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Anastasia Lisitsyn
Pricing of maintenance service contracts: case VR FleetCare Ltd.

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1st Examiner: Mikael Collan
2nd Examiner: Mariia Kozlova

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Viime vuosina junaoperaattorit ovat ulkoistaneet sisäistä kunnossapitoa ulkoisille palveluntarjoajille. Tämä tutkimus käsittelee kunnossapitosopimusten hinnoittelua ja niiden mallintamista raideliikenteessä. Tapaustutkimus keskittyy junatelien kunnossapitosopimukseen ja käytetty aineisto koostuu teleihin kohdistuvista huoltotyötapahtumista aikaväliltä 1.1.2015-31.7.2019. Tässä tutkimuksessa tutkitaan kunnossapitopalveluihin, niiden sopimuksiin ja hinnoittelumalleihin liittyvää kirjallisuutta. Työssä käytetään kvantitatiivisia tutkimusmenetelmiä ja kirjallisuuskatsauksen pohjalta sekä kohdeyrityksen rajoitusten pohjalta muodostetaan hinnoittelumalli. Sopimuksen hinnoittelu muodostetaan Monte Carlo-simulaatiolla.

Tässä tutkimuksessa ennakoivan- ja korjaavan huoltotöiden kustannuksissa sekä sakon estimoinnissa hyödynnetään simulaatiota, kun taas muut muuttujat tulevat annettuina. Tulokset osoittavat, että optimointi malli ja simulaatio edistävät päätöksentekoa mahdollistamalla sopimuksen kustannusten, niiden luottamusvälien, sekä määritellyn marginaalin kannattavuuden mallintamisen ja kuvaamisen. Kannattavuuden riskiarvio osoittaa, että sopimuksen vähimmäispituus tulee olla puoli vuotta ja simulaatio kierrosten oltava 10 000 tai yli, minimoidakseen epävarmuutta.

Abstract

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Over the past years, train operators have been outsourcing their in-house maintenance services to external service providers. This thesis explores pricing of maintenance service contracts and how it can be modelled in rolling stock setting. Case study focuses on train bogie's maintenance service contract and data used in this study consist of maintenance service events between January 2015 to July 2019. In this study, literature related to maintenance services, their contracts, and pricing models are investigated. Quantitative methodologies are used in this thesis and based on literature review as well as case company limitations pricing model is constructed. Results for contract pricing are then obtained from the Monte Carlo-simulation.

In this study, preventive and corrective maintenance costs as well as penalties are generated using simulation, while other are defined by the case company. Results of this thesis show that optimization model and simulation contribute to decision making by enabling modeling and illustration of contract costs, their confidence levels as well as profitability of given margin. Risk assessment of risk of loss shows that minimum length for the contract is half year, while simulation rounds need to be 10 000 or over to minimize uncertainty.

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I started my journey at LUT University in 2014 and now with this thesis it has come to an end. The time has gone by swiftly and I’m grateful for all the memories made along the way. Finally, I wish to especially thank my family and friends for all the support during this project and my studies.

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Anastasia Lisitsyn

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1. INTRODUCTION

1.1 Research background

Downtime in operations caused by malfunctional equipment can have serious negative effect on a business performance of the company (Murthy & Asgharizadeh 1999). Economic analyses show that investing in development of maintenance services to prevent downtime in operations have proven to be profitable in rolling stock setting (Schlake et al. 2014). Other trend dominating maintenance services over the past years, is the outsourcing of the maintenance service to an external party in form of a contract rather than maintaining services within house which has grown substantially (Murthy & Asgharizadeh 1999; Jackson & Pascual 2008). Many incentives drive this forward as maintaining inhouse services can become uneconomical for the owner or the user of the equipment as it often requires specialized equipment and personnel (Jackson & Pascual 2008). Even though in 2010 70 % of the total market in rolling stock were still maintained in-house, outsourcing is a trend slowly followed in train operations. Rolling stock companies have gradually decided to focus more on their core competence of operating passengers and goods, and leave the maintenance to original manufacturer or third party. Countries have differences on how the maintenance of rolling stock is organized, varying from state owned subsidiaries to private firms. In Europe however, the direction is towards open market with privatization of train operations. Since the companies lack in maintenance capabilities, they seek those services from outside which causes market to open to new service providers. Many countries in Europe such as Sweden and the United Kingdom already have third parties in the aftermarket and major manufacturers such as Alstom and Bombardier Transport. Companies are also separating their maintenance services into their own functions giving them independency. (Wolf 2010)

Current literature identifies several approaches to in-house maintenance actions such as reliability centered maintenance and models that have been developed to optimize in-house maintenance strategies (Murthy & Asgharizadeh 1999). But as outsourcing in-house maintenance is becoming increasingly popular, new maintenance service contracts are being made to ensure continuity of the operations, redirecting demand of the research field. Also, centralizing maintenance service to one provider enables the service provider to present broader repertoire of maintenance services leaving the service provider and customer with optimization-problem under the terms of a contract (Murthy & Asgharizadeh 1999; Jackson & Pascual 2008). This has created freedom of choice and a new demand for research on how to price and possibly optimize content of this outsourced maintenance and its contract. When the content of the agreement is known, service provider is left with the task of assessing the profitable price based on the known maintenance and repair requirements (Bowman & Schmee 2001). Research on the maintenance service contracts can be roughly divided into maintenance service contract optimization and its sub-category pricing of the maintenance service contract. But as literature on pricing of the maintenance service contract often overlaps or is integrated in optimization of the maintenance service contracts, it is difficult to make clear division between them, thus making it an interesting research topic.

Pricing models are usually applied on expensive or complex equipment which are more profitable to maintain than replace (e.g. Bowman & Shmee 2001; Guang-ping et al. 2006; Wang 2010; Kong et al. 2019). Target of the application can be a component that is part of larger unit such as aircraft engines which are independent subsystems on their own (e.g. Bowman & Shmee 2001). Other applications can be larger devices in a set of these devices, for example wind turbine in a wind farm (e.g. Kong et al. 2019). Additionally, application objects include industrial equipment (e.g. Wang 2010), for example forklifts (e.g. Huber & Spinler 2014) and manufacturing equipment (e.g. Guang-ping et al. 2006). Overall, as the target of applications show, maintenance service contracts are mostly used between two companies in B2B-market.

Studies that use models in pricing of the maintenance service contracts have different angels depending on what parties are involved. In contract optimization, approach changes depending from who’s perspective the maximization of value or profit is done. In few cases, it is limited to two parties: one unique service provider and one customer (e.g. Bowman & Shmee 2001; Wang 2010). On the other side, some use scenario with one service provider and multiple customers to service by adding option for additional service channels (e.g. Murthy & Asgharizadeh 1999; Jackson & Pascual 2008; Kong et al. 2019). Literature has several various definitions for the parties involved. Often, the party that provides maintenance services is referred as the agent (Murthy & Asgharizadeh 1999; Jackson & Pascual 2008), maintenance service organization (Bowman & Shmee 2001), service provider (Huber & Spinler 2012), service supplier (Guang-ping et al. 2006), or combination or variation of these (Wang 2010; Kong et al. 2019). The receiver of the service, in other words customer, can be the owner of the equipment (Murthy & Asgharizadeh 1999; Jackson & Pascual 2008; Huber & Spinler 2014) or an unspecified party (Wang 2010; Bowman & Shmee 2001; Huber & Spinler 2012). Similar to parties, there are also variation in describing the contracts. While other use term full service contract for contracts where a fixed payment is payed, and maintenance actions are made without additional costs (Huber & Spinler 2012; Huber & Spinler 2014), other describes it as fixed priced (Murthy & Asgharizadeh 1999) or constant fee-based contract (Jackson & Pascual 2008). As seen, the terminology is not most coherent in the literature and may change depending on the research. Therefore, to clarify the terminology, in this study the following definitions are: service provider for the provider of the service, customer for the equipment owner or user and full-service contract for fixed priced contracts (see page 13).

Even though pricing affects substantially the financial performance of the company, it is still not well researched and the studies are often trampled by beliefs that pricing is zero-sum game with customer, or that it is given by the industry (Hinterhuber 2003). Therefore, this makes maintenance service contract pricing an interesting subject as it combines both pricing and numerical methods in maintenance contract setting. Although there have been different numerical examples in applications and a few real-life cases of maintenance service contract pricing, such as the contract simulation for airline engines, there are not many cases that are applied to the rolling stock or its components. According to Borndörfer et al. (2018), numerical models have not gained popularity in railway industry due to various reasons: they list that for example the monopolistic structures, and problems taking the theory into practice are obstacles that are clearly slowing down the process. Nevertheless, they name the algorithms as a main problem. Algorithms are not able to capture the complexity and vastness that is typical in rolling stock setting. This however is slowly changing, as number of mathematical models have been applied to real life cases, for example network design, timetabling and train routing (Borndörfer et al. 2018). In this study, the objective is to contribute to this field by pricing the train component's maintenance service contract that is used for outsourcing maintenance services from customer to service provider using mathematical simulation model.

1.2 Research problem, objectives, and focus

The main objective of this thesis is to study what kind of maintenance service contracts are used in the field of B2B-operation where maintenance is outsourced to an external service provider, such as original equipment manufacturer or third party. Specifically, how these contracts can be introduced to equipment and component maintenance and how to price the maintenance service contract from service provider's perspective. The objective is to provide the case company with a budgeting tool and pricing mechanism for service the price of which is often difficult to model due to its high complexity.

This study aims to add to the research field of maintenance service contracts and especially in understanding what models are practiced in pricing and its optimization, what variables are incorporated into the models, and to give practical implication through the case analysis. The chosen industry is the rail transport and bogies used in rolling stock in Finnish context. As the outsourcing trend of maintenance services in rolling stock is fairly new and real-life applications scarce, the study aims to give understanding of its characteristics and implementation possibilities. Overall, the goal is to gain better understanding on the contract pricing methods and its application to rolling stock maintenance.

To understand how to find pricing for bogie's maintenance service contract, following research question is formed:

How to price maintenance service contract from service provider's perspective?

The main research question is supported by following sub-questions:

What is said about maintenance service and its contracts in previous studies?

How maintenance service contracts pricing has been modeled?

By answering these questions, the thesis aims to provide pricing method that can be used for budgeting bogies, financial risk management, and for their maintenance contract design. The focus of the study is presented in figure 1.

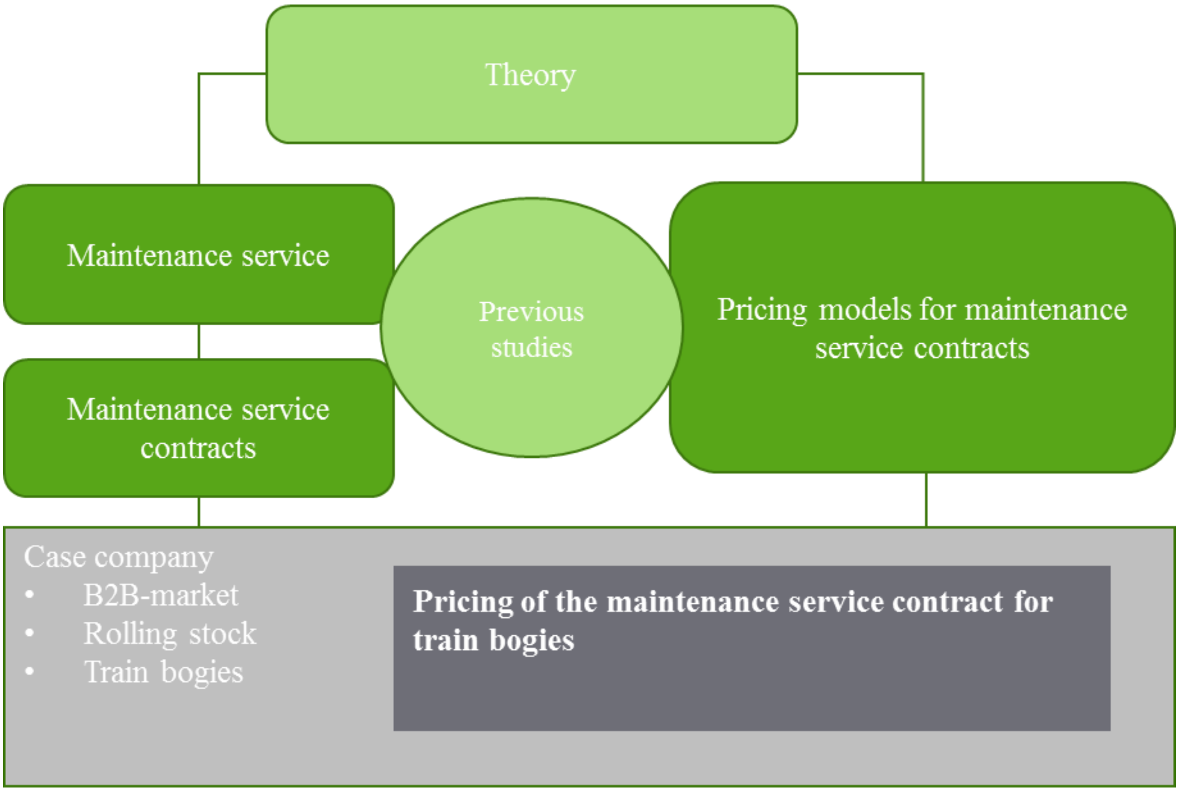


Figure 1. Theoretical framework

Goal is to find pricing model for train bogie's maintenance service contract by researching maintenance services, its contracts and mathematical models used in the literature and previous studies. There are also limitations in the application of the model such as geographical location, market and industry.

1.3 *Research methodology*

This thesis uses quantitative research approach in finding pricing method for maintenance service contract for bogies. Quantitative research method is used to answer following questions: What? Where? How much? How often? (Heikkilä 1998, 16). In this case, the objective of this study can be formed followingly: What is the right price for the maintenance service contract? As the main goal of this study is to form numerical model for pricing, variables incorporated in the model need to be defined and estimated to obtain right price for the contract. Valli (2001, 9) states that statistical research method is a number exploiting methodology and a tool in providing better analysis, understanding and presentation of statistics, thus fitting well the purpose of this study. All in all, computers have enabled many new applications of statistical methods that require calculating efficiency. One of the applications is statistical computing where quantitative statistical data processing, in other words simulation, produces artificial observations. (Heikkilä 1993, 8) Through this method more precise estimates of variables are obtained and utilized in the pricing of the contract.

Research methodology used in this study follows basic quantitative research process, where the first step consists of defining research question. In following step, a research plan is drawn. Research plan specifies the objective of the study as well as methodology used, in addition to delimitations that limit the research subject. After preparation, the next steps are to collect, handle, and analyze the research data. Results and conclusion are then drawn based on the analysis. Finally, the results obtained are utilized. (Heikkilä 1998, 24) Following this methodology scientific conclusion along with practical decision and implications can be made based on the results obtained (Heikkilä 1993, 2). Using statistical methodology, the goal is to acquire valid pricing model for bogie’s maintenance service contract.

Research data is obtained mainly through company’s data warehouse and ERP system. Data used in the study is secondary data, meaning that it is originally produced for other purposes (Heikkilä 1998, 16). Here, the research data is generated in everyday operations when actions are entered into the ERP system.

In quantitative research, collected research data is often altered before usage (Heikkilä 1998, 32-33), which is also the case in this study. Human errors appearing in the data are filtered from the data to give more realistic picture. Research is conducted through sample survey, where the data sampled is representative sample of the whole population (Heikkilä 1998, 33). Main function on sampling is to gather data that is able to represent the whole population and to give scale model of the overall view (Heikkilä 1998, 32-33; Valli 2001, 13). To acquire sample that depicts the present best, only newer (1.1.2015-31.7.2019) data is used in the research. However, it is good to know that technological solutions might also limit the sampling size.

1.4 *Key definitions and structure of this thesis*

Some important concepts need to be defined and cleared to ensure consistency through this thesis. As terminology varies in the literature, following definitions are provided for easier reading.

Maintenance service = maintenance actions that include preventive and corrective actions.

Preventive maintenance = planned maintenance services that are based on maintenance program. In this study, it includes bogies overhaul maintenance as well as work related to it.

Corrective maintenance = unplanned maintenance services such as breakages of the components and all other unscheduled actions. In this thesis, all maintenance actions that are excluded from preventive maintenance.

Maintenance service contract = contract where maintenance actions are outsourced from the customer to external service provider.

Service provider = an external maintenance service provider who provides maintenance actions for agreed fee. In this case, service provider is a maintenance company specialized in fleet care and a subsidiary of the customer.

Customer = owner and user of the equipment and party that purchases maintenance services from service provider. In this study, customer is the group company.

Full service contract = a contract where fixed price is paid for all maintenance services over agreed period of time.

Risk of loss = Probability that there will be loss with given maintenance service contract price. In this thesis, probability is calculated based on how many times (percentage) simulated overall costs are over set contract price.

