forecasting (i.e. market trends or Bill of Materials (BoM)), setting up a management team, business model innovation, conscious design (modularity, open source) and partnerships could be successful implementations. The benefit contra reactive approaches are according to Bartels, et al. (2012) that it avoids costly long-term investments or redesigns. Additionally, in industries like railway, aerospace and defense, products are security relevant and therefore an obsolete part might cost millions to redesigns or find alternative parts, due to the need of extensive testing (p.c. Sandborn, 2020). A similar case is given by Employee B (p.c. 2020) and Employee C (p.c. 2020) for the trucking industry when they point to the long and costly testing times of a new component. Finally, a strategic obsolescence management approach is taking a bigger picture view of a system (or component) at risk of being obsolete. The aim is to set up a more holistic strategy including all phases of a components life cycle, the correct knowledge and data management systems and delegating the correct mandate. Looking the six steps that Sandborn et al. (2011) mention for successful obsolescence management, this would indicate that the truck OEM is "lifting the focus beyond single parts or components, thereby enabling management above the part level".

5.1.3 Intended or unintended?

Another view is that a distinction can be drawn between intended and unintended efforts against mitigation. As such, the unintended efforts are those that have grown organically from other parts of the organization. Here, the proactive and strategic efforts can be placed. The knowledge or risk analysis efforts are clear examples of efforts that has grown unintendedly into obsolescence management strategies - either from other functions of the company or from individuals within the company. As for more intended efforts, the company has initiated its reactive approaches in reaction to previous experience with obsolescence. At this point in time, the truck OEM can be seen to be quite heavily reliant, in line with Kidd & Sullivan (2010). Reactive measures can be seen as an easy way out of these issues, but is also costly and can take a long time to verify. Furthermore, as claimed by Employee A (p.c. 2020) and Employee B (p.c. 2020), the reactive obsolescence management of today is very time consuming for employees and can take up to 75 percent of someone's working time. As such, an initiative to formulate more strategic and proactive approaches to obsolescence mitigation will likely according to Kidd & Sullivan (2010) be the cheaper and more time efficient option. However, it should be said that the task to reach a proactive and strategic mitigation process is very challenging and requires investment and time - especially when compared to a reactive approach.

As for the truck OEM, they have commenced their journey to a more proactive and strategic obsolescence management system. While the truck OEM might be quite reliant on reactive approaches today, it should also be mentioned on the positive side that they already have lots of puzzle pieces that can be worked into that holistic obsolescence approach. As such, while there is processes to develop, the results indicate that the truck OEM has a good foundation to stand upon for strategic obsolescence management.

5.2 Learning from other industries

This section seeks to inform the reader of what a large truck OEM can learn and implement from other industries that have previously undergone similar technological transitions. This will shed light on the second supporting research question: *SQ2: As a truck OEM, what can be learnt and operationalized from other companies in industries that have gone through similar technological transitions?* In total, general insights as well as five different key areas of obsolescence management have been identified, in which companies can implement strategies to develop more effective proactive and strategic obsolescence management. These key areas are management, design considerations, knowledge, supplier management and innovation.

Key area	Examples
Management	- Creating a cross functional obsolescence team - Making sure the management and governance support obsolescence management
Design considerations	- Modular design - Involving R&D and design functions - Using open source and open architecture - Look at function over component - Standardize components
Knowledge	- Coordinate and share data internally - Manage data correctly - Develop early warning indicators - Recruit and reeducate personnel - Acquire and share knowledge externally
Supplier management	- Source from countries with markets further back in the S-curve - Choose suppliers based on ability to adapt - Collaborate with strategically important suppliers - Utilize contracts to highlight importance of obsolescence issues
Innovation	- Investigate new business models - Look at emerging innovative solutions, such as additive manufacturing - Evaluate new solutions such as actors specializing in lifetime buys or reverse engineering

Table 5.1 - Overview of learnings from benchmark industries

5.2.1 General insights

In both categories of data collection, there have been a large number of different methods implemented to deal with technological obsolescence, characterized as obsolescence caused by more technologically advanced components becoming available (Bartels, et al., 2012). Actors in analyzed industries are naturally implementing differing approaches to deal with obsolescence, often dependent on what the source of obsolescence is. In the music and outdoor lightning industries, the main source of obsolescence was a technological revolution (streaming and LED), which involves a new technology displaces its predecessor abruptly (Lafontaine & Slade, 2007; p.c. Uggla, 2020; p.c. Börjesson, 2020). In the railway industry the main sources of obsolescence are technological evolutions (increased usage of software), where a new generation of a technology makes its' predecessor increasingly obsolete. This was combined with governmental policies (ERTMS) and original component manufacturer withdrawal, where the OCM disappears from the market as a result of bankruptcy or industry exit (Lafontaine & Slade, 2007; p.c. Bartels, 2020; p.c. Tydal, 2020). In the car industry, environmental regulations combined with technological evolution drives most obsolescence issues (Lafontaine & Slade, 2007; p.c. Bryntesson, 2020). This situation is similar to the previously mentioned trucking situation, just moving at a faster pace in the cars industry. The solutions also differ between these industries, according to data from the case study review as well as the qualitative interviews, indicating that the source of the problem will influence the solutions implemented to deal with it. In other words, as pointed out by Bartels (p.c. 2020), different actors within different industries will definitely come up with different solutions.

However, from the case study review it is evident that certain strategies appear to be highlighted and discussed more often frequently than others, regardless of industry. In the reactive category, LTB (last-time-buys) is the most popular approach (17 cases), followed by redesign (13) and usage of alternative parts (10). These methods have, according to the review, been successful on multiple fronts and is a foundation of many companies' obsolescence strategies. However, the review along with expert interviews show that companies also risk being over reliant on reactive measures (p.c. Bartels, 2020; p.c. Sandborn, 2020).

On the strategic and proactive side, monitoring (23 cases) is the most common approach, followed by forecasting (16), partnership/cooperation (14), information sharing (13) and risk analysis (13). The emphasis on proactive measures is likely due to this common use of reactive measures, which would gain less attention from academia. In other words, due to the need of many companies to implement proactive and strategic approaches, these topics are given more attention in the literature of obsolescence. In the qualitative interviews, strategic and proactive measures like partnership/cooperation, information sharing, and data management is brought up regularly, and generally given more weight than reactive approaches. In the reactive category, issues of obsolescence seem to be dealt with largely by focusing on last-time-buys, redesigns and contracting.

5.2.2 Management

The first of the key areas which can enhance a company's ability to pursue proactive and strategic obsolescence mitigation is the role of management and leadership. Multiple interviewees from the qualitative interviews mentioned that a change of management or corporate leadership can be required to enable the organization to change in accordance with new conditions caused by technological disruptions (p.c. Antonov, 2020; p.c. Bryntesson, 2020; p.c. Bartels, 2020). People who have reached executive position in stable times, through their ability to manage stable and predictable operations, might be hesitant or paralyzed by the need to change. Thus, looking to promote or recruit change agents in unstable times is likely to enhance the organization's ability to deal with challenges of disruptive technologies.

