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LIFE-CYCLE MODEL OF INJECTION MOLDING MACHINE

Examiners: Professor Timo Kärri
Post-doctoral Researcher Antti Ylä-Kujala

ABSTRACT

Lappeenranta-Lahti University of Technology LUT
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LIFE-CYCLE MODEL OF INJECTION MOLDING MACHINE

Master’s thesis
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Keywords: lifetime, life-cycle costing, machinery replacement, investment planning

When comparing investments, the lowest purchase price is often not the most economical choice, and engineering system ownership costs exceed acquisition costs. For that reason, it is good practice to examine investment projects with life-cycle costing tools.

This thesis's objective was to design and create a life-cycle cost model of an injection molding machine for a pharmaceutical equipment manufacturer company. The model gives a deeper understanding of how the injection molding machine costs develop during its lifetime.

The research is a combination of qualitative and quantitative research. Research methods included interviews and examination of maintenance history data of an injection molding machine. Life-cycle costs and investment planning literature was used as a reference.

As a result of this thesis, a usable life-cycle cost model was constructed. The model can be used to examine the cost driving factors of an injection molding machine, when planning new investments.

TIIVISTELMÄ

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

Petteri Särkkä

RUISKUVALUKONEIDEN TALOUDELLINEN ELINKAARIMALLI

Diplomityö
2020
65 sivua, 18 kuvaa, 11 taulukkoa ja 2 liitettä
Tarkastajat: Professori Timo Kärri ja Tutkijatohtori Antti Ylä-Kujala

Hakusanat: lifetime, life-cycle costing, machinery replacement, investment planning

Vertailtaessa investointeja, alin kauppahinta ei usein ole taloudellisin vaihtoehto, ja järjestelmien koko omistamisen kustannukset ylittävät hankintakustannukset. Tästä syystä on hyvä käytäntö vertailla investointihankkeita elinkaarikustannustyökaluilla.

Tämän tutkimuksen tavoitteena oli suunnitella ja rakentaa ruiskuvalukoneen elinkaarikustannusmalli lääketarviketeollisuudessa toimivalle yritykselle. Mallin tarkoitus on antaa syvällisempi kuva koneen elinkaaren kustannuksista.

Tutkimus on kvalitatiivisen ja kvantitatiivisen tutkimuksen yhdistelmä. Tutkimusmenetelmiin kuului haastatteluja ja ruiskuvalukoneen huoltohistorian tutkiminen. Tutkimus sisältää elinkaarimallin sekä investointi- ja elinkaarilaskennan teorian tarkastelun, tärkeimpinä lähteinä on käytetty elinkaarikustannuksiin ja investointien suunnitteluun painottuvaa kirjallisuutta.

Työn tuloksena rakennettiin ruiskuvalukoneen elinkaarimalli, jonka avulla voi tarkastella ruiskuvalukoneen kustannuksiin vaikuttavia tekijöitä, ja miten kustannukset kehittyvät ajan myötä.

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16.11.2020

Petteri Särkkä

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1 INTRODUCTION

1.1 Background of research

Life-cycle costing has become a standard tool in business investment project planning. Life-cycle costing is particularly suitable for long term investments. Typical practice for firms is to compare investment projects payback period and initial procurement costs. The lowest purchase price is often not the most economical choice, and engineering system ownership costs exceed acquisition costs. For that reason, it is good practice to examine investment projects with life-cycle costing tools. The business wishes to make better investment decisions but suffer from a lack of resources and knowledge in life-cycle costing theory. The theory for this thesis was gathered from various sources that are listed in the reference list. The leading books used as a reference covered cost accounting and management, investment planning, and injection molding machines' technology. The essential articles that were used in this study discuss the theory and history of life-cycle costing.

Often new investment is related to the replacement of the existing machinery or equipment. Regarding Götzte (2008, 6) businesses should use appropriate investment appraisal methods that helps choose the best investment options. Modeling is proven to be a good practice to compare different investment options. Models can be customized to the needs of the company.

This thesis started with the target company's needs: Medisize Oy to research the total costs of ownership of the injection molding machine and improve the investment planning process. There has not been any previous research on the subject made in the company. The thesis is essential for the company because it can gain more accurate information concerning the injection molding machine's life-cycle costs, and it can be used as a reference for investment appraisals.