The structure of this thesis is presented in figure 2. Thesis starts with introduction and ends with discussion and conclusions.

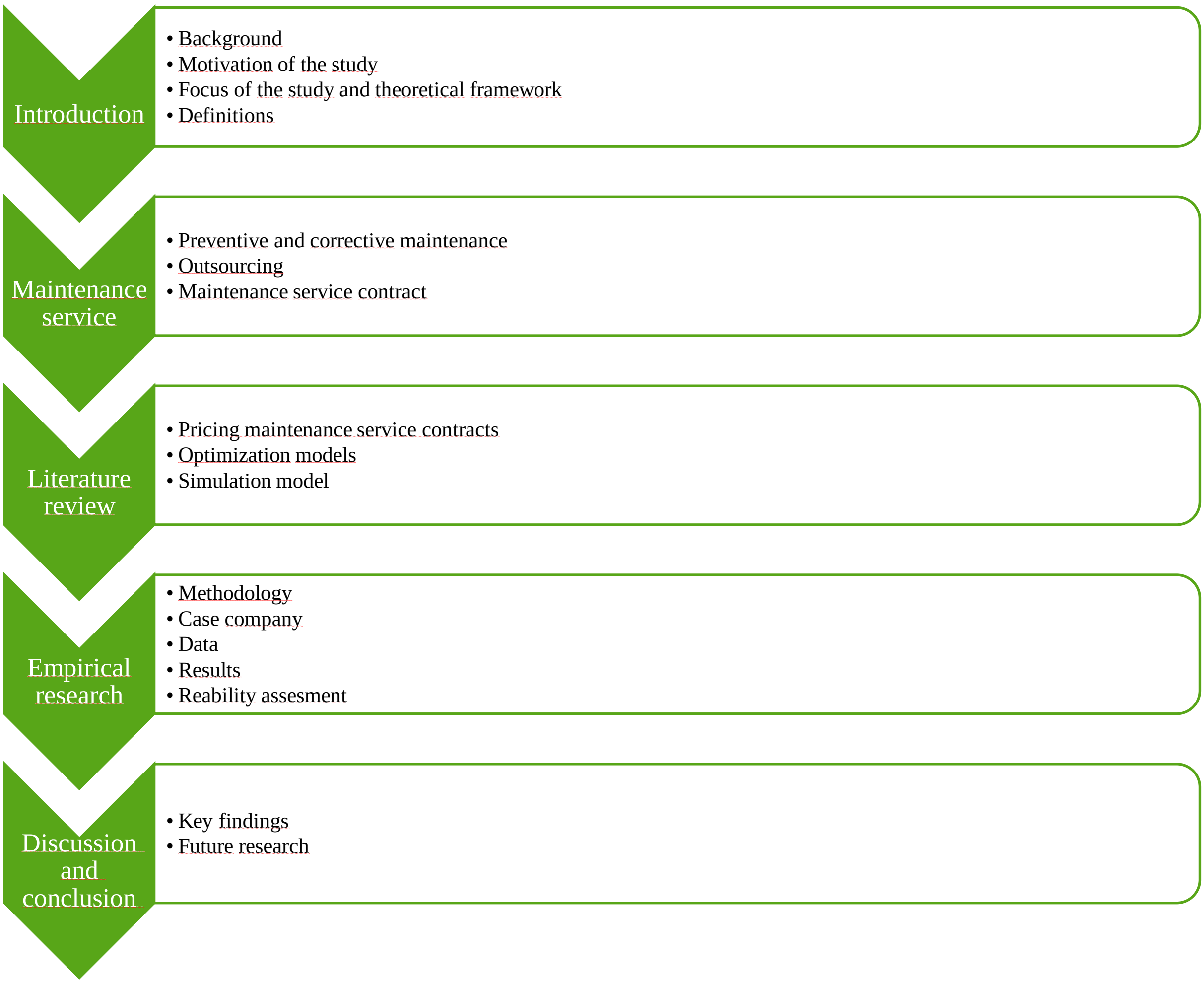


Figure 2. Structure of the thesis

The first chapter consists of background and motivation of the study. It also presents the focus and limitations that shape the main research question and its supporting questions. Key definitions for main concepts are also introduced and structure of this thesis is presented.

In second chapter, there is a dive into maintenance service and its related aspects. The main focus is defining maintenance actions and future trends of the maintenance service. Motivation behind outsourcing maintenance services and risks associated with it are also presented. This chapter also takes a closer look at contract aspect of the maintenance services and its characteristics, such as contract shaping terms and conditions. Pricing strategies of the contracts are also discussed.

Third chapter, the literature review, presents the most common models that the literature has identified and that are used in pricing of maintenance service contract. Here, optimization models and simulation are taken for closer examination. Chapter describes what approaches have been used in the past, how they have evolved over time, and what are the differences between them. Relevant models and methods are then presented more broadly, and their assumptions, variables, and restrictions are discussed more precisely.

Fourth and fifth chapter cover the empirical part of this thesis. In fourth chapter, methodology of the research is explained, while fifth chapter takes a closer look at case. Case company and subject of the study, bogies, are taken for closer inspection and analysis on the market as well as future trends are presented. Fifth chapter also details data that is obtained and presents values derived from estimation. After further analysis, the results are discussed and the pricing of the bogie’s maintenance service contracts is introduced. Then, the reliability evaluation is conducted to ensure feasibility and application possibility as well as limitations caused by the data constrains.

In chapter six, the conclusions are discussed based on the previous chapters, and research questions of this thesis are answered. To conclude the study, the main findings are reviewed and analyzed. In addition, future research questions based on the subject of study are discussed and proposed.

2. MAINTENANCE SERVICE

As stated by Kumar et al. (2014) the arising need to do maintenance work usually stems from the need “*--to overcome product weaknesses impossible to design out because of design constrains--*”. As these weaknesses can cause unreliability and failure of the equipment, maintenance services are used as an answer in maintaining the condition and restoring the broken (Murthy & Asgharizadeh 1999). There are many studies to find optimal maintenance strategies that aim to balances maintenance actions together with other factors related to maintenance services, such as Zanjani & Nourelfath’s (2014) study on spare part logistics and operations planning and Cheng & Tsao’s (2010) that focuses on balancing maintenance service ratios, intervals and stock in rolling stock maintenance. As Schlake et al. (2014) show in their study on economic impact of maintenance strategy, it is possible to acquire substantial savings with fine-tuning the maintenance strategy so that the operational waste, failures, and overall fumbling can be avoided.

In general, maintenance services can be divided into two categories: preventive and corrective maintenance (Kumar et al. 2014), categorization also used in maintenance of rolling stock (Cheng & Tsao 2010). According to Kumar et al. (2004) planned, namely, preventive maintenance includes actions such as planned repairs, replacements, lubrication, system monitoring etc. In other words, all activities that aim to avoid unexpected failures or stoppages and to improve performance. They also add planned schedule as a characteristic to preventive maintenance. Preventive maintenance is usually the main maintenance cost in rolling stock environment. Preventive maintenance can help to reduce the need for corrective maintenance as risk for failure of the equipment is minimized. (Cheng & Tsao 2010) In addition, it makes spare part inventory more manageable due to better predictability and possible decreases in downtime and costs related to replacements. Condition-based maintenance is one type of preventive maintenance, where condition dictates if the equipment is maintained. Equipment is inspected or monitored, and based on the weariness or the state of deterioration, it is either maintained or left without treatment. In addition to condition-based maintenance, preventive maintenance can be based on time, where fixed interval are set and as the equipment reaches the right time, maintenance is carried out.

Usage- and age-based preventive maintenance bases its maintenance need on usage of the equipment or the age of the equipment. When equipment reaches a certain milestone, for example certain amount of kilometers, hours, or years, it is taken in for upkeeping. In design-based maintenance, modification is applied through redesign, enhancing the reliability of the equipment. Opportunistic type of maintenance can be applied if the equipment has spare parts that can themselves be maintained separately. Whether the equipment or spare part is taken for preventive or corrective maintenance, the other equipment or spare part can also be maintained at the same time. (Rahman & Chattopadhyay 2015) Unlike preventive maintenance, unplanned, corrective maintenance is a result of unpredictable failure. When it occurs, all participants involved strive to resolve the issue at minimum cost and loss of profit. (Kumar et al. 2004) Generally, corrective maintenance includes replacing or refurbishing of broken spare part that caused the failure of the main equipment (Rahman & Chattopadhyay 2015). Cheng & Tsao (2010) stress that balancing preventive and corrective maintenance is important in rolling stock maintenance where safety risk and comfort of travel is weighted against the costs. In addition, according to them, safety can be not the interest only for passengers and owners or the users of equipment, but also for safety officials.

There are supplementary maintenance services that are offered by service providers compared to the traditional maintenance actions, such as lubrication or filter changes. Maintenance service provider might include work that supports upholding equipment creating additional value for both parties. One example is maintenance program, where service provider assists customer with designing optimal maintenance strategy for the equipment. This can include preferred equipment specifications and assisting customer with installations and renewals as well as refining maintenance schedule. (Kumar et al. 2004) Overall, prolonging equipment's life cycle and bettering the operational condition. Kumar et al. (2004) also list that service provider might offer analysis and diagnostics on the equipment and its usage. They also add complementary services to the list such as help desk assistance through online or phone along with field work, logistics support, and disposing of the product at the end of its life cycle.

Maintenance services can vary in scope depending on how comprehensive the repair policy is. Barlow & Hunter (1960) study two different maintenance policies: one where component is repaired to be “as good as new” and other with minimal repair done and the failure intensity remains the same. Rahman (2014) extends their thinking by broadening policies into four categories based on restorability. First policy is replacement, where the at failure the component is replaced by new or identical one in terms of condition. The second policy, overhauling or perfect repair on the other hand, leans on restoring rather than replacing, returning the equipment into nearly original condition. Both policies strive towards minimizing failure intensity close to zero or zero. (Rahman 2014) Other two policies settle for little or no change in failure intensity. According to Rahman (2014) imperfect repair-policy lies between “as good as new” and minimal repair, while minimal repair is a policy where only the broken components are refurbished leaving other spare parts untouched.

Outsourcing maintenance services where equipment is expensive or complex and requires substantial financial or human resource investment can release capital to other operations (Jackson & Pascual 2008). In some situations, the owner or user of the equipment is simply unable to maintain needed scale of operations to be economical or assure that safety and environmental legislation is up to date, and personnel is well trained (Wang 2010). This is more often in situations where manufacturers are scarce such as in defense industry related products (Wang 2010) or with advanced technical systems where availability is important, yet local maintenance is impossible (Zanjani & Nourelfath 2014). Outsourcing maintenance services also reduces financial risk originating from volatile costs if contract is fix priced (Jackson & Pascual 2008) and adds financial flexibility if different contract types are available (Wang 2010). Concentrating maintenance services to service provider can also have beneficial results as they can more easily access high level specialist and upgrade their technological capabilities adapting to fast market changes (Jackson & Pascual 2008; Wang 2010). However, there are also possible disadvantages to outsourcing that needs to be considered. For example, if price of the contract steeps too high, the cost of outsourcing itself can become an impediment when contracting maintenance service out (Jackson & Pascual 2008).

Furthermore, not maintaining own personnel for the maintenance services can result in situation where the customer does not have needed knowledge to make rational decisions. In addition, one noticeable drawback is dependency on the service provider, which further weakens customers' negotiation power. (Jackson & Pascual 2008; Wang 2010) Besides, provider-customer -set up and power struggle, in rolling stock maintenance, there are valid concerns on ensuring safety of outsourcing maintenance, lessening the readiness of train operators to contract out (Wolf 2010). There are different ways to concretize outsourcing of maintenance actions with one of them being maintenance service contract that is formed between customer and service provider (Wang 2010). And despite the downsides, outsourcing is a growing trend in this industry.

2.1 Maintenance service contract

Maintenance service contracts are billion dollars annual business (Rahman & Chattopadhyay 2015) and have received more attention in past 20 years due to outsourcing trend of maintenance actions (Rahman 2014). While customers see outsourcing as a possibility for cost savings and efficient management, increased profits and decreased risk due to specialization, attract service providers to the market (Rahman & Chattopadhyay 2015). Rahman & Chattopadhyay (2015) state that maintenance contract "*is the outsourcing of maintenance actions where defect/failures are rectified by an external agent (service provider) for an agreed period of time*". Kumar et al. (2004) add that maintenance service contract is drawn when negotiation between service provider and customer reach point that there is mutual understanding on what service, when and how the service is delivered as well as overall satisfaction on both sides.

2.1.1 Terms & conditions

In maintenance service context, factors such as number of components, type, and usage typically impact the terms and conditions of maintenance service contract (Bowman & Schmee 2001). In rail industry for example, failing component is a safety risk in addition to financial loss (Rahman 2014). Therefore, it is important for contract to incorporate both preventive and corrective maintenance. Defining terms and conditions clearly is an important preventive action in avoiding disputes and legal issues between parties of the contract. If those are not defined clearly and consensus is not achieved, financial ramifications can follow affecting both parties. (Lai et al. 2004) According to Lai et al.'s (2004) study on building maintenance service contracts, service provider and customer benefit from defining loose terms such as "*wear and tear*" and "*vandalism*" that are often under interpretation.

Factors that alter terms and conditions contribute to the overall costs of the contract and through that, pricing as well (Bowman & Schmee 2001). Pricing is also affected by the payment method of the contract that is usually disclosed in terms and conditions. Maintenance service contracts can be either full service contracts or price for repair. In full service contract, service provider is expected to maintain and repair the component or equipment for an annual or other time-based fee (Huber & Spinler 2014). This type of contract is a rising trend that is applied in leasing (Huber & Spinler 2014) and airline maintenance (Bowman & Schmee 2001). For example, in Bowman & Schmee (2001) study, aircraft engines that are under "availability"-agreement where in long time contracts annual payments are made for the service promise of available engines. In this kind of a setting, operational risk is either fully or partially transferred from customer to service provider. Price for repair on the other hand, exposes customer to potentially highly volatile costs that arise when maintenance is needed. Deciding between price for repair and full service contract can based on customer's ability to foresee and financially handle risk associated with costs. Smaller companies can benefit from full service contracts as they might not have financial reserves to handle surprising one-time cost. (Huber & Spinler 2014)

2.1.2 Pricing strategies

Pricing typically has significant impact on the financial result of the company, yet it is still often neglected tool on improving operating profits despite its effectiveness (Hinterhuber 2003). Hinterhuber (2003) and West et al. (2016) both argue that pricing strategies should be based on value rather than costs or competition. In service logic, the value created depends not only on the service provided but also on factors surrounding it, such as how well the supplier stays on time, what is the quality of handling and additional services. The value stems from the whole spectrum of supplier-customer relationship rather than only the core product. (Grönroos 2011) This also applies to value creation in maintenance service context. According to West et al.'s (2006) study however, this is not the most popular pricing strategy amongst maintenance service companies and mostly other, more cost or market related pricing objectives, strategies and methods are in use.

Pricing objective directs what pricing strategy will be used to support company's overall strategy. Depending on company strategy, for example market penetration or growth, pricing objectives are changed to match with the pricing strategy that is exercised. There can also be various pricing objectives within one company depending on the product or geographical location of the company. (Hinterhuber 2003) In West et al.'s (2016) research, most popular pricing objectives strongly lean on cost plus -practices as many pricing objectives set by maintenance service providers are financially related. This suggests that companies are more supplier- rather than customer-oriented (West et al. 2016). West et al. (2016) introduce pricing tools as a way to support objectives and strategy of pricing. In their study, all maintenance service companies applied the following tools: market benchmarking, cost build up and bundling. In market benchmarking, company draws comparison with competition and its pricing. Whereas, cost build up is a natural tool where most of the pricing objectives are finance based. Bundling of goods and services can also work as another price and negotiation tool. (West et al. 2016)

In West et al. (2016) research market-based pricing strategy is one of the most popular pricing strategies among the companies. Market-based strategy is found to be used as control mechanism to ensure that the price is close to competition. Cost plus -strategy is the least risky strategy to the service provider as the pricing is closely related to the inputs adding the margin on the cost, eliminating probability of losses. Depending on the company's financial strategies, cost can include only components, such as labor and spare parts or costs of the capital as well. Payment for performance and willingness to pay are also used as a pricing strategy in maintenance world and enjoy popularity amongst the companies in the research. (West et al. 2016) According to West et al. (2016), combining the two provides alignment with customer value creation compared to adding margin to the costs and should therefore be preferred approach in building pricing strategy.