Furthermore, a range of case studies highlight the importance of establishing an obsolescence management team to lead the efforts and monitor risks with the correct mandate (Boeing, 2001; ECSS, 2017; Heiskanen, 2018; IAEA, 2004; Mitsdarffer, 2014; NASA, 2012; NAVSEA, 2012; Meyer, Pretorius & Pretorius, 2012). The benefits of an obsolescence management team in a company's efforts to become more strategic in their handling of obsolescence is also pointed out in Bartels, Ermel, Pecht & Sandborn (2012). Such a team should be cross-functional and given sufficient authority, since it allows for increased coordination and knowledge sharing, which is a similar pattern to the case study review. Knowledge sharing is deemed critical by Sondermann (1994) who in the four stages of implementing strategic obsolescence management argues that all such initiatives need to start with raising awareness. The obsolescence management team will also be responsible for the planning/design stage, where you develop preliminary obsolescence management plans and determine weaknesses, risks and causes of obsolescence (Sondermann, 1994). The team needs to be cross-functional, since obsolescence is a practice that needs to be performed in many different functions of the organization (R&D where you plan for obsolescence, design and development where you design for obsolescence, installation where you check for obsolescence, and operation/maintenance where you act according to the plan that has been created).

5.2.3 Knowledge

Acquiring and sharing the correct knowledge is furthermore seen as critical (IAEA, 2004; Taberner, 2015) and co-locating actors can be a way to facilitate communication and sharing resources (Cole, 2013). In connection, there is the need to manage the organization’s tacit knowledge, making it available to everyone organization wide, including people who produce forecasts which create the foundation for obsolescence decisions. This was brought up by Alexandersson (p.c. 2020) as a key step in standardizing and rationalizing a number of the organization’s processes, including the management of obsolescence. As new technology emerges, other capacities, competencies and organizational structures are commonly required than previously (p.c. Sandborn, 2020, p.c. Bryntesson, 2020). Thus, the recruitment process might need to be altered, and internal personnel might need to be reeducated to better understand future challenges. This can be true both for engineers, with the automotive industry needing to reskill 30 000 - 40 000 engineers to meet the future of digital, autonomous and electric vehicles, but also for CEOs who are experts in corporate maintenance but not necessarily at leading change (p.c. Bryntesson, 2020).

One proactive area related to knowledge, which was highlighted by both the interviews and case study review was the importance of data and forecasting. As previously mentioned, a large amount of cases in the case study review (together mentioned in over 50 cases) showed success stories from monitoring, forecasting, risk analysis and data management (i.e. Al-Qahtani, et al., 2010; Broadbent, 2020; Djoukuimo, 2019; ECSS, 2017; Heiskanen, 2018; Hunt & Melicker, 2008; Jennings, Dazhong & Terpenny, 2016; LeCompte, 2017; Ma & Kim, 2017; Macaulay, 2010: Moore, 2014; NAVSEA, 2014; Nunes & Downes, 2015; Sandborn & Pecht, 2001; Sandborn, Mauro & Knox, 2007). In the interviews it was stated that, in order to implement a proactive approach, companies need access to high-quality data (p.c. Bartels, 2020), which is also indicated by the case study review. Design refresh planning is also a process that requires large amounts of high-quality data, since the process involves forecasting the system's lifetime and seeing where the ultimate dates for refreshes are, and what subsystems or components are likely to be in need of such actions (Singh and Sandborn, 2006).

However, knowing what consists high-quality data is difficult and requires insights and competency. Often, companies are required to go through a process of 'data cleaning', where they sort and refine the existing data (p.c. Bartels, 2020). In the case study review, it is concluded that in order to leverage useful tools like machine learning and simulations, the correct data and data management systems are needed (ECSS, 2017; Xiaozhou, Thornberg & Olsson, 2014). The usage of proactive approaches like forecasting, life cycle analysis and simulations, all of which are dependent upon high-quality data, can be effectively leveraged to understand and mitigate risks of obsolescence (Godenes, 2017; Ma & Kim, 2017; Sandborn, Mauro & Knox, 2007; Xiaozhou, Thornberg & Olsson, 2012). Another usage area of data is in machine learning, which was mentioned as an effective tool to enhance decision making, both in the case study review (Djoukuimo, 2019) and the interviews (p.c. Bartels, 2020).

5.2.4 Design considerations

Another important takeaway for a large truck OEM is the benefits that proactive concepts like modular designs and open architectures bring (Bayruns & Koenig, 2002; Godenes, 2017; Jibb & Walker, 2000; Rahman, et al., 2019; Vanderseypen, 2018; Yali, et al., 2012). These two concepts help facilitate system subdividing, which involves the replacement of a component affecting the larger system as a whole (Livingston, 2000). Using these approaches enables the system to be subdivided so that portions of it are replaceable without the entirety being affected, which is required when reactive measures like alternate parts usage and uprating are desirable options. Usage of open architecture was a relatively common term in the case study review, and was mentioned by several interviewees, especially in industries providing sustainment-dominated systems, like the train- and outdoor lightning industries (p.c. Börjesson, 2020; p.c. Tydal, 2020). Furthermore, the usage of open source software was seen as a favorable practice to reduce costs related to maintenance of sustainment-dominated systems, since the increased usage of software in them have increased system interdependencies (p.c. Tydal, 2020) and made it harder for an operator to understand the configuration of the system (p.c. Bartels, 2020).

As mentioned, management of obsolescence should be a practice that runs throughout the entire organization (Sandborn et al., 2011). As such, R&D and design departments should take obsolescence into account when developing new models, products and systems. This was mentioned in 11 cases of the case study review (i.e. Khalil & Wahba (2009) and Dubos (2011)). In these departments, there are a number of practices that are worth implementing. Some of these are to start looking at functions and attributes rather than specific articles (p.c. Bryntesson, 2020). In other words, a truck OEM can analyze what they can do with a system, what functions they want it to fill and what attributes they want it to have, rather than just looking at the obvious articles available or the already existing components. In this way, a truck OEM can come up with novel ways of bringing value to users, and consequently also to reducing obsolescence problems (if obsolescence risk mitigation is an attribute you are focusing on). Another important practice for the design department is to not design an entire product, for example a train, where all the different systems have a 30-year expected life. This is because, in many cases, a truck OEM might not want certain systems to work for that long. Bartels (p.c. 2020) exemplifies this through one client interaction; a train conductor who wanted all systems of the train to run for 30 years. But Bartels (p.c. 2020) argues that this is not desirable for certain systems, like the infotainment system or the wireless network reception hardware. In 30 years, users will not be satisfied with using today's infotainment systems (for example the phone chargers of 30 years ago would be quite useless today). Similarly, the users will want an antenna that only transmits 4G-signals in 2050. A better way to design such sustainment-dominated systems, like trains, is to create a product with limited system interdependencies, and create a process where the system is continually updated through redesigns and maintained through design refresh planning. And usage of open source hardware and software will make such processes easier as well as cheaper.