3. LITERATURE REVIEW

A broad part of literature on maintenance service contracting takes qualitative approach to the problem (Jackson & Pascual 2008), such as creating framework (e.g. Kumar et al. 2004) or conducting a survey (e.g. West et al. 2016), yet the number of mathematical models is small (Jackson & Pascual 2008). However, there are a few quantitative models that have been developed over the last two decades. One approach is to create optimal maintenance strategy by drawing optimal decisions using game theoretic formulation where either service provider or customer can be a leader or a follower (e.g. Murthy & Asgharizadeh 1999; Kong et al. 2019), other is by using non-cooperative game formulation to bargain (e.g. Jackson & Pascual 2008) or alternatively use hybrid game process (e.g. Guang-ping et al. 2006). The noticeable trend among these models is the use of game theoretic formulation to bargain and it continues to be favored approach in maintenance service contract negotiation and optimization. Key literature on pricing of maintenance service contracts is presented in table 1.

Table 1. Key literature on maintenance service contract pricing

Author	Year	Title	Keywords	Method	Setting	Aim of the study	Main points and findings	Published
Murthy & Asgharizadeh	1999	Optimal decision making in a maintenance service operation	Maintenance, Service contract, Game theory, Optimal pricing	Model and Stackelberg game theoretical formulation	Monopolistic service provider. Contract type: fixed price contract and payment for repair.	To develop model where optimal strategy with variables such as pricing strategy, number of customers to service and number of service channels is determined.	There are many assumptions that needed to be made in order to use the model. Two assumptions are: steady state distribution and mean time is very small in relation to mean time to failure. Also, assumption of failure and repair times are exponentially being distributed is made in order to use Markov queues to require analytical results. Model also uses assumption that there is perfect information between service agent and customer as well as assumption of homogenous customer base.	European Journal of Operational Research
Bowman & Schmee	2001	Pricing and Managing a Maintenance Contract for a Fleet of Aircraft Engines	Aircraft maintenance, Risk management, MSO, Contracts, Aircraft engines	Simulation model	Large corporation as a service provider. Contract type: full service contract.	To develop model to price aircraft engine service contract based on failure and cost data.	Simulation model is discovered to be effective in addressing the financial risk of long-term maintenance and repair contract using statistical failure and cost models. It also allows to explore operational issues and sensitivity and what are their effects on cost and financial risk.	SIMULATION : SAGE Journals
Guang-ping et al.	2006	Study on Pricing of a Sort of Maintenance-Service Contract Based on Adjustment of Quantity and Cost	Service Value, Maintenance-Service Contract, Pricing, Adjustment of Quantity and Cost, Hybrid Game	Model and two-stage hybrid game formulation	Service supplier and manufacture. Contract type: full service contract.	To determine price structure for maintenance service using multiple pricing adjustments such as quantity, adjustment of manufacture, cost adjustment of supplier and comprehensive adjustment.	The service value created by agents together should be divided between agents. Cooperation is best for value creation and distribution and ensures economic profit for both sides. In first non-cooperation stage the service supplier chooses whether to provide service and manufacture. In second stage of cooperation agents captures value correlative to its bargaining power and service price is attained. Observation variable Actual Cost is introduced allowing making adjustments to bargaining competence of service supplier in next stages.	International Conference on Service Systems and Service Management
Jackson & Pascual	2008	Optimal maintenance service contract negotiation with aging equipment	Game theory, Maintenance, Optimization, Reliability, Stochastic processes	Model and Nash game formulation	Monopolistic service provider. Contract type: fixed price contract.	To develop model where optimal maintenance strategy and pricing of the service contract is determined.	There are many assumptions that needed to be made in order to use the model: all clients have same aversion to the risk, failed equipment is repaired in first come - first repair order, lifecycle for units is sufficiently large and the number of customers in manageable so no infinite queue is born. To characterize aging equipment, failure is described to be linear with time. First, both parties determined optimal strategy (number of preventive maintenance actions and life-cycle of the unit). Secondly, the service provider selects optimal number of customers. There are also limitations for the model to be applicable: longevity of life-cycle, time of overhaul needs to be short and no leader-follower positions.	European Journal of Operational Research
Wang	2010	A model for maintenance service contract design, negotiation and optimization	Maintenance, Service contract, Repair, Inspection, Reliability, Delay time	Model	Monopolistic service provider and customer. Contract type: all repairs and inspections, failure based repairs, and inspections and repairs identified.	To develop a model to design, negotiate and optimize maintenance service contract.	There are many assumptions that needed to made in order to use the model such as repairs are minimal, homogenous Poisson process for arrival of defects and inspections interval are constant and perfect. Also, model uses new variable delay time in the formulation of inspection models to evaluate different contract options. Model can be used for budgeting purposes.	European Journal of Operational Research
Huber & Spinler	2012	Pricing of full-service repair contracts	Service contracts, Contract pricing, Risk management, Mean–variance customer utility	Model	Mechanical machinery service provider. Contract type: full service contract.	To develop a model for technical investment products in presence of risk-averse customers.	Service contract prices are strongly driven by the variance of the repair cost as expected by the customer. Also, distribution of risk aversion is a significant decision making parameter for the service provider. It is found important for customer to know the true magnitude of cost variance or they often underestimate it, reducing profitability of service provider.	European Journal of Operational Research
Huber & Spinler	2014	Pricing of Full-Service Repair Contracts with Learning, Optimized Maintenance, and Information Asymmetry	Full-Service Contracts, Maintenance, Pricing, Repair Learning, and Risk Aversion	Model	Manufacturer of forklifts as a service provider. Contract type: full service contract.	To find optimal pricing by taking various variables into consideration (learning effect, asymmetrical information etc.)	There are three factors that needs to be considered in pricing. Firstly, when decreasing customer loyalty is taken into account on call-service profit is not that of fully loyal customers. Therefore, if original equipment manufacturer engages in competition of on call-service, on call-service and full-service margins fall and the original equipment manufacturer is better of accepting small customer drains. Secondly, learning is one of the key profit drivers which affects both costs and full-service absolute profit. Thirdly, asymmetrical information influences price and customer cost experience needs to be considered in order to avoid over/under pricing.	Decision Sciences Institute
Kong et al.	2019	The optimization of pricing strategy for the wind power equipment aftermarket service	Pricing strategy, Channel effort level, Wind turbine aftermarket service	Model and Stackelberg game theoretical formulation	Turbine manufacturers as a service provider. Contract type: revenue-sharing contract.	To design optimal service pricing strategy in a wind turbine aftermarket.	In both scenarios, there are revenue-sharing ratios that enable maximization of profit and optimal service pricing-, maintenance demand- and channel service effort policies that are applied. Manufacturer can reach maximum profit with maintenance quantity and optimal service channel effort level, while wind farm can do reach it using maintenance quantity. Also, manufacturers can decide optimal channel effort based on revenue-sharing ratio to maximize profit.	Industrial Management & Data Systems

Other extension to traditional maintenance service contract optimization includes taking the qualities of aging equipment into consideration by incorporating failure intensity to their model (e.g. Jackson & Pascual 2008; Huber & Spinler 2014), while some authors also add new variables to the mix (e.g. Wang 2010; Guang-ping et al. 2006). Some use simulation method to derive pricing for the maintenance service contract as well as risk management (e.g. Bowman & Shmee 2001). Many studies incorporate real-life cases and build models around that (e.g. Bowman & Shmee 2001; Guang-ping et al. 2006; Huber & Spinler 2014; Kong et al. 2019), whereas other provide numerical example to test their model (e.g. Murthy & Asgharizadeh 1999; Jackson & Pascual 2008; Huber & Spinler 2012). As observed, there is a research gap in field of maintenance service pricing as there are as many approaches as there are authors and applications.

3.1 Literature on optimization models

In general, the current literature identifies a few distinctive optimization models. Murthy & Asgharizadeh (1999) have created optimization model for maintenance service contracts that focuses on optimizing pricing structure of the contract, number of customers and number of service channels. They introduce game theoretic approach to maintenance service contract optimization. On the other hand, Jackson and Pascual (2008) integrate previous models used in literature such as Murthy & Asgharizadeh’s (1999) model and extend those by assuming imperfect maintenance and taking aging of the equipment into consideration with linear function of failures over time. Unlike in most of the previous studies, in Wang’s (2010) model terms of the contract are predetermined and therefore he does not use game theoretic approach in the optimization of the service contract. New variable delay time (Wang 2010) is introduced in maintenance service contract optimization to better describe maintenance setting developing it further. These models are introduced more broadly below.

Murthy & Asgharizadeh (1999) use their optimization model on industrial equipment’s optimal maintenance service contract to formulate optimal strategy for monopolistic service provider. There are three options of cooperation between the service provider and customer: A_1 – full service contract where all repairs are fixed without additional cost, A_2 – no contract and payment for each repair is made and A_0 – customer does not by the equipment and does not need services. To reflect parties' intentions, customer's utility for each contract is described by model with variables such as time to failure and time in which the equipment is back in operational state. It is then used as base for customer's decision problem. To solve service provider's decision problem, models are introduced to depict service provider's profit for each contract. Models for service provider's profit are constructed using variables such as price, cost, number of customers and service channels, all of which are under service provider's control.

$$\pi(P, C_s, M, S, A_1) = \sum_{j=1}^{M} \left[P - C_m N_j - \alpha(\sum_{i=1}^{N_j} max\{0, (Y_{ji} - \tau)\})\right] - C_0 S - C_1 S^2 \qquad (1)$$

In Equation 1 $\pi(P, C_s, M, S, A_1)$ is a function for full service contract A_1, where P is price of the contract, C_s is cost of repair, M is number of customers, S is number of service channels. C_m is cost of labor and material to service provider, N_j is number of failures over time of the contract. Penalty incurred by the service provider is $\alpha(\sum_{i=1}^{N_j} \max\{0, (Y_{ji} - \tau)\})$, where Y_{ji} is denoted time to return the equipment into operating state after failure and τ is the period of time if exceeded penalty is issued, while $-C_0 S - C_1 S^2$ is the set up cost associated with service channels. (Murthy & Asgharizadeh 1999)

Two other contracts are variations of the model, although A_1 is more focused on costs and A_0 is simply zero as there is no need for service. To draw optimal values for these decision variables, they use Stackelberg game formulation based on exhaustive search that maximizes the expected profit. In the game formulation, service provider is a leader and customer is a follower as the service provider is in monopolistic position and therefore has the power to make pricing decisions. The game is based on service provider's maintenance service profit and on customer's utility from operating equipment.

The model is limited by following assumptions:

- Only corrective maintenance is included as there is assumption that failure rate is constant
- All customers have identical attitude to risk
- All customers choose the same option of cooperation
- There is perfect information between service provider and customer
- Mean time between failures is sufficiently large
- Mean total of waiting and repair is very small in relation to mean time between failures

Jackson & Pascual (2008) develop optimization model for aging equipment's service contract. Only one type of service contract is considered – full service contract that includes both preventive and corrective maintenance. Again, to understand both customer's and service provider's motivation their profit is modeled. Customer's profit is expressed by function to which random variables such as number of failures and time returning equipment back to operational state are added. The same random values are also added to describe service provider's profit.

$$\pi = \sum_{j=1}^{M} \left[P - C_m F_j - C_o(N-1) - \alpha(\sum_{i=1}^{F_j} max\{0, \left(Y_{ji} - \tau\right)\})\right] \qquad (2)$$

In Equation 2 π is a function for service provider's profit in full service contract, where P is pricing value of the contract, C_m is cost of corrective repair, M is number of customers, C_o is cost of preventive maintenance, F_j is number of failures over time of the contract, and N is the number of overhauls. Penalty incurred by the service provider is $\alpha(\sum_{i=1}^{N_j} \max\{0, \left(Y_{ji} - \tau\right)\})$, where α is the cost rate for service provider, Y_{ji} is denoted time to return the equipment into operating state after failure and τ is the period of time if exceeded penalty is issued. (Jackson & Pascual 2008).

Jackson & Pascual (2008) derive optimal value for pricing using Nash game theoretical formulation where expected values are counted for random variables of penalty incurred by the service provider and number of failures. Price for the contract is given by Nash equilibrium and it is assumed that both parties share expected profits as they are equal in the negotiation situation. The model is also limited by following assumptions:

- All units are statistically similar in terms of reliability
- All customers have identical attitude to risk
- Repairs are repaired on first-in, first-serve -basis
- Lifecycle of the equipment is sufficiently large
- Failure intensity is smaller than repair rate/ Mean total of waiting and repair is small in relation to mean time between failures

Wang (2010) has developed a model for maintenance service contract that is used between unique service provider and a customer. There, three type of contracts are taken into consideration: Option 1 – full service contract where all repairs are fixed, and inspections are made without additional cost, Option 2 – payment for each repair, Option 3 – payment for each inspection made and emerged repairs are fixed at the inspections. Customer’s decision problem is approached by describing customer’s profit through calculation involving variables such as total revenue, income from penalty, cost for contract, purchase or repair depending on the contract chosen. After customer’s choice, service provider’s profit is modeled for each contract option where delay time concept is used in constructing inspection models.

$$E(P_{a1}) = Z - \begin{bmatrix} M_{p1} + M_{d1}E\big(N_d(t_1)\big) + M_{f1}E\left(N_f(t_1)\right) \\ +E\left(N_f(t_1)\right)\alpha max\{0, (D_{f1} - k)\} \end{bmatrix}\frac{T}{t_1} + P - C \qquad (3)$$

In Equation 3 $E(P_{a1})$ is a function for expected service provider ‘s profit in Option 1, where Z is service contract price, M_{p1} is inspection cost, M_{d1} is cost for rectifying a defect at the inspection (excluding spare parts), $E\big(N_d(t_1)\big)$ is expected number of defects identified and rectified, M_{f1} is repair cost per failure (excluding spare parts), $E\left(N_f(t_1)\right)$ is the expected number of failures over time of the contract, P is purchase price of the equipment and C is production costs of the equipment. Penalty incurred by the service provider is $\alpha max\{0,(D_{f1}-k)\}$, where α is the cost rate for service provider, D_{f1} is downtime per failure and k is the period of time if exceeded penalty is issued. (Wang 2010)

Wang (2010) states that since the terms such as downtime, price and cost of the contract are assumed to be known, the optimization of service provider’s profit is done through inspection intervals. Yet, reliability and availability constrain need to be considered in defining inspection interval before choosing optimal contract option. After examining profit in different inspection scenarios, negotiation is carried between parties and contract option with highest profit expectancy is chosen. In addition to certain parameters in model are known, the model is also limited by following assumptions:

- Attitude of the customer towards risk is negligible
- Failures follow two-stage failure process, first stage being from new to the initial point of identification and second being from initial point to an eventual failure caused by unattended defect
- Arrival of defects follows homogenous Poisson process
- Inspection are perfect, and interval is constant
- Corrective repairs and repairs at inspections are minimal and bring the equipment to as good as before condition

Other approaches include usage of hybrid game process with two stage non-cooperation and cooperation which again draws from Rubinstein-Stahl bargaining model, such as Guang-ping et al.’s (2006) study. They also introduce variable actual cost that contains the transparent cost information used in negotiation. Other changes in the literature can be noticed in Hubler & Spinler’s (2012) study where they change the traditional dynamic of optimization by introducing full-service pricing model that assumes heterogenous customer base where customers have different aversion to the risk. Hubler & Spinler (2014) extend their previous study by addressing key factors influencing pricing of full service -contract. They take into consideration that customer and service provider might not have perfect information between them and customer is not necessary fully loyal. Also learning is found to be the key profit driver. Kong et al. (2019) design maintenance service contract to maximize profit for both customer and service provider in wind turbine aftermarket in Chinese context. They develop model and draw optimal values for parameters using Stackelberg game formulation introduced earlier.

3.2 Literature on simulation model

While some use more theoretical approach, Bowman & Schmee (2001) use practical approach by doing a case study and developing simulation model for large aircraft maintenance service provider. They use simulation method in estimating costs and failure risk to manage financial uncertainty of a long-term service contract as well as addressing operational and sensitivity issues affecting the risk. In their study, financial risk exposure over the length of the maintenance service contract is calculated. Focus of the study is on aircraft engines and their potential contract and data gathered is from the case company. To answer the question on profitability and risks of the contract Bowman & Schmee (2001) develop simulation model presented in figure 3.