5.2.5 Supplier management

Another important area of developing a strategic approach to obsolescence management involves the handling of suppliers potentially at the risk of being affected by the technological disruptions.

Sandborn et al. (2011) argue that one key step in implementing strategic methods of obsolescence management involves taking obsolescence management into consideration in the process of part selection. When analyzing data from the case study review and qualitative interviews, it becomes apparent that such considerations must also be made in the process of supplier selection. Thereby supplier selection becomes an important process, and companies should not just determine what suppliers to source from based on price (p.c. Börjesson, 2020; p.c. Ermel, 2020). Instead suppliers should be evaluated based on the likelihood of current business model failure, their options to develop new ways to attain revenue streams in a shifting market environment, and their ability to transition if needed. A novel approach to select suppliers to source from is to look at the geographical/market location of the supplier. In this method, suppliers are chosen based on their domestic market's technological maturity (p.c. Antonov, 2020). The argument was that if a supplier's home market was lagging in the adoption of new technologies, they would have a domestic market to serve legacy products to for a longer period of time, resulting in an increased ability to stay in business and maintain operations. Technological revolutions are unlikely to happen simultaneously all around the globe, and thus having suppliers located in markets not experiencing such a revolution decreases problems on the supply side.

Another important supplier-related issue is related to contracting. In both the case study review and the qualitative industries, the concept of contracting was a common topic. A solution to obsolescence issues proposed through the interviews was that suppliers could be required to offer service contracts spanning the system's total lifetime, where obsolescence management services are included (Heiskanen, 2018; Rojo, Roy & Shehab, 2009; p.c. Tydal, 2020). In this way, the risks of obsolescence are shared, motives are aligned, and cooperation is facilitated. This can be described as a novel way to facilitate partnerships with suppliers, which was the third most commonly mentioned strategic measure to combat obsolescence in the case study review. Another method brought up to deal with failing suppliers, which is a more drastic version of a redesign (commonly mentioned in the case study review), was to vertically integrate the activities previously carried out by suppliers who are struggling to supply important components or materials (p.c. Uggla, 2020). This allows for the continuation of production in a situation where there are few alternative suppliers, or these are likely to also go out of business soon.

The next important factor to handle obsolescence issues, evident from both the case study review and the interviews, was value chain collaboration and ecosystem coordination. This was the third most common strategic measure mentioned in the case study review and was brought up in all industries where representants were interviewed. Increased cooperation with suppliers can provide increased understanding of a system's configuration (by receiving more information about part details and the following implications), collaboration in collecting and analyzing relevant data, as well as receiving early warning signals provided by the supplier (e.g. decreased demand for parts). Furthermore, there are benefits to the relations and interactions between truck OEM and suppliers. The data shows that it allows the truck OEM to help suppliers prepare for the long term maintenance phase (p.c. Bryntesson, 2020), it enables the truck OEM to help supplier adjust to changing market conditions and technologies (p.c. Alexandersson, 2020), and it increases suppliers' willingness to keep provided parts despite decreasing demand (p.c. Ermel, 2020). Lastly, it increases the likelihood to receive parts even in times when suppliers of new technologies might be experiencing periods of high demand. Some ways to increase supplier collaboration is continuous dialogue, collaborating with suppliers on strategic issues, and implementation of creative initiatives like supplier competitions desirable behavior is rewarded (p.c. Alexandersson, 2020; p.c. Employee B, 2020). Such cooperation would also increase the likelihood of striking novel contracting agreements which would reduce the risks of obsolescence carried by the truck OEM, such as service agreements throughout the system's lifetime.

In Sondermann's (1994) listed four different stages of strategic obsolescence, good supplier cooperation can help facilitate strategic obsolescence management in the *initiation* stage, by assisting in analyzing and building knowledge regarding obsolescence. Furthermore, it can also positively influence the *planning and design* stage by providing data to better analyze processes and detecting weaknesses/causes of obsolescence, the *execution* stage by helping in strategically operating the obsolescence management (for example give tips on best times for system redesigns or refreshes) and the *monitoring* stage by providing new alternatives to current obsolescence practices. As such, collaboration in the ecosystem and information sharing is a measure that can significantly strengthen other measures of obsolescence management, but it will rarely solve issues alone.

5.2.5 Innovation

This category revolves around different innovative solutions to deal with obsolescence, made possible by new market developments or technological advancements. Additive manufacturing is a new technology which has the potential to mitigate many problems with obsolescence. It was the fourth most common reactive measure in the case study review, and brought up by several cases as an emerging potential solution to resolve obsolescence issues (Concini & Toth, 2019; DB Fahrzeuginstandhaltung, 2018; Global Railway Review, 2018; Togwe, Eveleigh & Tanju, 2019; van den Bogaard, 2019; van der Zijl, 2019).

In many of these cases, additive manufacturing was described as a successful way to redesign obsolete products. Multiple interviewees from the qualitative interviews also highlighted the potential of additive manufacturing. However, in their opinion technological barriers often still exist hindering it from being a fully viable solution for many companies. For example, it is not able to print certain forms of parts reliably and it needs to be guaranteed safe when used (p.c. Employee B, 2020; p.c. Ermel, 2020), which is required if it is to be leverage by a large truck OEM, whose products are required to be safe. However, additive manufacturing is a phenomenon that is growing in relevance and is becoming useful in more and more cases - especially where simpler spare parts are needed (Concini & Toth, 2019; van der Zijl, 2019).

Other important developments for a large truck OEM to keep in mind and investigate further are new actors and business models, for example companies who make lifetime buys and store parts for companies, and companies who specialize in reengineering (p.c. Ermel, 2020). These new actors, and additive manufacturing in certain cases, can be viable alternatives beyond the typical reactive measures listed in the literature, and an estimation of total cost on a case-by-case basis should be conducted to determine the usefulness of such alternatives.

5.3 Finding early warning signals

Given what is now known of the large truck OEM, and what has been done to mitigate obsolescence in other industries, the next logical step is to determine what indicators in the company's operations or external environment can be used to detect the need for such measures. This will enable answering the third supporting research question: *SQ3: As a truck OEM, what early warning indicators and insights should be implemented to handle obsolescence issues before they become a liability?*

The detection of effective early warning signals has shown to be a critical part of managing challenges caused by disruptive technologies. In two benchmarked industries - music and outdoor lightning - actors managed the growth of new technologies in different ways. The speed and potential impact of the technologies (LED and streaming) were rather similar, but what separated the outcomes in the two industries were the actors' ability to accurately detect early warning signals.

In the lightning industry, both interviewees pointed out their ability to detect the changes coming early on, through noticing various early warning signals (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). The technology was well know, LED had been around for a long time in other usage-areas, but its' potential future usage in outdoor lighting products became apparent through supplier and customer communication, reading up on new developments and being aware of governmental directives that were likely to come (p.c. Alexandersson, 2020; p.c. Börjesson, 2020). By making sure that they had the production capabilities to support LED products, by investing heavily into R&D, and by making existing products able to integrate LED technologies as effectively as possible during the transition stage, the companies created a platform from which they could handle present and future technologies (p.c. Alexandersson, 2020; p.c. Börjesson, 2020).

In contrast stands the actors in the music industry, who had no indication that the transition to streaming was coming (p.c. Antonov, 2020; p.c. Uggla, 2020). They had detected no early warning signals, even though they existed. Napster had already shown that music could be converted and distributed in a digital format, and the success of the platform illustrated the preference that consumers had for the new format over the CD (Fairchild, 2015). This made the actors passive, disregarding any proactive or strategic initiatives that would have mitigated profitability issues caused by streaming. It is likely that there are other major differences between the industries that influenced the outcomes of the actors within them. Simply looking at the lightning industries, there were many incumbents who did not manage the transition to LED, largely due to a lack of awareness of the technology's potential. As a result, some outdoor lightning incumbents who were once major players now barely exist (p.c. Alexandersson, 2020). Through this case, and other insights from the case study review and the interviews, it can be argued that effective detection of early warning indicators can have massive impact on a company's ability to deal effectively with disruptive technologies.

Early warning indicators has been divided into two categories in the context of this thesis. First of all, there are early warning indicators that signal the impending entrance of a new technology that will significantly disrupt the market. The response to such signals should be broad and include measures beyond those strictly obsolescence related. Some useful early warning signals in this category that have been found across the interviews are:

1. *The need for new capabilities and competency.* The need for personnel and management with new competencies in areas other than those traditionally valued by the company is a strong indicator of a shifting industry landscape, likely caused by technological advancements (p.c. Bryntesson, 2020).
2. *Changing customer demands and industry "rumblings".* Despite being a broad category, it is of vital importance to remain responsive and detect any changes in

discourse or demand in the industry since this can indicate the emergence of new disruptive technologies (p.c. Alexandersson, 2020; Börjesson, 2020).

3. *New governmental directives and standards.* These can serve as a catalyst for innovation and increase the rate of transition from an older technology towards newer ones. This was evident in the outdoor lightning industry (p.c. Alexandersson, 2020; Börjesson, 2020), the car industry (Bryntesson, 2020) and the railway industry (Tydal, 2020).
4. *Existing technologies, with slight alterations, could be used to serve the function that products in the industry currently are.* For example, LED had been used in computers long before it was usable for outdoor lightning. But by monitoring and realizing the potential of this technology, actors were able to prepare for its' future disruptive nature (p.c. Alexandersson, 2020; Börjesson, 2020).
5. *Changes in quality and cost of a technology.* In the case study review, Nunes & Downes (2015) describes how Haitz's Law was used as an indicator of disruptive developments. LED lights faced technical improvements (quality) and decreased costs over time. At a certain point, this led to them being more effective for their cost, which made them viable for the industry to invest in.

Second of all, the other category of early warning indicators signals increased problems and occurrences of obsolescence in the actor's industry. Some examples of these found throughout the thesis are:

6. *A growing aftermarket (alternatively a growing number of aftermarket suppliers)*. This indicates increased obsolescence challenges since aftermarket sources are used to reactively mitigate such challenges (p.c. Sandborn, 2020).
7. *Number of available suppliers*. A decrease in suppliers for a particular component is likely to indicate a decreased demand for such components. As a result, remaining suppliers in the same field are more likely to issue PDNs for these parts in the near future (P.c. Ermel, 2020).
8. *Relative change in R&D spending used for maintenance of old technologies versus development of new technologies*. If the relative spending on technology maintenance increases, this is likely to indicate increased rates of obsolescence, since more efforts are directed to this area (p.c. Bartels, 2020).
9. *Frequency of PDNs and reactive measures*. Both these occurrences signal increased problems of obsolescence (p.c. Ermel, 2020).

Important to note is that these two categories are separate yet strongly interrelated. So, an increase in obsolescence problems likely means that there are new technologies made available at a faster than usual pace. Simultaneously, the emergence of disruptive technologies is likely to increase problems with obsolescence. So, indicators in one category can be used to determine current and future states of the other category. In this thesis, they are still best kept separate, since there are instances where obsolescence can occur without disruptive technologies and vice versa. Furthermore, it is important for a certain company within a specific industry to determine themselves what early warning indicators are most suitable for their situation. It is unlikely that all listed early warning indicators are equally useful in detecting future shifts in the industry or technologies used in systems.

Early warning indicators is another example of why data management is key to obsolescence management. In order to accurately monitor many of the indicators listed above, you need high-quality data which is updated, structured and exhaustive (exemplified in the case study review by i.e. ECSS (2017), Geng, Dubos & Saleh (2016), NAVSEA (2014), Sandborn, Mauro & Knox (2007), and Xiaozhou, Thornberg & Olsson (2014)). Furthermore, in order to be more proactive in detecting changes, it is preferable not just to look at current frequencies and numbers, but to forecast future changes in these measurements (forecasting being one of the most mentioned measures in the case study review).

In summation, the importance of a robust system to detect early warning indicators cannot be overstated. From the benchmark interviews, it has often been the difference between leveraging new technologies to gain market share, versus experiencing drastically decreasing sales numbers and potential industry exit (p.c. Börjesson, 2020; p.c. Antonov, 2020). Early warning indicators provide the company with a chance to gain advantages in a new or obsolete area of the industry, and when missed the company is unlikely to catch up. Therefore, often late movers can merely watch while others take over the market share that is held by providing increasingly outdated products.

5.4 Developing strategies

The next step of the analysis is to understand which strategies could and should be implemented by the truck OEM. This section will highlight and help answering the fourth supporting research question: *SQ4: As a truck OEM, how can strategies and operations be developed to manage obsolescence issues?*

5.4.1 Where to start

There are numerous ways to approach the topic of which strategies could and should be implemented by a truck OEM to manage obsolescence issues. In the theoretical framework and results, a number of strategies have been highlighted, all of which can bring different perspectives on the likely daunting task.

Given that developing such a strategy is challenging, it is important for the truck OEM to know where to start. As previously mentioned, Sandborn (2008) argues that both reactive, proactive and strategic obsolescence management efforts are needed to handle obsolescence optimally. Additionally, Kidd & Sullivan (2010) highlights that an overreliance on reactive measures will lead to higher costs in the long term. Thus, reaching a proactive and strategic level is preferred when a company aims to reduce obsolescence risks and costs.