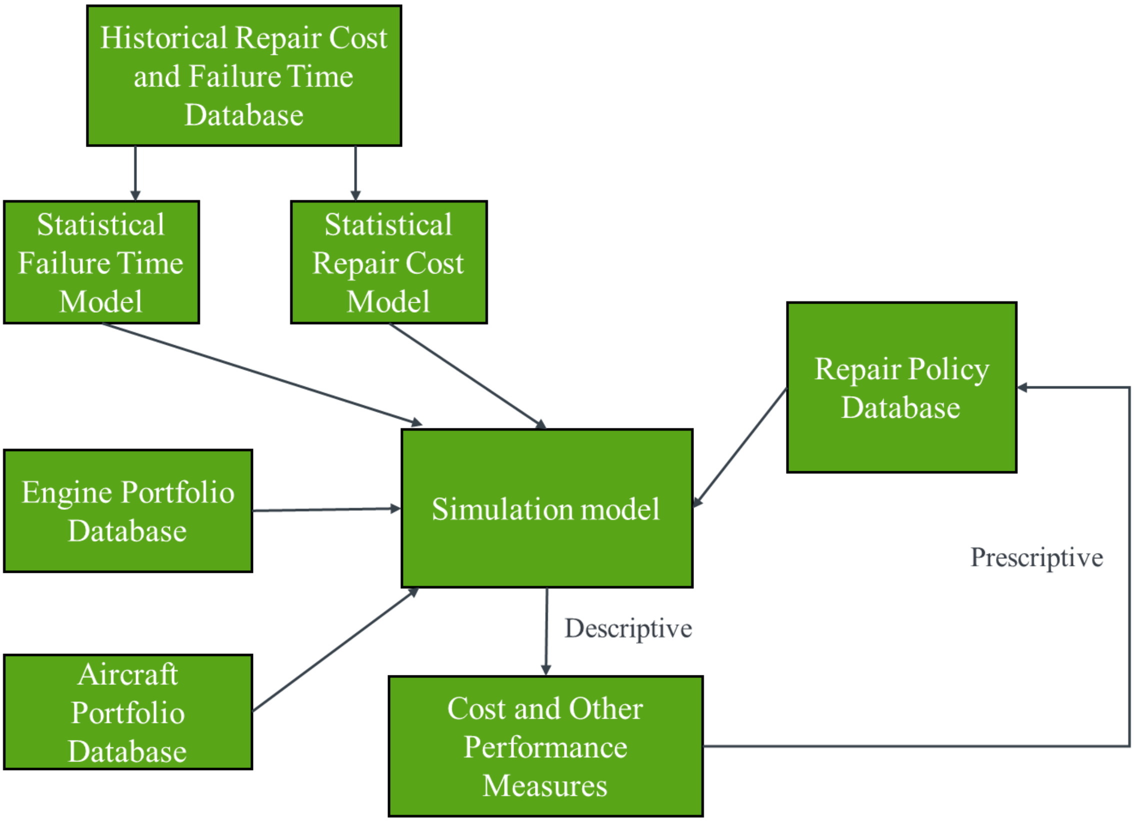


Figure 3. Simulation model (Bowman & Schmee 2001)

Produced event simulation model uses attributes and events in the simulation. Databases, Engine Portfolio, Aircraft Portfolio, and Repair Policy contain attributes, such as compatibility with the aircraft, status and usage of the engines, and repair policies. Events generated are then constructed based on these attributes. Failure rate for the engines is simulated based on the status attribute that contains knowledge about the engines, such as the age and use limit, as well as usage of the engine derived from Aircraft Portfolio -database. Failure rate then determines when failure event occurs, which then in return affects status attribute and so on. These variables combined produce maintenance actions that are further categorized under event file updating the status, failure rate, and maintenance interval. Statistical models generating failure time and repair costs for the simulation are based on the historical data gathered from the case company. (Bowman & Schmee 2001)

Bowman & Schmee (2001) use program function to derive an equation to produce estimates for failure time. Ten significant coefficients are then derived from Weibull regression including intercept and random variates for failure time are produced. Repair costs on the other hand, are generated from normal distribution rather than number covariates as the data source has its limitations. Simulation is then performed to gain generated values for each maintenance action. Bowman & Schmee (2001) also take inflation into the consideration by altering costs to mirror inflation rate of the real dollar.

Simulation model produces several outputs: total cost of the contract, number of maintenance actions, proportion of engines requiring service, availability in hours and number of engines as well as costs. Percentiles and key statistics are also presented to acquire better understanding on phenomena. (Bowman & Schmee 2001) According to Bowman & Schmee (2001) simulation model is able to capture complexity and uncertainties related to maintenance service contract pricing. They state that using statistical models is an effective method in managing financial risk of maintenance service contract.

4. METHODOLOGY

Main methodologies applied in pricing of the maintenance service contract are optimization models and simulation. Optimization models can be used not only in optimizing pricing but also maintenance strategies, service channels, and contract choices etc. While optimization models often relay on different game theoretic formulation from Stackelberg to Nash equilibrium to derive optimal values, simulation uses statistical methods in estimating variables. Simulation method also enables risk analysis of the variables involved. This study takes quantitative approach to pricing of maintenance service contract. Similarly, to other quantitative models used in optimization and risk management of pricing, this study uses numeric model to derive pricing for the train bogie's contract.

Chosen approach for this study is Bowman & Schmee's (2001) simulation model, because it does not require customer's profit function, but focuses on service provider's costs and risks. Simulation is applied to this case study and used to review pricing model and financial risk associated with it. Simulation methods, for example Monte Carle, are often used when behavior and properties of variables of interest need to be investigated (Brooks 2008, 547). Stochastic simulation evaluates behavior of the object of study by using random variables from multiple simulations. This kind of simulations have been used in rail operations optimization to acquire better understanding on phenomena as well as in validation processes. (Borndörfer et al. 2018) Simulation is particularly effective when input data sample is small, and it allows user to experiment in controlled conditions. In finance, Monte Carlo-method is a useful tool for stress-testing. (Brooks 2008, 548) According to Brooks (2008, 548) stress-testing is a risk management, where models are subjected to investigation whether they "*generate capital requirements sufficient to cover losses in all situations*". In parallel to stress-testing, risk assessment is exercised and analysis is conducted to see, what are the plausible financial outcomes based on the existing data. Risk related to variation of the maintenance costs and penalty that the pricing is based on, can be examined looking at the results.

Model used in this study to calculate pricing of the contract, mirrors mainly Jackson & Pascual’s (2008) optimization model for aging equipment presented in equation 2. Their service provider’s profit model reflects the case company’s maintenance service practices closest and provides base for this study. Unlike in Jackson & Pascual’s (2008) study, this study leaves out game theory approach as the case company is subsidiary for its customer. In current scenario, maximization of the profit at customer’s expense is not desirable as it would only result in money transfer within the group. Although, value-creation is a recommended base of the pricing strategy, group vs. subsidiary -position steers pricing strategy towards a cost plus -strategy as it is in company’s interest to appear affordable for the group company as well as the potential competitors. For that reason, model used in this study is based on Jackson & Pascual’s (2008) optimization model but focuses mainly on the expected costs from preventive and corrective maintenance as well as the penalty, leaving profit out. Even though profit maximization is not the objective, a margin is added to the equation to guarantee profitability of the case company. Modified cost plus- based pricing model is then presented in equation 4.

$$P = \sum_{j=1}^{M} \begin{bmatrix} (C_m F_j + C_o N_j + \alpha(\sum_{i=1}^{F_j} max\{0, (Y_{ji} - \tau_c)\}) \\ + \alpha(\sum_{i=1}^{N_j} max\{0, (V_{ji} - \tau_P)\}) \end{bmatrix} * K \qquad (4)$$

Equation 4. Pricing model for the maintenance service contract of train bogies, where P is the pricing value of the contract, M is number of customers, C_m is cost of corrective repair, F_j is number of failures over time of the contract, C_o is cost of preventive maintenance, N_j is the number of preventive maintenance actions, K is the sales margin of the contract. Penalty incurred by the service provider is $\alpha(\sum_{i=1}^{F_j} \max\{0, (Y_{ji} - \tau_c)\})$ for corrective maintenance and $\alpha(\sum_{i=1}^{N_j} \max\{0, (V_{ji} - \tau_P)\})$ for preventive maintenance. α is the cost rate for service provider, while Y_{ji} is denoted time to return the equipment into operating state after failure and V_{ji} is denoted time to perform preventive maintenance. τ_c and τ_P are the period of time in corrective and preventive maintenance that if exceeded, penalty is issued.

Based on the literature review and request of the case company, a proposal for pricing method is suggested along with profitability analysis. Employed simulation model is illustrated in figure 4 and is ran in MATLAB. The idea behind Monte Carlo simulation is to derive random samples from distributions of the existing data (Brooks 2008, 548). Described approach is applied in this study in order to gain statistical values for failure rate, workhours and costs. Monte Carlo simulation can be divided into three stages: specification of the model and probability distributions, parameter estimation, and definition of number of iterations (Brooks 2008, 548).

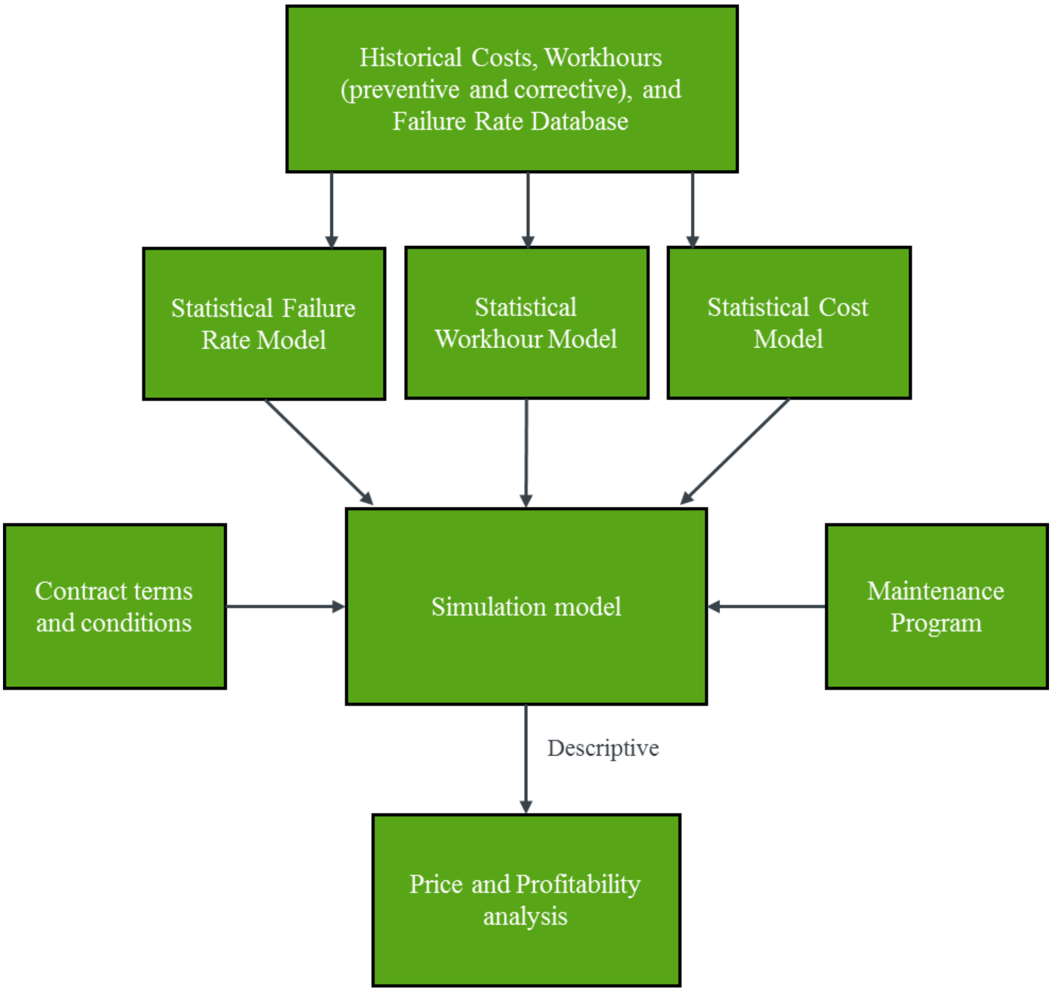


Figure 4. Simulation model

In first stage, the time series or structural model used in simulation is constructed and often normal distribution is used as a probability distribution (Brooks 2008, 548). In this study, the model is based on the literature review and shaped by the limitations brought by the case company. Contract terms and conditions as well as maintenance program are given by the case company and do not require statistical estimations. Other variables follow second stage of Monte Carlo simulation and expected values are calculated. Failure rate, workhours and costs associated with preventive and corrective maintenance are all generated based on historical data. Historical data is analyzed to find distribution describing the data best. Distributions are specified using distribution fitter and χ^2 goodness-of-fit test, where more precise results can be derived. Then based on the distribution specifications, the simulated values for variables are obtained. The number of repetitions of second stage is determined in third stage of Monte Carlo. In Monte Carlo method, the number of quantity n gives the number of repeats, in other words how many simulations are performed for each variable. Random estimate of the variable is then produced from the distribution n times. (Brooks 2008, 548) Brooks (2008, 548) highlights that in Monte Carlo the number of simulations need to be large enough to give feasible results. Here, the number of simulations is 10 000, and thus seen suitable for Monte Carlo analysis.

5. CASE: VR FLEETCARE LTD.

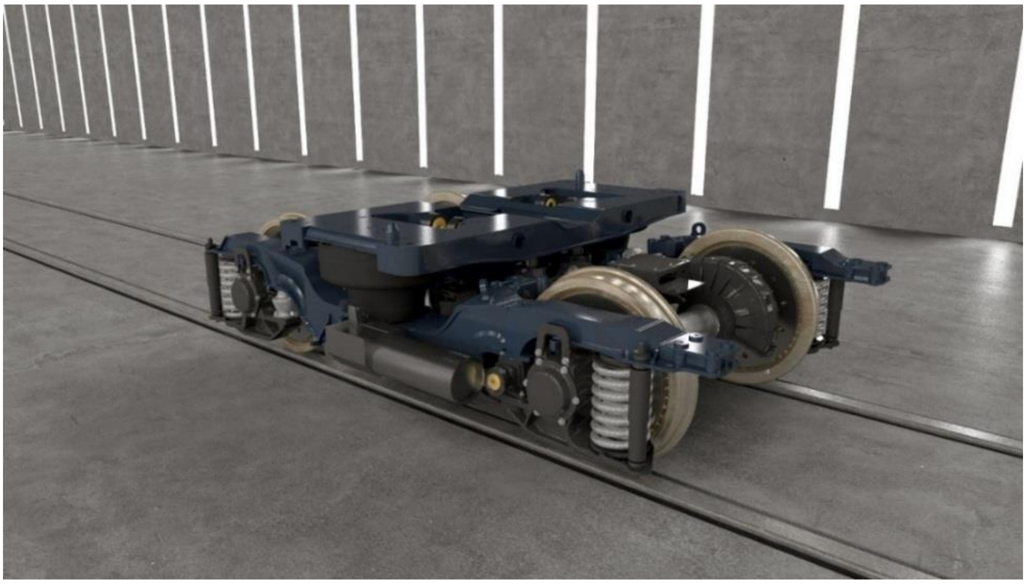
The case organization VR FleetCare Ltd. is a new maintenance service company operating in the rolling stock maintenance market. It is a former business unit turned subsidiary of its parent company VR Group. (VR Group 2019e) VR Group itself specializes in providing transport for people and different goods using rolling stock as well as other supplementary activities. VR Group is fully state owned and operates mainly in the Finnish market employing 6 300 people, but also has operations in other countries such as Russia. (VR Group 2019d) According to VR Group (2019b) in 2018, the turnover exceeded 1 270 million euros. It has multiple business operations: Passenger traffic, Logistics, Maintenance (currently subsidiary) and Real estate, with Passenger Traffic being the biggest in terms of turnover with 553 million euros in 2018 (VR Group 2019b). These units are further supported by Train operation and Group service functions (VR Group 2019a). In this study, the focus is on Maintenance i.e. VR FleetCare Ltd. VR FleetCare Ltd., formally known as VR Maintenance Ltd., began its operation as an independent subsidiary on first of January 2019 and employs around 990 employees (VR Group 2019e). The main customers are its parent company VR Group and its business units, but it also provides services outside its parent company, for example to HSL (Helsinki Regional Transport) and other customers such as Karelia Trains Ltd. (VR Group 2019c), with newest addition being HKL (Helsinki City's Transport) and their metro trains (VR Group 2019f). VR FleetCare Ltd. (hereafter referred as VR) provides component and rolling stock maintenance, fault repairs, technological support as well as diagnostics and overall lifecycle management. It has depots and machine shops across Finland in cities such as Helsinki, Tampere, and Pieksämäki. (VR Group 2019c)

Liberation of the railway market in Europe, high speed and electrified network, and growth are currently dominant trends in rolling stock industry and affect VR in the future. According to report issued by the European Commission (2019), rail industry is significant actor in EU economy, employing over 1 million people, transporting 1.6 billion tons of freight, and 9 billion passengers annually. In VR Group, passenger traffic counted over 123.7 million travels, while freight transport was up to 44.4 million tons in 2018. VR Group reports growing numbers in passenger traffic where both long distance and commuter travel have increased over 4 % and freight transportation increasing by 2 % in 2018. (VR Group 2019b) Railways are a key piece in EU's sustainability strategy as it only uses 2 % of the energy used in transportation yet carries 11 % of freight and 7 % of passengers making it important player in fight against CO_2 emission. Significant trends in EU rail network, including Norway, has been electrification of the network which has increased more than 1.7 % since 2011 and high-speed network which has doubled in length since 2003. Even though density of rail networks is less dense in the Nordics and Baltic, it is the highest if proportioned to population. In EU, rail freight has been opened to competition in 2007 and the competitors in market has increased in all countries. While domestic passenger markets are still regulated by the member countries and they can choose from monopolistic operator to open market, market for international travels have already been opened for competitors in 2010. (European Commission 2019) European trend of market liberation can have effect on Finnish railway industry through open market in freight and international travel. In addition, a plan for opening passenger traffic market has been made in 2018. It is set to be liberated for competition in 2021 for commute traffic and 2010 for long travel. (VR Group 2019b)

5.1 Data

The study's focus is on the component maintenance and more precisely on a single component – bogie. Bogies are safety critical and if damaged, the rolling stock containing the component halts, stopping the traffic. It is also one of the most expensive components used in rolling stock and generates substantial part of the costs in component maintenance making it relevant object of study. In this study, they are assumed to be the same type, have same characteristics and reliability, therefore effects of maintenance policies are not examined in this study. As seen in picture 1 and 2, bogies are heavy components that contain other smaller parts which are either repairable or disposable items. In this study, the focal point is on the component as a whole and it is treated as one component rather than dissecting it to smaller parts.

At VR, bogies have the same maintenance program structure as rolling stock. They are subjected to both preventive and corrective maintenance. The timing of preventive maintenance is based on the carriage. When the carriage has been in circulation for several years it is taken in for maintenance and bogies are detached from the carriage. As carriage incorporates two bogies, both components are maintained at once. Bogies are refurbished and restored close to its original condition. They are then attached back to the carriage or placed in storage. Other preventive maintenance actions include alteration work which are irregular additional maintenance and therefore excluded from this study. Bogies are also subjected to corrective maintenance which vary from fixing leaking component, detached spare part to changing worn insulation etc. All maintenance actions that are not included in planned maintenance program fall under corrective maintenance category.



Picture 1. Train bogie (Bombardier 2019)

Picture 2. Train bogie (Alstom 2019)

Case company uses full service contract, meaning one payment is made for maintenance services performed on agreed period of time. Content of the full service maintenance service contract for the bogies and data related to it is presented in table 2. Collected data sample consists of the preventive and corrective maintenance actions done by VR that have been directed towards bogies between 01.01.2015-31.07.2019 including the starting and ending date. In first step, needed data sets have been defined and data sources mapped based on the interviews with specialists. Next, data is drawn using company's data warehouse and further divided into preventive and corrective maintenance data. There are two different data sets describing preventive actions, while one data set describes corrective actions. First data set describing preventive actions consists of overhauls of the bogie and will be referred as an overhaul. It is a maintenance action where comprehensive maintenance work is performed on a bogie and returns it close to "good as new"-state. Second preventive data set is a supplementary work to overhaul. These observations occur whenever the overhaul is performed. It incorporates detachments and attachments of bogies, logistics as well as other overhaul related work excluding the overhaul itself and will be referred as related work. Corrective maintenance data on the other hand incorporates all work that does not fall under preventive maintenance and its primary source is separate system which has integration to the ERP system. Data sets include costs and work hours taken to perform the particular maintenance action as well as the date of the events for corrective maintenance data. Both preventive and corrective maintenance data sets have costs and workhours from the whole time period, while monthly failure rate is derived from time period of 01.01.2018-31.07.2019. Set time is based on relevance and data availability which is dependent on technical solutions that limit the data sample size.

Table 2. VR bogie’s maintenance contract and data sample

<table>
<tr><th>Maintenance</th><th>Type</th><th>Based</th><th>Policy</th><th>Content</th><th>Data</th></tr>
<tr><td>Overhaul</td><td rowspan="2">Preventive</td><td rowspan="2">Time interval (fixed)</td><td>Overhaul</td><td rowspan="3">Material and work force</td><td rowspan="2">Costs and workhours</td></tr>
<tr><td>Related work</td><td>(Supplementary)</td></tr>
<tr><td>Corrective maintenance</td><td>Corrective</td><td>Failure</td><td>Imperfect repair/ Minimal repair</td><td>Costs, workhours, and failure rate</td></tr>
</table>

Data used in analysis is entirely drawn from company’s ERP system and further transformed for easier reading. ERP system provides extensive information on maintenance actions and is further enriched by other data sources which are integrated to the main ERP system. Essential data from ERP system is brought to data warehouse and provides explanatory information needed in the analysis. Used data sample is subjected to alterations as there are human errors involved that need to be dealt with. To ensure relevant data, review of the data is arranged with specialists responsible for maintenance actions.

Data requires alteration to describe maintenance actions realistically. As unfiltered data has many observations that have unrealistically high or low costs or work hours due to wrong entries to the ERP system, proper screening is needed. If the inaccurate values are left in data sample, errors and exceptions could distort values. On the other hand, too airbrushed data could depict too rosy picture of the maintenance as many aspects can be unpredictable and lead to financial losses. Therefore, based on the specialist’s estimates an upper (worst case scenario) and lower (best case scenario) limit are set for preventive and corrective data sets. Also, extreme values are screened to ensure their credibility.

Based on the reviews and estimates, all three maintenance and corrective data sets are separated into three different data samples: 1) all data 2) data without obvious errors and 3) ideal. (1) All data -sample incorporates the whole data set from 01.01.2015 to 31.07.2019 and is not altered manually. (2) Data without obvious errors -sample is cleansed sample where observations that are deemed impossible by specialists are removed as they are produced due to human or system error. Data sample still integrates observations that are over or under set limits yet deemed plausible although exceptional. (3) Ideal- sample data has been cleansed from the variables that are over or under the set upper and lower limit to describe ideal picture of the preventive and corrective maintenance. Data selected for the study is the (2) -data sample where obvious errors have been removed from the data set. By taking exceptional observations into the consideration, the model attempts to integrate the risk that comes from variation and special cases.

5.1.1 Distributions of the variables

In order to generate random values for Monte Carlo simulation, probability distribution for each variable needs to be determined. According to Brooks (2008, 607) "*a random variable is one that can take on any value a given set*". Given set is determined based on probability distribution and specifying information, such as mean and variance in normal distribution (Brooks 2008, 607). To derive probability distribution of the data and its descriptive information, various distributions from normal to logistic distribution, are fitted for every (2) data samples of preventive and corrective maintenance. To find the best fitted distributions, they are plotted, and χ^2 goodness-of-fit test is implemented using MATLAB's chi2gof-function. In addition to hypothesis, χ^2 goodness-of-fit test produces p-value for each distribution. P-value gives the marginal significance level and describes whether the null hypothesis is rejected or is not. For example, if p-value is greater than 0.05 with 5 % significance level, null hypothesis is not rejected and vice versa. (Brooks 2008,73)

The hypotheses for χ^2 goodness-of-fit test are:

H_0: the null hypothesis is that "*the data in vector x comes from a -- distribution with parameters estimated from x*" and

H_1: the alternative hypothesis is that "*the data does not come from such a distribution*". (MathWorks 2019a)

If null hypothesis is not rejected, used distribution is considered as a distribution for the data.

Distribution fitting for overhaul's costs (2) data sample is shown in figure 5. As seen in plot a few distributions fit data nicely and H_0 remains valid. Best p-values are found in Normal- (0.8450), Weibull- (0.8290), and Logistic- distribution (0.8067). Normal distribution is chosen as it has the highest p-value and the plot fits the data and its tales. According to the parameters from Normal distribution, costs for overhaul of the bogie is ~N(89.3, 24.4)* and p= 0.8067.

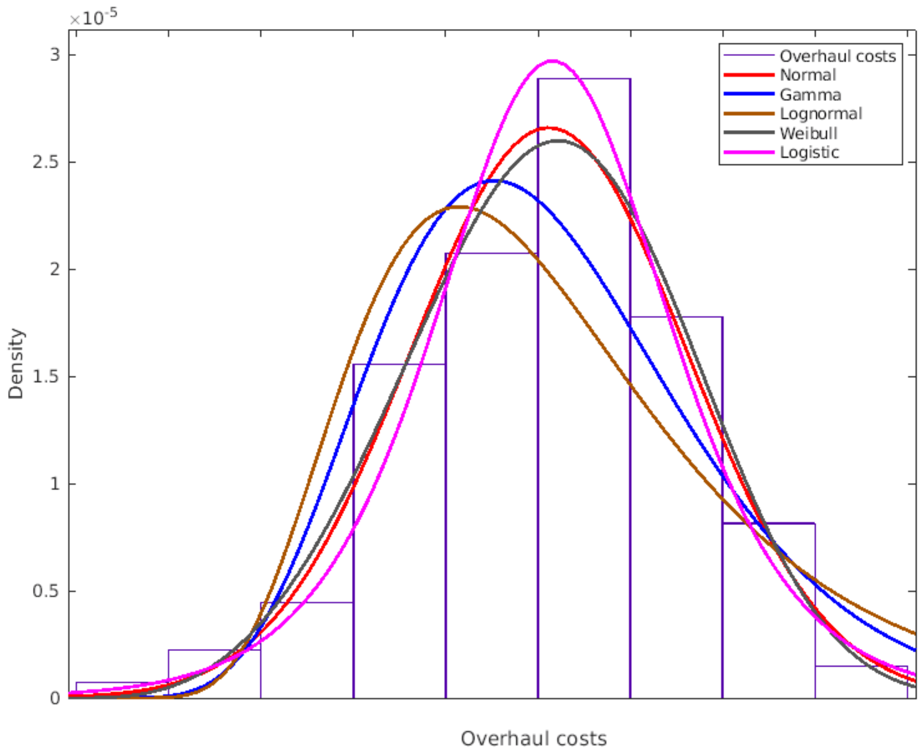


Figure 5. Overhaul costs, (2) data sample§

* Numbers have been altered
§ Numbers not visible due to confidentiality

Distribution fitting for overhaul's workhours (2) data sample shows that none of the distributions fit as the H_0-hypothesis is rejected in each case. Fitted distributions are shown in figure 6. Same distributions are then fitted for (1) and (3) data samples to see if the distribution fits data if more filtered or unfiltered. In both Normal and Logistic distributions, H_0 stays valid when fitted to (1) and (3) data samples. Normal distribution has p-value of 0.1653 in data sample (1) and p-value of 0.9652 in data sample (3), while Logistic distribution has p-value of 0.2472 for data sample (1) and p-value of 0.9071 for data sample (3). Normal distribution has μ of 1 578.56* (2), 1 958.98* (1), and 1917.99* (3) and σ of 573.45* (2), 939.47* (1), and 384.98* (3). Logistic distribution has μ of 1 745.08* (2), 1 590.25* (1), and 1 589.21* (3) and σ of 372.21* (2), 610.87* (1), and 268.65* (3). Logistic distribution is chosen as a distribution as it shows less variation in values in μ and σ for all data samples. When fitted for data sample (2), workhours for overhaul of the bogie is ~Logistic(1 745.08, 372.21)* and p= 0.0044.

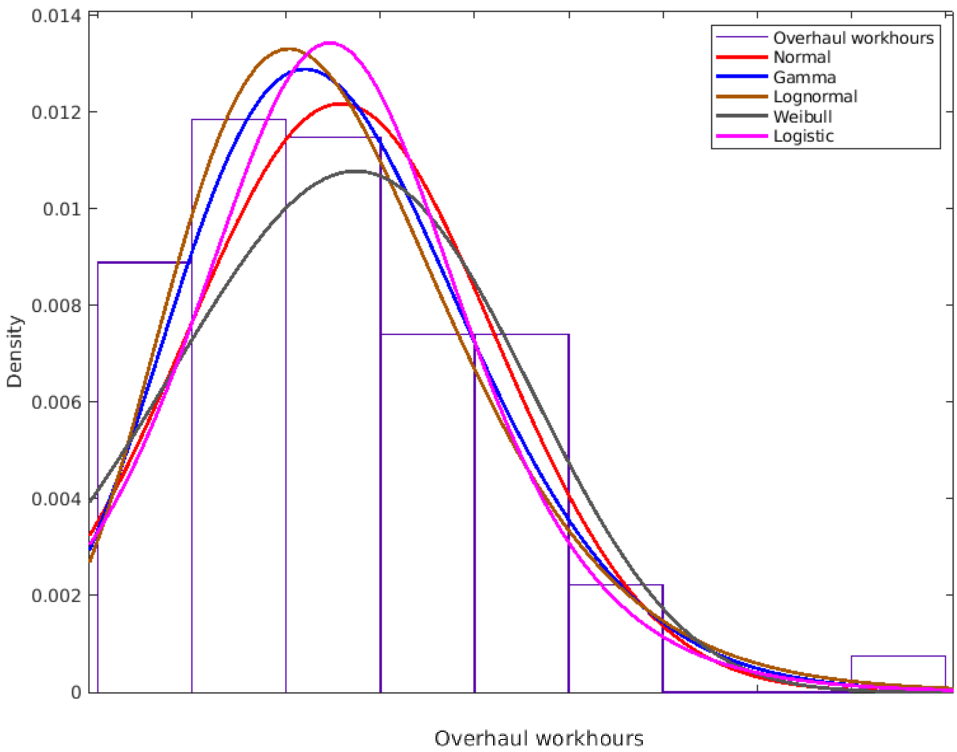


Figure 6 . Overhaul workhours, (2) data sample§

* Numbers have been altered

§ Numbers not visible due to confidentiality

Costs for related work is also fitted with distribution and plotted in figure 7. As in overhaul's workhours, none of the distributions fitted fit the data sample and H_0-hypothesis is rejected in each case. Same procedure is performed, and distributions are fitted for (1) and (3) data samples. Only in Normal distribution there is readable p-value and a hypothesis that stays valid. Data sample (1) has the p-value of 0.0656 with H_0-hypothesis remaining valid, while data sample (3)'s the p-value is NaN. But as others only have rejected H_0-hypothesis, Normal distribution is chosen. When fitted for data sample (2), costs for related work of the bogie is ~N(157.55, 61.85)* and p= 0.0236.

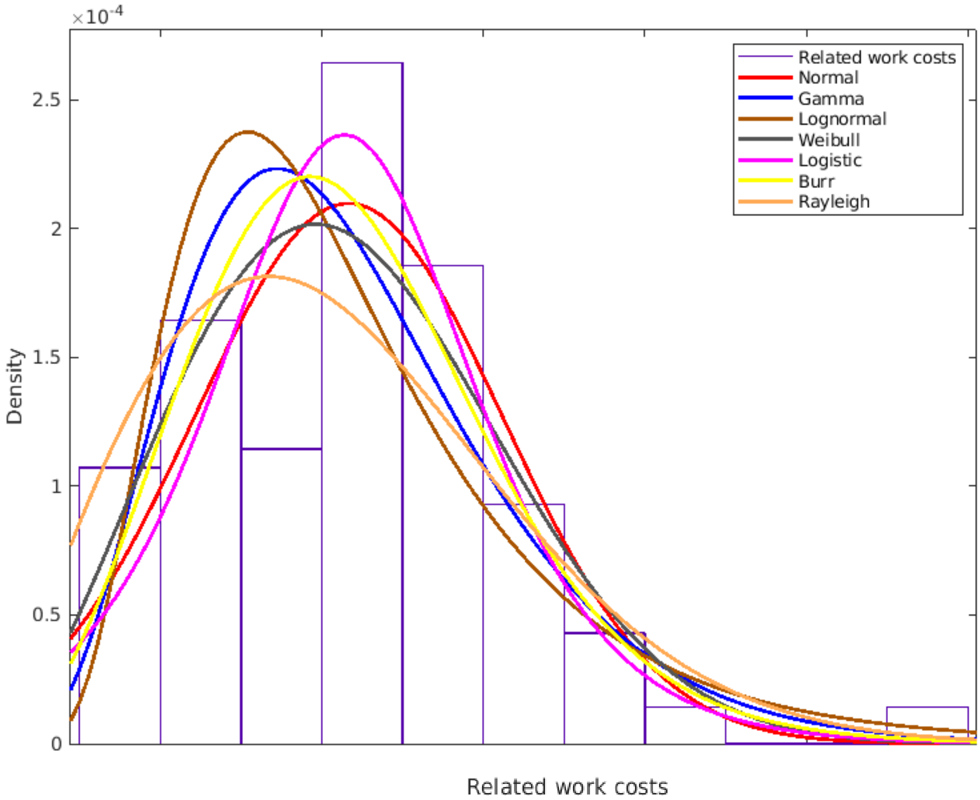


Figure 7. Related work costs, (2) data sample§

Distribution fitting for related work's workhours (2) data sample is plotted in figure 8. There are a few distributions where H_0-hypothesis stays valid and fit the data: Burr distribution with p-value of 0.1817, Generalized Extreme Value distribution with p-value of 0.1365, and Log-Logistic with p-value of 0.0862. Generalized Extreme

* Numbers have been altered
§ Numbers not visible due to confidentiality

Value distribution is chosen as it is more common than Burr distribution and p-value is the second highest among the distributions. Using Generalized Extreme Value distribution workhours for related work of the bogie is ~GEV(372.35, 1132.00, 5.04)* and p= 0.1365.