However, Bartels (p.c. 2020) raises an important point in that a company such as the truck OEM needs to have a robust reactive process in place in order to take care of the day-to-day obsolescence issues that occurs. He argues further that improvements in reactive processes are likely to create the most benefits in the short term (p.c. Bartels, 2020) which can be an important step in achieving stakeholder buy-in for further obsolescence measures. When a company like the large truck OEM has refined these processes, the company is ready to move on to more proactive and strategic measures.

5.4.2 How to continue

In order to reach a more holistic strategy Sondermann's (1994) four stages of obsolescence management can be considered. The four stages are a roadmap of four levels for how a company can implement obsolescence management in their operations. The four stages are (1) initiation, (2) planning and design stage, (3) execution stage and (4) monitoring and controlling stage. As previously mentioned, the current situation of the truck OEM is that they are in the initiation stage of their obsolescence strategy. This is especially highlighted by the interviews with the three truck OEM employees (p.c. 2020). They all indicate that they are in the starting pit in terms of creating an overarching obsolescence management strategy. According to Sondermann (1994), the initiation stage involves building a knowledge base, auditing and raising awareness on the topic.

Whether or not they are in the second stage - planning and design - is debatable. The stage involves developing preliminary obsolescence management plans and evaluating risks, designing products to avoid obsolescence issues, and analyzing the internal capacity to handle them. Connecting to the previous argument, the truck OEM is not at this stage yet, due to just starting the journey toward a holistic obsolescence management strategy. However, as this thesis has pointed out, there are tendencies in the current obsolescence management efforts that can be utilized and taken advantage of when shaping their preliminary strategy in the second stage. For example, Employee A (p.c. 2020), Employee B (p.c. 2020) and Employee C (p.c. 2020) indicate that they have quite established reactive measures of last time buy, harvesting, refurbishment, supply switch and early development of 3D printing. Additionally, they have some tendencies for proactive and strategic measures in risk analysis, monitoring, financial controlling, forecasting (i.e. for design and LTB), contracting, gathering knowledge and having dialogues with suppliers. However, while they might benefit obsolescence issues, these efforts are either parts of other functions in the organization (i.e. risk analysis being part of the whole purchasing function and not only focusing on obsolescence) or is generally present (i.e. knowledge of segment leaders). As such, there is a requirement for the truck OEM to coordinate these proactive and strategic efforts before they can be seen as a coherent obsolescence management strategy, and thus be in the second stage.

If they can reach the second of Sondermann's (1994) stages, the following stage would be the execution stage. In this stage, the strategy would be up and running with different efforts, as indicated in the case study review and interviews: forecasting and simulation measures in place;

optimization and standardization of products; information sharing; effective contracts; design refresh planning; and so on. Exactly what the strategy will entail is very contextual to the truck OEM (p.c. Bartels, 2020). The full range of examples from the case study review and interviews are examples for the truck OEM to implement according to what they learn, and the context of their value chain.

After the strategy has been executed, the final of Sondermann's (1994) stages is monitoring and controlling. This stage is involving more ongoing, proactive measures for obsolescence management. Sondermann (1994) mentioned defining, analyzing and evaluating the different costs of obsolescence. Looking at the case study review and interviews, these are quite common and could be seen as quite ordinary proactive measures to obsolescence management.

5.4.3 Continuous improvement

This process that Sondermann (1994) suggests depicts a quite linear process to reach a strategic level of obsolescence management. For the truck OEM, it can serve as a roadmap for the journey toward a holistic obsolescence management strategy. However, there are other characteristics of the truck OEM to consider when creating a strategy. Looking at the PDCA (Plan-Do-Check-Act) framework by IEC (2004; also provided in Bartels, et al, 2012), it is important to consider where and when to do apply obsolescence management strategies. The framework, shown in *Figure 2.3*, highlights all the different operations of a company (from concept/definition to disposal) and how obsolescence ties in. As such, it is not only important to add more measures to reach a higher level of Sondermann's (1994) stages, but it is also important to reflect on where to conduct certain mitigation strategies.

IEC (2004), Singh and Sandborn (2006) and Bartels, et al. (2012) suggests a PDCA cycle, which includes the whole operation of a company. As have been indicated in the case study review and interviews, planning for obsolescence early in a product's life cycle is key to avoiding obsolescence issues (CMCA.uk, 2020; Concini & Toth, 2019; Dubos, 2011; Dubos & Saleh, 2016; Khalil & Wahba, 2009; Underwood, 2011). This goes the same for design and development, where modularity and subdividing comes in (Bayruns & Koenig, 2002; Godenes, 2017; Jibb & Walker, 2000; Rahman, et al., 2019; Vanderseypen, 2018; Yali, et al., 2012). In manufacturing, installation and operation/maintenance, the PDCA cycle suggest continuous check for obsolescence and acting according to the plan.

While being a framework that the truck OEM can apply to their operations, the cyclicality of PDCA also brings another benefit. Following the end of the PDCA cycle, Singh and Sandborn (2006) suggests that there should be a process of optimization and improvement. An interpretation of this is that there is an opportunity for a feedback loop, that in turn improves the obsolescence management strategy. So, where Sondermann's (1994) framework is a roadmap for getting to a state where the strategy is in place, the PDCA cycle would add a process of feedback and continuous improvement of the strategy. This is deemed as critical, as the rate of development and disruption of the combustion engine is still quite unknown, so reiterations of the strategy will likely be needed.

In summation, the road to an extensive and effective obsolescence management strategy is long and challenging. In order to get there, you need to establish an understanding for the need of these issues, map out what you already do and know, as well as what you need to do and know, then create a preliminary strategy. This strategy should then be operationalized and reiterated. However, in order to reduce risks while developing the proactive and strategic front of obsolescence management, it is important to have reactive measures in place to cater to the day-to-day obsolescence issues.

5.5 Wrapping up: Insights and recommendations

Concluding the analysis section, the intention is to synthesize the findings of previous sections, thereby using the knowledge of the large truck OEM, the benchmarked industries and early warning indicators to answer the overarching research question *RQ: How can a truck OEM effectively manage obsolescence issues caused by disruptive technologies?* In order to analyze the question, it is important to understand why the truck OEM needs to work with obsolescence issues, what their efforts might include and, finally, how achieving a holistic obsolescence management strategy might be done.

5.5.1 Why

Starting with *why* the truck OEM should work with managing obsolescence issues, the analysis has shown a number of critical factors. It is apparent that the automotive industry is on the verge of a number of technological disruptions - the most impactful one being vehicle electrification. This "legislation first" disruption puts industry actors in a situation where they face many unknowns of the future of their industry and how it will impact their current operations (mainly the combustion engine). This poses many risks and potential costs, which must be managed. Currently, the truck OEM is working mainly in a reactive manner to manage these issues. If they can start working more proactively, they might reduce risks and costs in a long-term perspective, while also keeping their customers satisfied.

5.5.2 What

Continuing with the *what* of the obsolescence management strategy, the analysis has gathered and synthesized potential learnings and methods from a broad set of industries. Strategic, proactive and reactive measures have been identified as important to companies facing disruption. Reactively, success cases for efforts such as LTB, redesign, finding alternatives, refurbishment, harvesting, reverse engineering and additive manufacturing have been identified. On the strategic and proactive side, there are numerous learnings that can improve the management of obsolescence. These can be summarized into five key areas: management, knowledge, design implications, supplier management and innovation (and are summarized in *Table 5.1*).

In addition to strategic, proactive and reactive approaches to obsolescence management, the analysis has also shown the benefits of investigating early warning signals of a disruption occurring. By tracking the correct indicators, a company such as the truck OEM can better predict and preemptively assess a disruption and what it might lead to - directly and indirectly. These early warning indicators are contextual to the specific industry, but some general patterns are changes to capabilities and competencies, changing customer demands, new governmental directives or standards, changes in quality to cost, a growing aftermarket, increased number of available suppliers, changes in R&D expenditure (to maintain legacy technologies), and increased frequency of PDNs.

5.5.3 How

Lastly, elaborating on *how* the truck OEM should implement these measures. In the previous section, a number of primarily strategic and proactive measures are listed. Reactive measures have also been investigated and are key to successful operations, but these already exist to a large extent within the truck OEM. These are important to consider and implement when suitable, since it has been established that the achievement of effective proactive and strategic management of obsolescence is preferable when aiming to reduce risks and costs of obsolescence. Nevertheless, a company such as the truck OEM needs to have established a robust reactive process first, so that day-to-day obsolescence issues are solved. This is also where the most short-term cost saving can be found, and the attainment of these can be an important first step to achieve stakeholder buy-in - a critical step to a strategic process such as this. Making such processes robust involves standardizing them and having established methods for determining what the best reactive measures are given specific circumstances.

Looking at the four stages of Sondermann's (1994) obsolescence management framework, the current placement of the OEM is in the initiation stage. They do have obsolescence management approaches in place, but these are often not structured or standardized. Efforts are also often internal within organizational functions or generally present. There is a large need for the truck OEM to coordinate existing proactive and strategic efforts more effectively, while integrating new measures described in the section above, if they are deemed suitable to their organizational context. When progressing to the execution stage, the new improved obsolescence strategy is up and running, with activities such as forecasting, simulation, designing for obsolescence, an obsolescence management team in place, information sharing, more effective contracting, usage of design refresh planning, and so forth. What these measures will be is very contextual to the truck OEM, but the analysis shows that they all can benefit an obsolescence management strategy of a disrupted technology - and thereby making obsolescence obsolete.

6

Conclusion

This thesis has aimed to investigate and answer what learnings a truck OEM might implement to manage obsolescence created by disruptive industry developments. The main research question the thesis aimed to answer was: *How can a truck OEM effectively manage obsolescence issues caused by disruptive technologies?* The truck OEM is currently facing disruption of the combustion engine through electrification (along with technological convergence, automation and digitalization). As a result, the truck OEM has begun implementation of early-stage strategic and proactive measures, to mitigate risks of disruption and subsequent obsolescence. In order to mitigate these impending obsolescence issues, this thesis concludes that the truck OEM should continuously improve their existing reactive approaches to obsolescence management and additionally develop a strategic and proactive framework including early warning indicators to preemptively assess and monitor potential developments leading to obsolescence. If done correctly, this will not only lead to reduced risks and cost in the long term, but might also benefit other actors in the value chain. The thesis has synthesized general insights as well as five key groups of learnings of how a truck OEM can manage these obsolescence issues. The groups of key learnings were that management, knowledge, design considerations, supplier management and innovation are key for a truck OEM's obsolescence management strategy in order to achieve long term benefits of cost savings and consumer satisfaction. In addition, a number of early warning indicators were identified as critical for a strategy. These involved both early warnings for technology disruption on a systematic level and obsolescence developments on a component level.

In order to reach this conclusion, the thesis has conducted two separate data gathering and analysis methods. First of all, a case study review was conducted through a Systematic Literature Review framework. This gathered and synthesized insights from 90 contemporary obsolescence management success cases within 11 industries relevant to the truck OEM. A majority of proactive and strategic measures were identified as beneficial, along with robust reactive measures. Furthermore, a semi-structured, qualitative interview study was conducted. In total, 12 interviews were held with employees of the truck OEM (3), experts (3), and experienced professionals within four relevant industries (7; one expert also functioning as experienced professional interview). These interviews gathered insights on obsolescence issues and how companies have acted when faced with challenges of obsolescence. In combination, the case study review served as a cumulative platform to support and triangulate the findings in the qualitative interviews, thereby strengthen the outcomes of the thesis.

This thesis has concluded concepts and insights that primarily fall within the existing, contemporary field of obsolescence management. The main contribution of the thesis is instead focusing on adding and extending the existing knowledge by synthesizing practical and empirical depth of obsolescence management from real-life situations.

6.1 Discussion

Given the intent of the thesis to put the theory of obsolescence into a practical context, it is worth noting that implementation of many measures described throughout this thesis is likely to be easier said than done in terms of execution. Implementation of fully strategic and proactive obsolescence management systems is an incredibly complex and likely costly matter, and many steps along the way will require significant amounts of time and effort devoted to them, before they begin providing value to the process of obsolescence management. For example, effective usage of machine learning and the data refinement process necessary to leverage it, is likely to require a monumental effort in and of itself in order to get it working properly.

Furthermore, there are constraints within most organizations, making implementation not just a matter of if and how, but rather of ability and resources to execute these steps. Naturally, collaboration with suppliers is a good method of mitigating obsolescence issues, but how much time and resources are the organization able to devote to such matters, while also attending to other matters. A company like the large truck OEM is likely to have thousands of different suppliers, so close collaboration with all of them is probably impossible. Additionally, there might be issues of IP rights and other classified information from either side of the dialogue.

The formulation of an obsolescence management team is a great method for spreading awareness and centralizing actions of obsolescence management, but do the firm have available personnel with the competence required to form such a team? How shall it be constructed and with which individuals? Many questions are raised. These questions are made even more difficult if there are already management issues or conflicts in place.