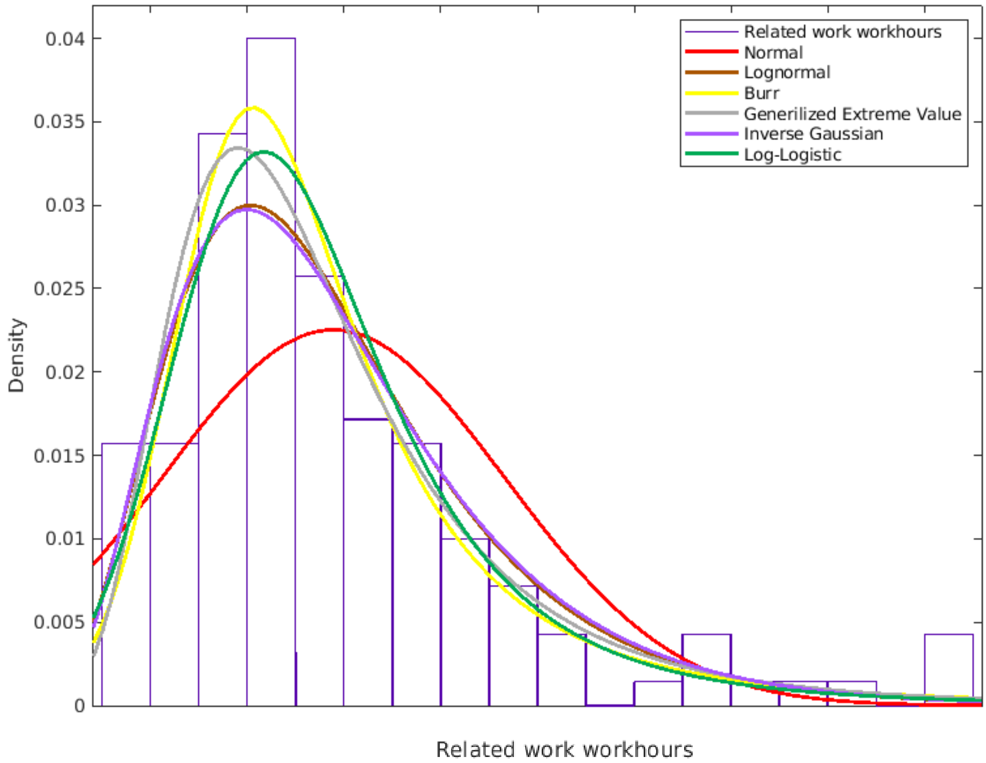


Figure 8. Related work workhours, (2) data sample§

While overhaul' and its related work's costs and workhours fit some distributions, corrective maintenance data rejects null hypothesis in every distribution or gives the p-value of NaN. As seen in figure 9 and 10, there is a very steep curve in both data samples and is hard to fit in any distributions. Therefore, empirical distribution is fitted using emprand-function in MATLAB. Emprand-function establishes cumulative distribution based on the data and generates random numbers based on the interpolate from cumulative distribution function (MathWorks 2019b).

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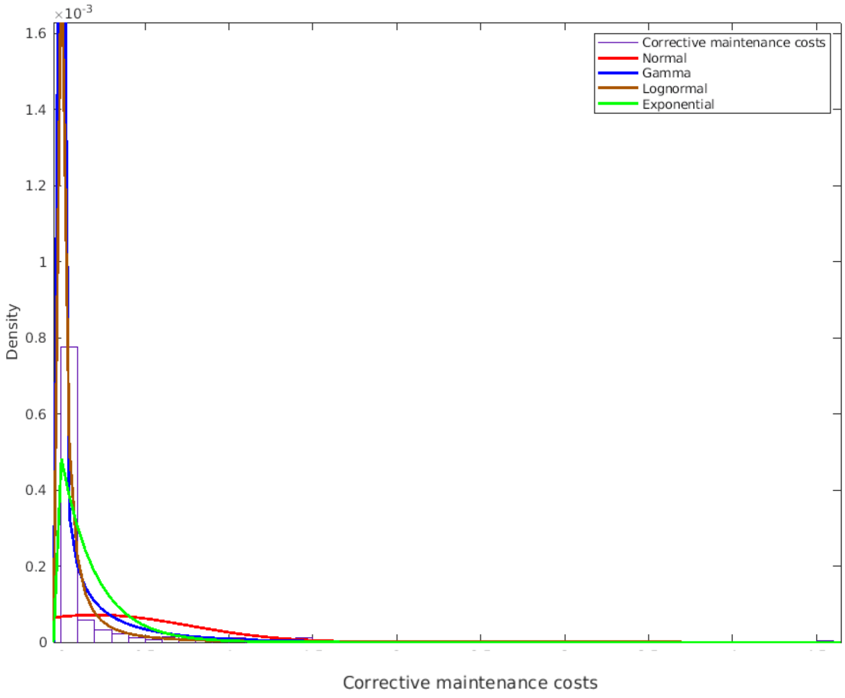

Figure 9. Corrective maintenance costs, (2) data sample§

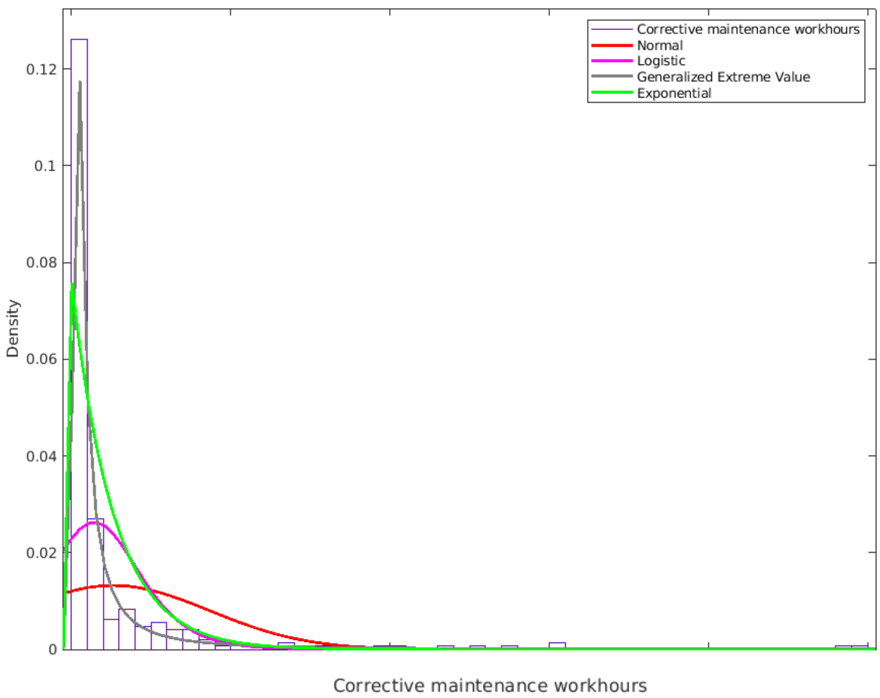

Figure 10. Corrective maintenance workhours, (2) data sample§

§ Numbers not visible due to confidentiality

To simulate failure rate of the bogies using Monte Carlo-method, distribution to draw random numbers is needed. Poisson distribution is fitted to corrective maintenance event data, as seen in figure 11. Null hypothesis, H_0, stays valid, therefore Poisson is considered as distribution. Using Poisson distribution failure rate for the bogies is ~POIS(239.73)* with p-value of 0.50.

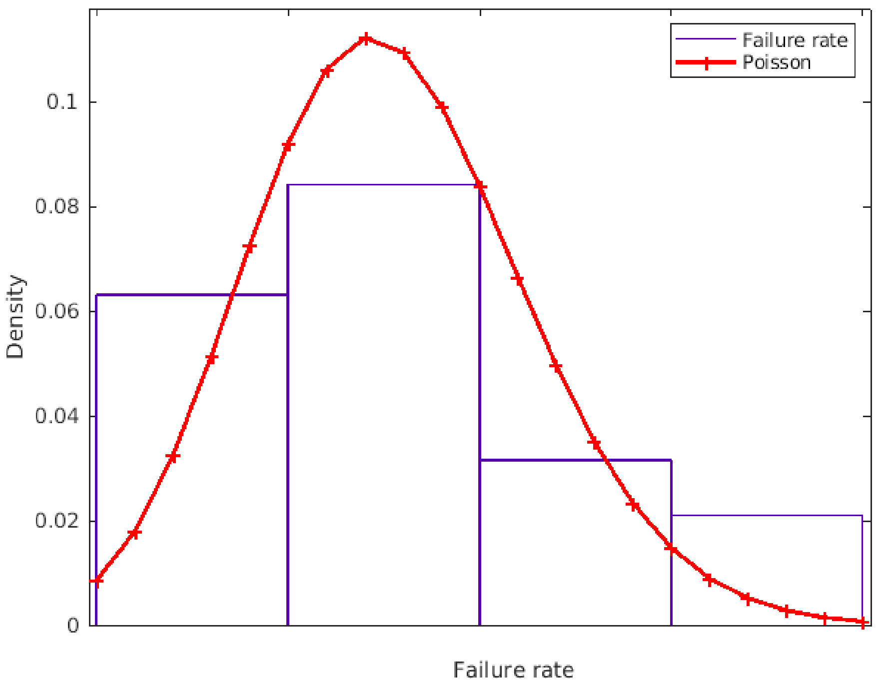

Figure 11. Corrective maintenance failure rate, (2) data sample§

Overall, most of the data samples used in this study demand altercations or application to find fitting distribution that captures the data. To find these other data samples (1) and/or (3) are fitted the same distribution or emprand-function is used in order to compensate rejected null hypothesis or NaN p-value. Therefore, conclusion drawn from simulation that uses distributions selected, needs to be applied with caution. As seen variables can also be drawn from empirical distribution, but by fitting distributions, statistical distribution is obtained through just few specifying parameters. This enables more easier applicability as it doesn't require historical data to derive simulations. Statistical distribution also allows continuity by smoothing the peaks and gaps.

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5.1.2 Simulation

To obtain random values for the variables that are based on historical data, Monte Carlo-simulation is applied. Summary of distributions used as a base for variable simulation is shown in table 3. Number of simulations is up to 10 000 for overhaul's, related work's and corrective maintenance's variables as well as failure rate. For each variable a yearly simulation values are drawn 10 000 times from the distribution given by the previous examination. Contract price is then modelled with given and simulated variables and ran through simulation 10 000 times. In addition to the price of the maintenance service contract, outputs from the simulation contain cost of preventive and corrective maintenance, penalty-, and overall cost to understand their share in pricing of the contract. Outputs are plotted along with their confidence intervals to see where 95 % of the time, the value of the variable will be contained in the interval (Brooks 2008, 59).

Table 3. Variables and their distributions

Maintenance	Variable	Distribution
Overhaul	Costs	Normal
	Workhours	Logistic
Related work	Costs	Normal
	Workhours	Generalized Extreme Value
Corrective maintenance	Costs	Empirical
	Workhours	Empirical
	Failure rate	Poisson

In figure 12, costs of preventive maintenance are presented. Figure 12 combines both costs related to overhaul as well as related work and categorizes them as preventive maintenance costs. Costs for each preventive maintenance are first simulated separately based on the normal distributions and then summed together. Skewness describes the degree to what extent the distribution is not symmetric about the mean (Brooks 2008, 161). As seen from the plot, there does not seem to be much skewness and values remain distributed symmetrically around the mean.

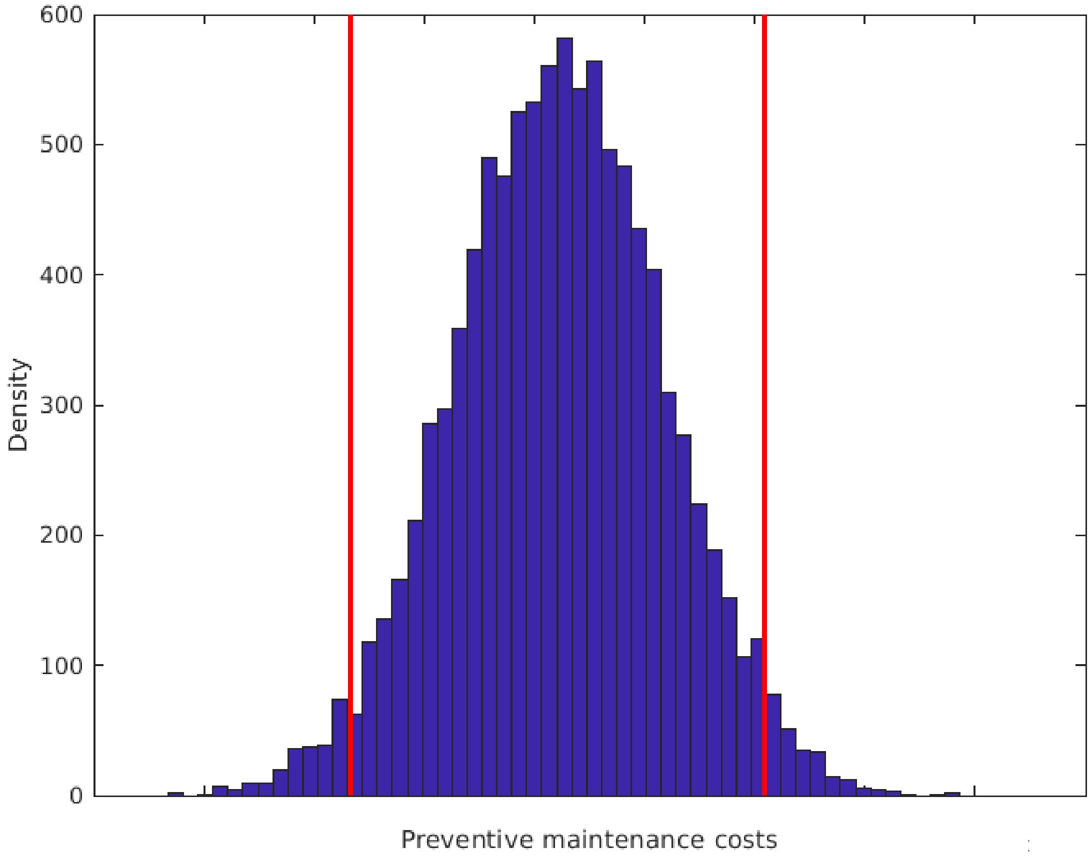

Figure 12. Preventive maintenance costs and confidence intervals[§]

Outputs of the simulation for corrective maintenance costs are seen in figure 13. As seen from the plot, corrective maintenance costs seem to be highly skewed to the right and most of the simulation values appear to be closer to lower bound of confidence intervals. Tail of the distribution is long and intermittent that can be consequence of empirical distribution that is used in estimation of the corrective costs.

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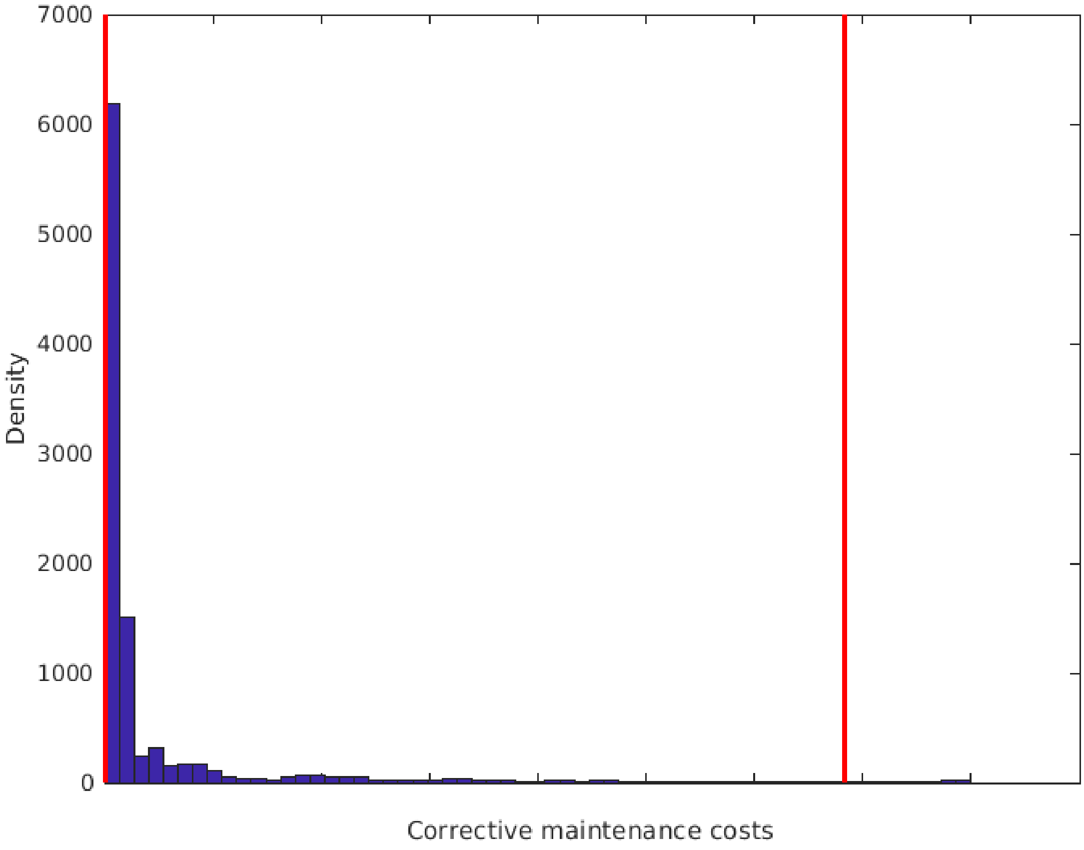

Figure 13. Corrective maintenance costs and confidence intervals[§]

Similarly to preventive maintenance, penalty from preventive maintenance and corrective maintenance are first generated separately. Workhours are simulated from logistic-, generalized extreme value-, and empirical-distributions. Generated workhours of preventive maintenance are added together and compared to preventive maintenance target time. If simulated workhours exceed given target time for preventive maintenance, penalty is issued. Comparably simulated corrective maintenance workhours are subjected to the similar comparison. Penalty costs of preventive and corrective maintenance are calculated together and plotted in figure 14. As seen from the figure, costs resulting from penalty are seemingly normally distributed and both tails are symmetrically distributed about the mean.