Looking at design, it is evident that involving the design functions in obsolescence issues is a viable strategy which will likely lead to reduced obsolescence costs. However, some of the design recommendations, such as usage of open architecture, modular designs or open source software, are probably not viable solutions for certain companies and products. This is especially true for the products that are already manufactured and sold. In other words, the choice of strategies to improve strategic and proactive obsolescence management is likely to become a choice between a few alternative options the fit the organizational context best, rather than just full implementation of every available strategy. Processes of prioritizing and deciding what strategies and actions will bring the most value is a matter best left to firms themselves, and these are likely to involve cost-benefits analysis given a number of company-specific conditions.

However, the truck OEM appears to be a company with many desirable prerequisites to develop and implement strategic and proactive obsolescence management. They have large amounts of resources at their disposal, they likely have the knowledge and expertise internally to develop a obsolescence management team and involve many different functions in the matter of obsolescence, they have strong management to lead the change and robust internal processes that can bring strategic measures into fruition. Furthermore, they already have relatively well-developed reactive and monitoring processes in place, making the transition towards more complex proactive and strategic matters more attainable.

Another discussion that has not been raised yet is which level of obsolescence measures is correct for an actor as the OEM. Given that the thesis has focused on gathering a broad set of measures that has proven successful, it does not consider if all efforts should or could be applied at the same time. Using no measures against obsolescence issues (in an industry that requires it) puts a company in a lot of risk. Using only reactive measures can mitigate this to a degree and is cost-effective in the short term. Adding on more measures would then reduce the obsolescence risks, but also require a higher upkeep (i.e. costs of obsolescence management team, costs of forecasting procedures, etc.). As such, there is a balance between adding more or less initiatives and prioritizing between different requirements.

In order to illustrate this issue, *Figure 6.1* was created by the authors. To simplify the issue, a company can in the model have low, medium and high investments of efforts into both strategic, proactive, and reactive measures. A company can thus have a medium investment in reactive measures (2), while only having few investments in strategic and proactive measures (1). The distance between the lines signifies the risk of obsolescence issues occurring and the costs of those issues (in the figure, this would mean that additional obsolescence issues slip through).

A company might then reflect on where to add additional efforts to close the gap and thereby reducing risks. Depending on their context, they might want to invest further into either strategic/proactive or reactive measures. This is an issue of analyzing the potential risks through early warnings, monitoring and forecasting. However, another alternative is that they might realize that their current balance of low proactive and reactive measures is actually the balance the company needs. Investing more might have led to an upkeep cost that exceeds its benefits. Analysis of where the suitable balance of obsolescence lies has not been carried out in this thesis, but is nonetheless important for a company to analyze and consider.

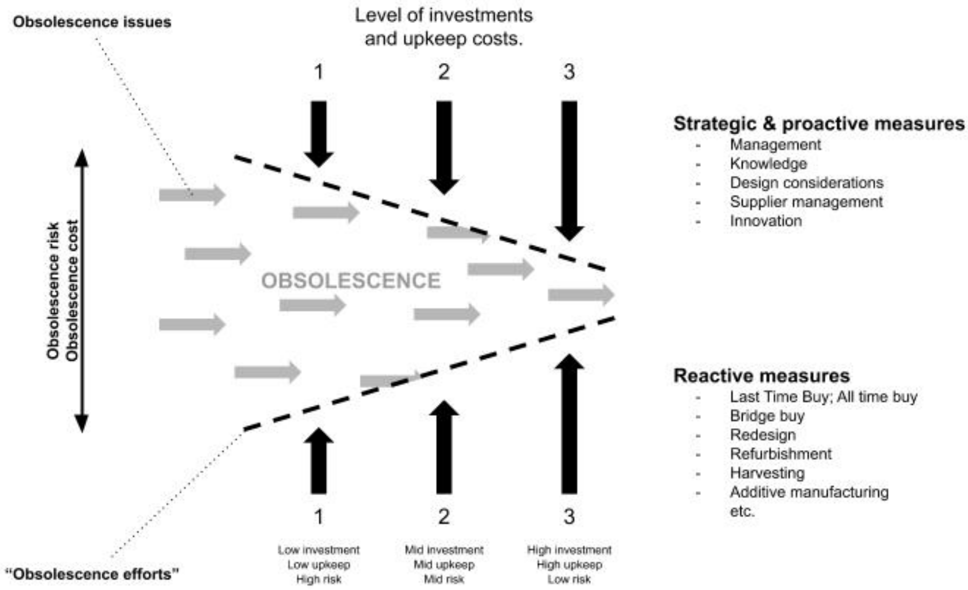

Figure 6.1 - Levels of obsolescence management efforts, developed by the authors

Finally, many of the learnings and insights gathered from this thesis are applicable in other industries as well. Primarily, the problem of obsolescence is found in industries characterized by providing sustainment-dominated systems, and as such the need to develop strategies to implement strategic and proactive obsolescence measures is probably largest in these. So, for industries like robotics, military, railway, outdoor lightning (etc.) the findings of this thesis are highly usable and relevant. The concept of practicality and limited resources naturally extend to these industries as well. In any industry, if you decide to increase the degree of your obsolescence management efforts, the related costs of upkeep and implementation will increase also. So, every actor, regardless of industry, needs to make an assessment of what strategies will bring most value to them given their internal and external circumstances.

6.2 Further research

While the results point to a broad set of potential applications of obsolescence management strategies for the truck OEM, it also raises the question of challenges with implementing the strategies. This is an expected consequence coming from the focus on finding success cases of obsolescence management. Additionally, as claimed in the research, these strategies and mitigation efforts are contextual to the specific industry and specific company. Thus, additional research into the application of the theories would be beneficial. This would generate new insights of how learnings can carry across company and industry borders. Furthermore, it can generate knowledge of how a company can incorporate such insights and how easily applied it is.

Another aspect that would be valuable to investigate further is regarding the different aspects and strategies of obsolescence management. The purpose of this thesis generated a quite broad outcome of obsolescence management efforts from different industries. However, it would be valuable to dive deep into specific trends and developments and investigate them thoroughly - what benefits, challenges and opportunities there might be. This is especially interesting regarding the more contemporary developments within the field such as additive manufacturing, machine learning analysis, business model innovation and open system architecture. Additionally, it would also be interesting to investigate the sections that were least researched - especially looking into early warning systems.

A final aspect to investigate further is related to the investigated industries. 11 industries were analyzed in the case study review and four of those in the qualitative interview study. These were chosen based on the established selection criteria and the pilot of the case study review. For the case study review, other industries might also be interesting to the truck OEM to analyze and those that were selected. As such, additional knowledge could be generated by trying to find other industries that might be relevant. For the interview study, it would have been valuable to investigate certain industries deeper (unfortunately not possible due to the situation of COVID-19 at the time of writing the thesis). As such, the additional knowledge could also be generated through conducting deeper investigations into each industry, its disruptions and mitigation efforts.

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Appendix A - Interview guides

OEM interview guide

N.B. the OEM has an internal nomenclature of obsolescence called “sunset technologies”.

A. Introduction. ● Recording ● Work and context ● Go through structure of interview
B. Role description. ● What is your role at the OEM? ● How do you come in contact with obsolescence and/or sunset issues?
C. Personal view and experience of obsolescence: ● When we talk about sunset technologies and obsolescence in the context of the OEM, what comes to mind for you? Is there a difference between the two? ● What technologies are the most likely to increase the rate of obsolescence/sunset technologies among components? What are some factors that contribute to the problem of obsolescence/sunset technologies? ● In your experience, are issues and challenges related to sunset technologies and obsolescence becoming more common? ● What do you see as risks related to obsolescence/sunset technologies?
D. OEM’s work on obsolescence and sunset technologies ● In what ways does your function work with handling obsolescence and sunset suppliers and technologies? ● Does the OEM drive enough volume to negotiate effectively with suppliers? ● Ask how they in their role within the OEM work with obsolescence/sunset tech. ● Do you have a systematic plan to manage sunset technologies? ○ What does it consist of today? How will it evolve going forward? ○ How does the detection of early warning signals fit in with this management plan, and in what ways are you working to identify early warning signals of obsolescence? ○ Can you see any gaps in your strategies that will be critical to fill in the coming future? ● What is the most common measures taken to deal with challenges regarding sunset tech? ● Is a majority of the work conducted related to sunset suppliers of the reactive nature currently? ● In reactive obsolescence management: When you get a product discontinuance notice, how do you determine what reactive action to take?
E. Contacts. Do you have any contacts you think we should interview to get a better understanding?

Expert interview guide

Section A - Introduction.
- Recording
- Work and context
- Go through structure of interview

Section B - Expert briefing.
- Could you briefly tell us about your work within the field?
- What is your view of obsolescence management?

Section C - Theory
- What is your main focus in obsolescence management?
- In our research, we have come across a number of different methods for mitigating and analyzing obsolescence. Can you tell us about them?
- Do you have any advice as to what specific strategy we should look into or consider, since there appear to be a bunch of them?
    - Are companies using these in their operations today?
    - Which ones are the most used today?
    - Does it vary by industry or are (X frameworks) implementable in all industries characterized by obsolescence?
    - Are any strategies to prefer over the others?
- What is the general way/process in which a typical company handles obsolescence issues today?
    - What should they be doing differently?
- Are there any new developments in the field? (i.e. in the light of 3D printing)
- What are some early warning indicators or signals that companies use in mitigating obsolescence management?

Section D - OEM context
- What are some of your thoughts of how a truck OEM can mitigate obsolescence issues?
- Is there anything that differentiates these companies, their business context and their obsolescence management strategies from those of other firms?
- Our main focus is to analyze obsolescence management in the trucking industry as a result of technological obsolescence caused by new technologies like electrification. Part of this research will be a benchmark of other industries that has gone through similar obsolescence challenges.
    - Do you know any good examples of industries (preferably with an aftermarket) that has gone through a disruption and obsolescence challenges?
    - Do you know any good cases of companies within those industries that we should look into?

E. Contacts. Do you have any contacts you think we should interview to get a better understanding?

Benchmark interview guide

Section A - Introduction.
- Recording
- Work and context
- Go through structure of interview

Section B - Role and experience
- What is your title and your role?
- What is your experience with technological disruption and obsolescence?

Section C - Company operations
- Can you describe your company's operations today and how they have evolved over time?
- Can you describe the current industry setting and how it has changed?
- How is the industry constructed?
    - Today? Before the disruption?
- How long is the aftermarket?

Section D - Technology shifts
- One focus that we have had in our study is industrial transformations - how would you say that the industry has been transformed through technology?
- What other technological shifts has the industry experienced would you say?
    - How did you manage these?
- How do you manage suppliers if they are at risk of being obsolete?
- How has your business been affected by disruptions over the past years?
    - Did you have any strategies for the transition?
    - Where there any (early) warning signals for the transition?
- Any technologies that you see will affect the industry going forward?
    - (If yes) How will you manage these?

E. Contacts. Do you have any contacts you think we should interview to get a better understanding?

Appendix B - Coding example

In order to provide a picture of how the interviews were coded, the following is the coding of the lighting industry interviews with Jan Börjesson and Frida Alexandersson.

Theme	Quotes
Situation	“Our fittings can have a lifetime of up to 50 years” (Alexandersson) “It was important to early on realize the potential of LED lighting” (Alexandersson) “In 2015 there was a new EU directive that banned quicksilver” (Alexandersson) “Looking back 10 years, there was an incredible change when transitioning to LED technologies from conventional lighting sources” (Börjesson) “Now the technology [LED] is in its maturing phase and we do not see many areas where LED can be further improved” (Börjesson) “[The value chain] has few actors and short lead times from start to finish” (Börjesson) “An ordinary outdoor lighting fitting has a lifetime of about 25 years” (Börjesson) “The LED technology has existed for a long time - in computer screens and such” (Börjesson) “We have had significant price erosion on LED the last couple of years” (Börjesson)
Challenges	“When I started working at the company, we had over 1000 articles and no manuals of how they were produced. There were no shelf labeling and it was very ineffective” (Alexandersson) “We had a hard time with getting everyone onboard” (Alexandersson) “We haven’t been able to compete with Chinese production” (Alexandersson) “One of the larger challenges was to construct product with a good enough dispersion of heat” (Börjesson) “We did not have dialogue with our old suppliers, but analyzed the market to find the best suppliers for our needs” (Börjesson) “I guess it is commonly known that Chinese suppliers are good at copying and offering a low price, which poses challenges to our local suppliers” (Börjesson) “For the end customer, a bankrupt supplier will result in large challenges, as in difficulties of finding spare parts” (Börjesson) “It is electronics we are talking about and electronics can always break” (Börjesson)

Solutions	"We started by looking at sales - which was most important. We restructured our sales channels to get larger batches and discontinued many articles" (Alexandersson) "Those who ran it before were all very talented - they had worked there all their lives - and we needed their knowledge" (Alexandersson) "We got a NPC system to gather and systemize all data" (Alexandersson) "We chose to see the potential of new business opportunities with the new EU directives" (Alexandersson) "We had to have our ear close to the ground and monitor changes in the industry" (Alexandersson) "It was important to get the suppliers on board, especially when changing production" (Alexandersson) "There are many new suppliers (mainly from China) that did not exist before LED technology" (Börjesson) "We always want to find at least two suppliers (Börjesson) "We took our existing fittings and modified them to have LED technology instead. It turned out OK, but not great. In parallel, we developed new products, totally dedicated to LED technology, but they took a while before reaching the market" (Börjesson) "We heard well beforehand that an EU legislation was coming and we had started to design the new products already" (Börjesson) "Since we are not providing service, we could leave the aftermarket alone" (Börjesson) "Don't put all eggs in one basket" (Börjesson)