[§] Numbers not visible due to confidentiality

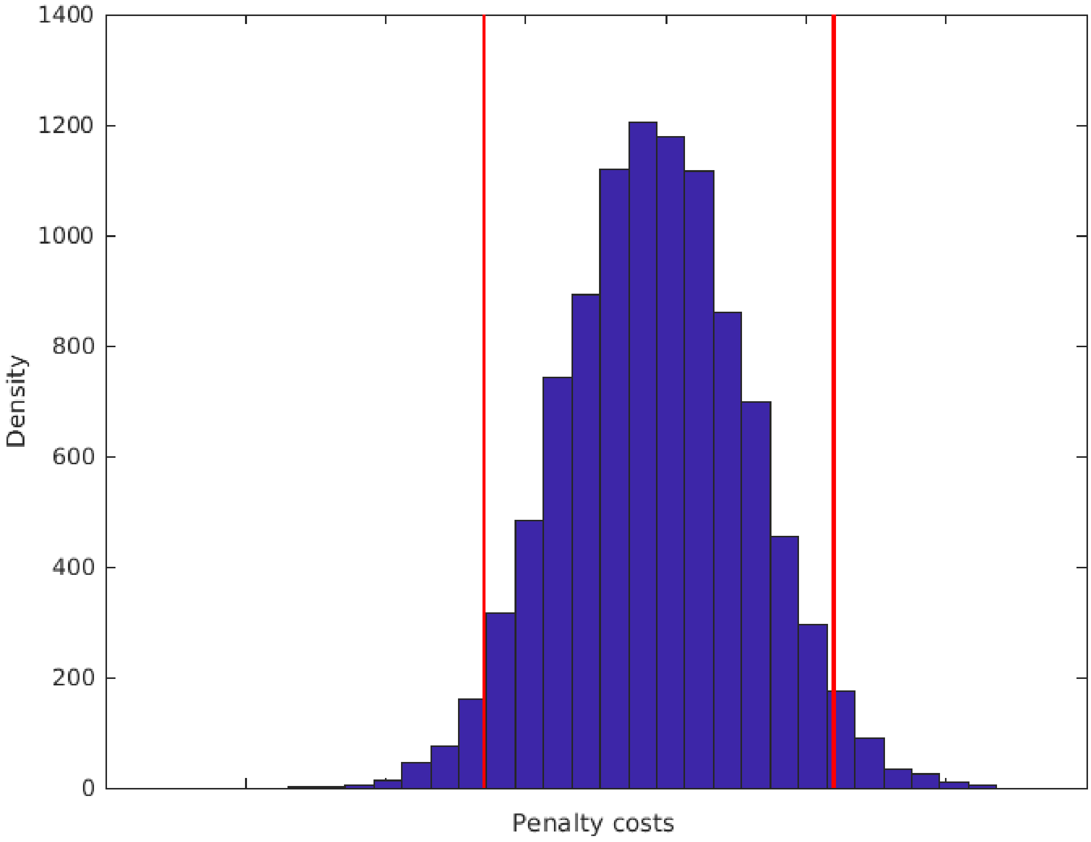

Figure 14. Penalty costs and confidence intervals[§]

Process of maintenance service contract pricing in case company is pictured in figure 15. While costs, workhours and failure rate are simulated (green), target times, maintenance interval of the bogies, and sales margin are given by the case company (grey).

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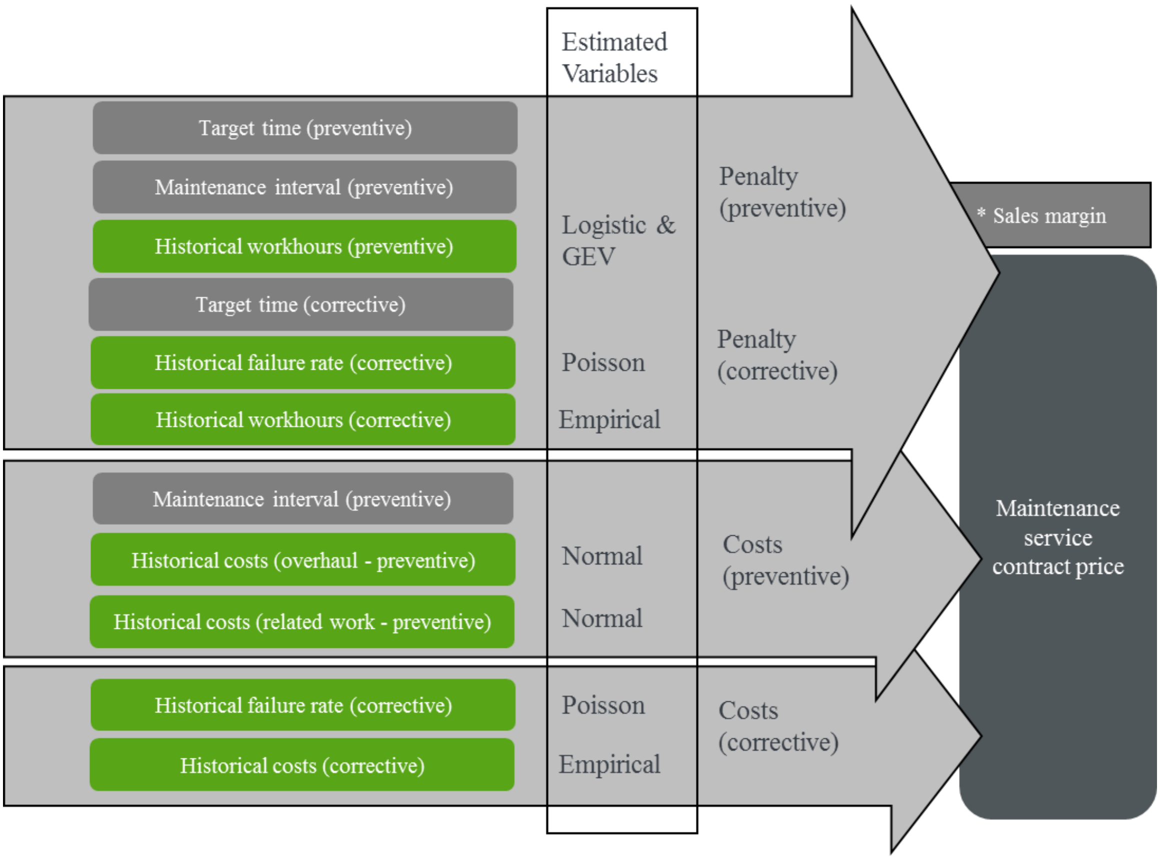

Figure 15. Process of maintenance service contract pricing

Costs for preventive maintenance (C_o) are derived from overhaul's and related work's cost simulations and their magnitude is based on the given maintenance interval that defines number of preventive maintenance actions (N). Corrective costs on the other hand relay on entirely on simulated corrective maintenance costs (C_m) and estimated failure rate (F) which dictates the incidence of the events in contract span. Penalty issued for both preventive and corrective maintenance are affected by simulated workhours (V_i for preventive and Y_i for corrective maintenance) and target time (τ_c and τ_P) for corrective and preventive maintenance respectively. Penalties (α) for preventive maintenance take place depending on fixed maintenance interval events, while penalty (α) for corrective maintenance is dependent on estimated failure rate and its occurrences. As there is only one customer, equation 4 is simplified and formed followingly as presented in equation 5.

$$P = \frac{(C_oN + C_mF + \alpha(\sum_{i=1}^{N} max\{0, (V_i - \tau_P)\}) + \alpha(\sum_{i=1}^{F} max\{0, (Y_i - \tau_c)\}))}{} * K \quad (5)$$

where

$C_o = \mathrm{N}(89.3, 24.4) + \mathrm{N}\ (157.55, 61.85)$

$C_m = \mathrm{Empirical(historical\ data)}$

$F = \mathrm{POIS}(239.73)$

$V_i = \mathrm{Logistic}(1\ 745.08, 372.21) + \mathrm{GEV}(372.35, 1132.00, 5.04)$

$Y_i = \mathrm{Empirical(historical\ data)} * \mathrm{POIS}(239.73)$

$K = (1 + \mathrm{Sales\ margin})$

Equation 5. Simulated price of the contract *

As seen from the equation 5, costs from maintenance services and penalties are then summed and multiplied with sales margin. Hence, pricing of the bogie's maintenance contract is formed through cost plus-pricing. Finally, price of the contract is simulated 10 000 times and mean of the price as well as 2.5 % and 97.5 % percentiles are obtained.

5.2 Results

Simulation used in this study gives overall picture of the maintenance service costs and penalties inquired by the case company in restricted environment. This gives case company's management method to make decisions based on more precise statistical results rather than relying purely on averages and conjecture. Presented simulation model works as a foundation for pricing maintenance service contract. Simulation also contributes to risk management and helps to assess effects of different variable changes on probability of loss. To assess profitability of proposed maintenance service contract, a risk analysis of possible losses is conducted based on the length of the contract and number of iteration rounds. Simulated overall costs and contract price are compared and the percentual share of estimates that would

* Numbers have been altered

result in loss are given as an output giving the calculated risk of loss for given marginal.

Overall costs incorporating costs of preventive-, corrective maintenance and penalties are plotted in figure 16. Confidence intervals are added in red. Plot indicates that the overall costs are not normally distributed but seem to be skewed to the right similarly to corrective maintenance costs. Mean of the overall costs is marked in pink, while blue lines signal contract prices based on unspecified small, medium and large margins. Risk of loss is calculated by counting estimates of overall costs landing on the right side of the blue lines. Hence, these simulated costs are greater than price of the contract, consequently resulting in loss. The risk of loss depends on the price of the contract and decreases when margin increases. Calculated risk of loss is somewhere between 13 to 14% for small margin, 11 to 12% for medium margin, and 7 to 8% for large margin.

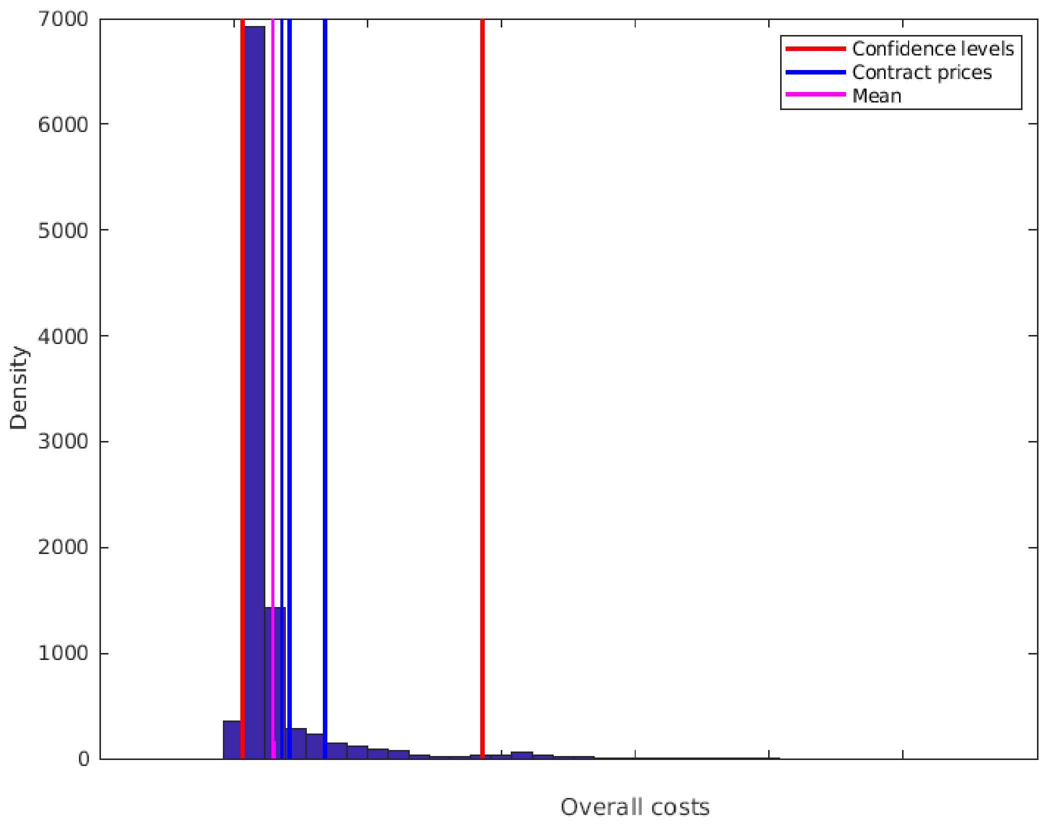

Figure 16. Overall costs, mean, confidence intervals and contract prices[1§]

[1] For given unspecified small, medium, and large margins
[§] Numbers not visible due to confidentiality

Risk associated with the length can be analyzed by changing the variable length of the contract and simulating possible outcomes of the loss. Length of the contract depends on contract terms and is negotiated separately. According to the law of large numbers, "*the average of a sample -- will converge to the population mean -- and the central limit theorem states that the sample mean converges to a normal distribution*" (Brooks 2008, 164), meaning the more values are simulated the closer it is to population mean (Hand 2008, 72). In other words, the longer the length of the contract, the smaller and more stable the risk of loss. However, as the annual failure rate is itself already high, the average sample has already converged close to population mean. Therefore, there is no great volatility between time periods beyond half a year as seen in figure 17. For that reason, changing the length of the contract to avoid risk of loss does not have effect after minimum half year length has been exceeded as the risk of loss remains somewhere between 13 and 14 % after that.

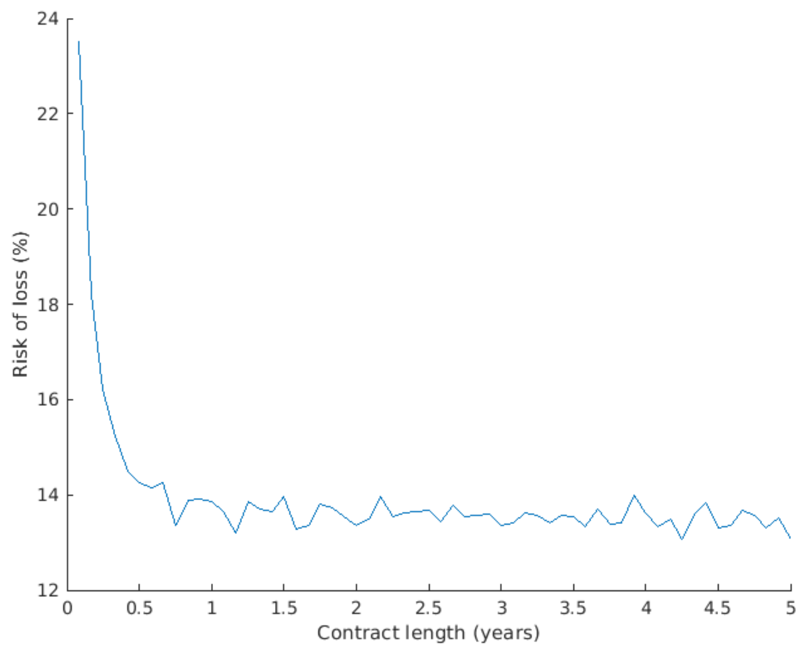

Figure 17. Risk of loss (contract length)[1]

The law of large numbers is also applicable in risk analysis of changing simulation's iteration numbers as seen in figures 18 and 19. Simulation iteration rounds affect how many times the simulation is performed and how many times generated variables are simulated. The more simulation rounds are performed the more

[1] For given unspecified margin

converged the variables are to the mean. As seen in figure 18, there is volatility in probability of loss between 1 and 10 000 simulation rounds. After that volatility diminishes and values have converged towards the mean giving probability of loss somewhere around 13 and 14 %. Therefore, minimum desirable number of simulation rounds are 10 000 and over to gain converged risk of loss.

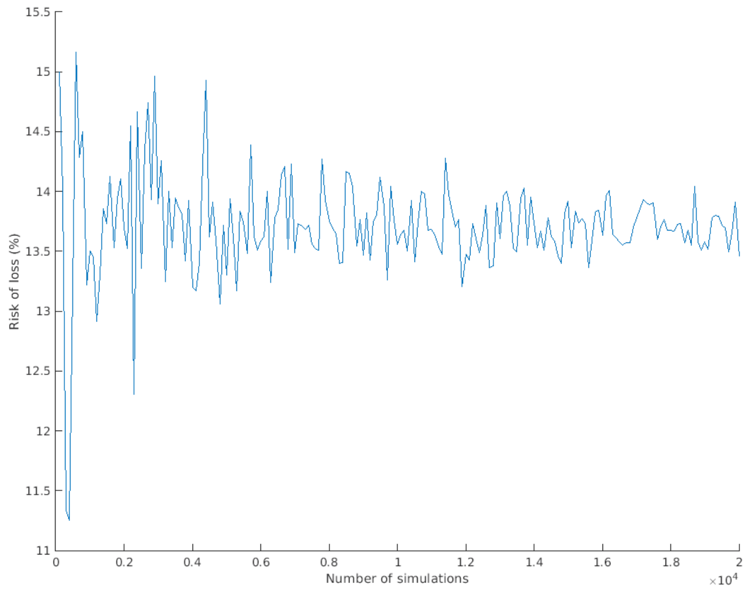

Figure 18. Risk of loss (simulation rounds from 100 to 20 000)[1]

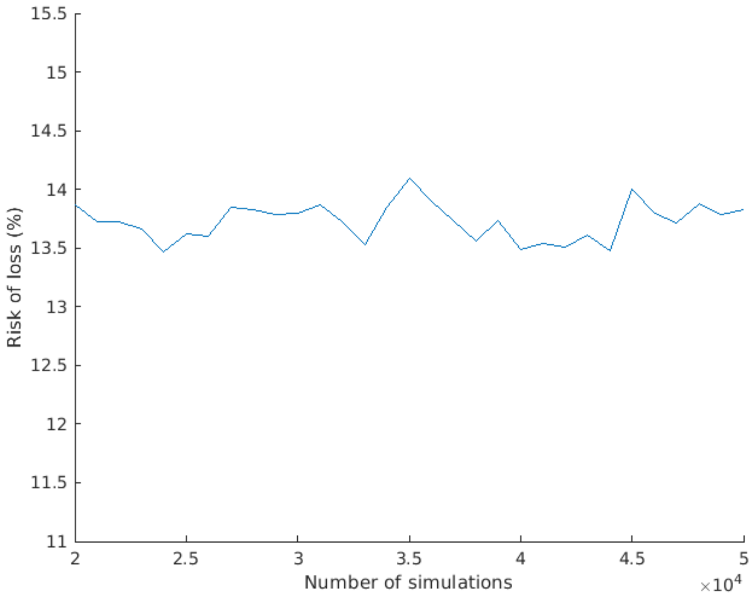

Figure 19 . Risk of loss (simulation rounds from 20 000 to 50 000)[1]

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[1] For given unspecified margin

Simulated preventive-, corrective maintenance, and penalty costs are calculated together following the process detailed in figure 15, whilst their simulated mean is used as base for maintenance service contract price adding sales margin on top of it. Sales margin is defined by the case company dictates the risk of loss. In summary, risk of loss for given margin remains close to 13 and 14 % when estimates are converged and excessive risk correlating with uncertainty has been removed. Risk assessment gives guidelines and based on the analysis, management can make changes to sales margin or negotiate terms affecting given variables a new.

5.3 Reliability

Reliability refers to accuracy of the results obtained (Heikkilä 1998, 29). In this thesis, reliability is influenced by both methodology and constrains associated with it, along with the human factor and system errors that are present in input data used in this research. Methodology has its own uncertainty factors that need to be taken into consideration and dealt with, yet some uncertainties are unfading. Also, to obtain reliable results it is important to ensure that the sample represents the population of interest (Heikkilä 1998, 29). Conducting research on pricing of the bogie's maintenance service contract and ensuring the reliability of this research, requires reviewing and changes to the data. Furthermore, a few limitations need to be taken into consideration when applying results.

In simulation, factors that can be weaken the reliability of the result is its preciseness, result variability, and specificness to the experiment. Brooks (2008, 558) states that even if number of rounds is great in Monte Carlo-simulation, it is sensitive to incorrect assumptions about its specifics and can result in unprecise outputs. This study uses χ^2 goodness-of-fit test to eliminate uncertainties related to probability distributions that are used to derive random values. Some of the uncertainty remains as few of the variables require adjusting in data samples or empirical distributions to find fitting probability distribution. Outputs from the simulation variate depending on simulation. This is characteristic to a method that uses sets of random numbers that change every simulation (Brooks 2008, 558), although due to law of numbers great number simulation rounds ensure that estimates converge towards the mean, removing some of the uncertainty. Other limitation associated with Monte Carlo-simulation is that the output it produces only applies in certain setting (Brooks 2008, 558). This needs to be considered when pricing model is scaled to other contracts. To obtain reliable results, each contract requires own simulation model as the maintenance program and statistics vary between equipment and fleets.

Some uncertainty connected with methods using probabilities is not possible to fade away as seen from figures 18 and 19. According to Köhn (2017, 64) aleatory uncertainty comes from assumption of fundamental randomness associated with probabilities. This kind of uncertainty cannot be reduced since it is independent of the observer (Köhn 2017, 64) meaning some uncertainty is always present, the same way it is in for example when throwing a dice, where the probability remains 1/6 no matter the throw. In this research, aleatory uncertainty is noticeable in the risk of loss that can be minimized to some extent, yet some remains as variation of risk of loss is somewhere between 13 to 14 %.

Probability of the simulation to derive realistic outputs is directly dependent on the quality of input data (Borndörfer et al. 2018). Furthermore, quality of data is dependent whether there are outliers that need to be examined (Hand 2008, 43) and if the input data correctly ciphered to produce reliable results (Borndörfer et al. 2018). As stated by Hand (2008, 44) "*poor data risk yielding poor result*". Epistemic uncertainty describes the degree of knowledge that is known about the objective of study (Köhn 2017, 64) and affects what assumptions are made about the data used in the study. To avoid poor results and epistemic uncertainty in this study, actual data describing maintenance events is presented to specialists. Data is then screened by the specialists for outliers and errors. Based on the review, incorrect data is removed from the data sample and handled data sample is further transformed to be used in simulation. Epistemic uncertainty is battled by not relying on raw data or specialist's estimates alone but using both actual data as well as specialist knowledge combined. Other uncertainties are brought by used data sets as they are connected. Historical data of costs for preventive and corrective maintenance correlate with workhours. In general, if workhours are high, costs are also higher. However, the effect of this correlation is toned down as workhours are only used to determine whether penalty is issued or not and historical data contains a three-digit number of samples.

6. DISCUSSION AND CONCLUSION

While some train operators still maintain their own fleet, many operators have been outsourcing their maintenance services especially in Europe. As a result, outsourcing of maintenance services has created new demand for service providers. To offer maintenance services, contract needs to be drawn between parties and price defined in exchange for the service. The aim of this thesis is to contribute to research on pricing maintenance service contract, while the main objective is to find pricing method for train bogie's maintenance service contract from service provider's perspective. Approach for this research problem is combining theoretical literature with practical implication through case study. Findings show that there are different approaches to maintenance service contract pricing from optimization to simulation. In this study, pricing model is derived from Jackson & Pascual's (2008) optimization model, while Bowman & Schmee's (2001) simulation method is used to generate random variables included. Utilizing simulation, it is possible to calculate simulated overall costs for the maintenance contract and use it as a base for cost plus-pricing along with modelling confidence levels as well as effects of different margins.

To answer the main research question on how to price train bogie's maintenance service contract, sub-questions are first reviewed. In the beginning of this study, different types of maintenance services and actions are examined. Further outsourcing of those services to service provider are discussed. Maintenance services and their contracts are investigated answering the following sub-research question

What is said about maintenance service and its contracts in previous studies?

In rail industry, maintenance services are divided into preventive and corrective maintenance and both are important in upkeeping safety and operational state of the fleet. Also, supplementary maintenance can be offered by the service provider. Maintenance services vary depending on their scope. Object of the maintenance can be refurbished when it's returned close to its original state, while minimal repair keeps the failure rate almost unaffected. Outsourcing of maintenance services is a growing business as inhouse maintenance can require uneconomical investments into technology, human resources, and facilities.

Literature define maintenance service contract as an agreement between customer and service provider, where service provider performs outsourced maintenance actions for agreed period of time. Maintenance service contract is shaped by its terms and condition and pricing is influenced by the pricing strategy. Terms and conditions need to be clearly defined to avoid disputes between parties and outline what is the content of the contract. Two payment method are presented in the literature: price for repair and full service contract where fixed payment is made for certain maintenance actions that are performed for agreed period of time without additional costs. Pricing strategy defines how maintenance service contract is priced. Even though, value based pricing is recommended, many companies still use market- or cost-based pricing in their contracts.

Literature review in this thesis takes a look at different pricing models that have been used in maintenance service contract setting. By examining pricing models including optimization and simulation models following sub-research question is answered

How maintenance service contracts pricing has been modeled?

Optimization and simulation model dominate literature on pricing of maintenance service contract. Optimization models often use game theoretic approaches where service provider can be either follower or leader and game setting vary from cooperative to non-cooperative. Models use profit or value as base for the game and negotiation power. Additionally, some optimization models have introduced new variables to improve the accuracy of the model and most of times include variables typical to contracts, for example penalty or delay. Simulation model expands research on pricing by enabling financial risk assessment of the contract and is therefore useful in risk management. It also uses interactive variables that are derived from databases and historical data using statistical models enabling more dynamic approach to contract pricing. In pricing models, price of the contract can be one variable amongst others. Objects of optimization depend on the model and usually include number of customers, service channels, and maintenance strategy. Pricing models also vary depending on setting and assumptions made by the authors. Models are often constructed based on certain equipment’s and setting’s characteristics which affect the end result. These specifications often limit the applicability of the models and require major modifications to fit other than original research setting. Therefore, applying optimization or simulation model used in literature require extensive background work and comparison to find the most suitable one.

By answering the supporting research questions about maintenance services and their contracts, main research question can be answered and applied to case study

How to price maintenance service contract from service provider's perspective?

In order to know what maintenance is included in the price maintenance service contract, the maintenance need for bogies need to be defined. Train bogies are subjected to preventive and corrective maintenance, which are either based on time interval or failure as seen in table 2. Preventive maintenance includes overhaul of the bogies, where it is furbished close to “good as new” condition and related work which includes logistics as well as detachment and attachment of the bogies from the carriage. Costs and workhours from preventive maintenance are fairly steady and seem to be normally distributed. As everything that does not fall under scheduled maintenance is deemed as a corrective maintenance, range of maintenance actions vary from leak to traffic stopping failure. For this reason, corrective costs and workhours have more variation and appear to be skewed to the right. Both maintenance services are important in upholding the bogie in operational state and are therefore included in the contract, while seasonal maintenance are excluded from this study. In this study, maintenance service contract is full service contract, where maintenance services described above are included into the contract and penalty is issued if target time for each maintenance is not met. The price is given for a specified period and maintenance services performed without additional costs. Although value based pricing is recommended, case company is subsidiary and hence cost plus-pricing is used.

After defining content of the maintenance service contract of bogie's, variables of the pricing model have been identified. This research uses Jackson & Pascual's (2008) optimization model as well as Bowman & Schmee's (2001) simulation model to calculate price for the contract. Jackson & Pascual (2008) provide pricing model that imitates case company's existing maintenance program making it easier to apply in this case. While profit sharing is not found to be beneficial between group and subsidiary, function is used as a base for equation 4. Simulation model of Bowman & Schmee (2001) is applied to calculate price for the pricing model. Expectation values for costs, workhours, and failure rate are derived using probability distributions and simulation, whilst fixed maintenance interval, cost for penalty and its target times are given by the case company. Simulation is effective in obtaining values, although distribution fitting demands altercations and affect reliability of the results. Based on given unspecified margins contract prices are computed and for each price risk of loss is calculated. Although some risk is inevitable, by increasing margin percentage of risk of loss can be reduced from 13-14% to 7-8% if margin is switched from small to large. Simulation is not only effective in obtaining results but also a practical tool for risk assessment. Risk assessment is extended by conducting analysis based on the length of the contract and simulation rounds. Main finding is that there are minimum length and simulation rounds for risk of loss to converge towards the mean. This can be used as a guideline in decision making. In summary answer to how to price maintenance service contract from service provider's perspective is presented in figure 20.

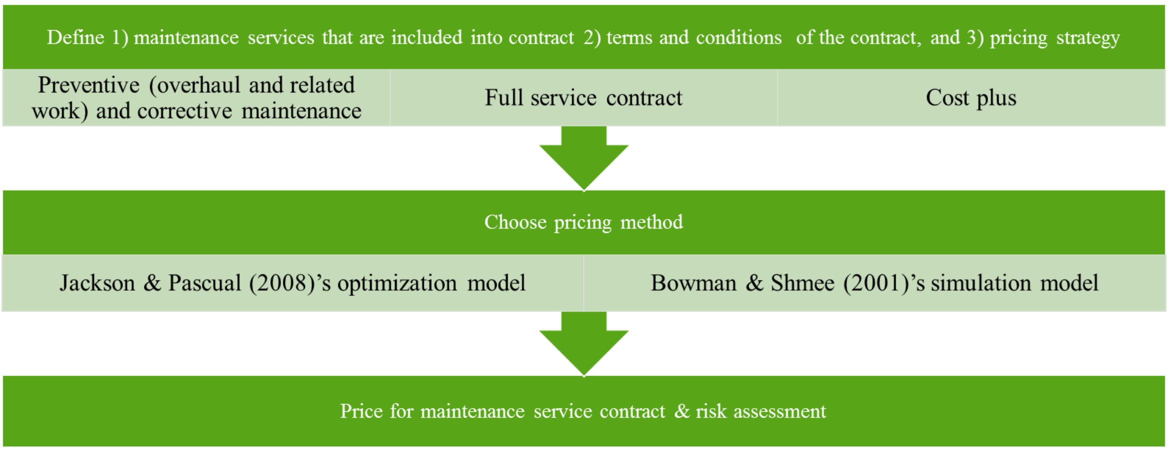

Figure 20. Process on how to price maintenance service contract from service provider's perspective.

Overall, pricing of the train bogie's maintenance service contract requires many steps in order to obtain results. First, maintenance program and terms as well as condition need to be defined to understand what kind of pricing model can be used. After the content and limitation of the contract is known suitable pricing model needs to be selected and simulation model built around it. Finally, risk analysis can be executed to understand effects of different variable modifications. As a conclusion, using optimization model and simulation it is possible to illustrate overall costs associated with the contract along confidence levels and expected returns at various margins can be calculated, facilitating decision making in budgeting, risk management, and contract design.

6.1 Future research

While answering research questions gave some answers and results to field of pricing maintenance service contracts, it also brought up new research questions to be examined. As case study has many limitations and the main focus is on pricing of the contract, many aspects of optimization and simulation are not utilized. This gives room for further research questions described below.

One of the aspects left unused is the profit based approach to optimization of the contract used in previous research (e.g. Guang-ping et al. 2006, Kong et al. 2019). Future research questions can extend this study by changing setting from subsidiary and group company to the case company offering its services to fully external customer. In this case, value based pricing is justified, and profit based game theoretic approach could be applied. This approach can be examined through research question below

How to optimize maintenance service contract profit using game theoretical formulation?

In this study, the focus is solely on pricing of the contract and other variables and terms are simulated based on the historical data or given by the case company. As in some studies before (e.g. Murthy & Asgharizadeh 1999, Wang 2010) these variables could be optimized along with price of the contract and/or different contract options be examined. Simulation model also allows more interactive variables to be included (e.g. Bowman & Schmee 2001) making the model more realistic as many do have effect on each other, for example the condition of equipment and usage. Case company could exercise these approaches in designing maintenance service contracts when entering the market or competition and for more precise results. Future research questions can be formed followingly

How to optimize maintenance service contract from service provider's perspective?

How to design optimal maintenance service contract?

Other further research questions could exploit new aspects of optimization and simulation models. Technology allows new variables to be included in optimization models, while digitalization and IOT enable more precise data to be used in simulation giving more comprehensive results.

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