Medisize Oy was founded in 2006. In 2020, the company employs approximately 500 employees in Finland. The revenue of the company in 2019 was 82 million euros. It is owned by Phillips Medisize Oy, a global and growing company that provides development and manufacturing solutions serving the pharmaceutical, diagnostics, and medical device customers. Phillips Medisize primary business focus is on complex, regulated drug delivery devices and connected health solutions. Medisize Finnish office is in Kontiolahti, and the company also has factories in Ireland and the Czech Republic. The owner company, Phillips Medisize factories, are located in the United States of America.

Medisize main products in Kontiolahti are SoloSTAR disposable single-patient-use prefilled insulin pen, Zoladex drug inserts, and Mirena hormonal contraceptive inserter. In addition to these three main products, other pharmaceutical and diagnostics related products are manufactured in Kontiolahti.

In the Czech Republic, the main manufactured products are appurtenance of respirators, related diagnostic products, and hospital equipment. In Ireland, the main manufactured products are infusion containers, medical devices, and hospital equipment.

1.2 Objective and research questions

This study's objective is to design and create a life-cycle cost model of injection molding machines to use the organization's investment planning. Besides, the research aims to define the machine hour rate and the cost factors of the injection molding machine. The research is conducted by studying the existing literature to understand how life-cycle modeling is designed and implemented. The research methods also include the investigation of the machine’s maintenance history data. The definition of the investment process is also included in the literature part of the research. Several interviews were performed at the target company to understand the organization's needs.

The model is designed for the target company's use, taking into consideration its objectives and strategy. The results of the model can be used to improve the planning of future investments. The study's focus is on the life-cycle costs (LCC). The life-cycle profits (LCP) are discussed shortly, but not considered in the construction of the model.

The study intends to answer the following questions:

1. What are the main aspects that influence an injection molding machine's total costs of ownership?
2. What is the construction and logic of the life-cycle model?
3. What is the machine hour rate of the injection molding machine?

1.3 Research methods and data

Chapters 2-4 presents the theoretical background of this research. The literature review shows different theories based on previous research and studies. All the references used in this research are listed at the end of the study.

In this case, the research method is a combination of qualitative and quantitative methods. Quantitative and qualitative research methods are explained in the following chapters.

Quantitative research method

The quantitative research method's objective is to deploy mathematical models, theories, and hypotheses using statistical, mathematical, or computational techniques. The numerical data is collected through polls, questionnaires, and surveys, or preexisting data is manipulated. The critical factors in quantitative methods are the process of measurement because it gives an essential connection between empirical research and mathematical definition of quantitative relationships. (FlexMr 2019)

Any data that is in numerical form is quantitative data. The data is analyzed and generalized to some larger population with the help of statistics. Quantitative research is commonly used in psychology, economics, demography, sociology, marketing, community health, health & human development, gender studies, and political science. In anthropology and history, another research method is more common, such as qualitative research. (FlexMr 2019)

Qualitative research method

The qualitative research method leans on unstructured and non-numerical data. Data for qualitative research can be gathered from observations, note-taking, interviews, documents, and artifacts. Qualitative research methods try to find answers to question about what people think and why. The benefits of qualitative research are that it can provide complex textual descriptions of how people experience a given research question. It gives the “human” perspective to the research question. (N Mack 2005)

Regarding Minchiello (1990, 5), quantitative and qualitative research methods can be compared as shown in Table 1.

Table 1. Qualitative and Quantitative comparison Minchiello (1990, 5)

	Qualitative	Quantitative
Conceptual	Concerned with understanding human behavior from the informant’s perspective	Concerned with discovering facts about social phenomena
	Assumes dynamic and negotiated reality	Assumes a fixed and measurable reality
Methodological	Data are collected through participant observation and interviews	Data are collected through measuring things
	Data are analyzed by themes from descriptions by informants	Data are analyzed trough numerical comparison and statistical inferences
	Data are reported in the language of the informant	Data are reported through statistical analyzes

As discussed, for this research, both qualitative and quantitative research methods were used. Several interviews were selected as the research methods. Also, data based on the company's internal and external documents were used. Quantitative data was available regarding the injection molding machine's maintenance history. The research attempts to be as objective as possible, and the researcher does not have any previous employment with the case company.

1.4 Structure of the research

This thesis is organized according to the input-output structure presented in Picture 1. Background and the motivation of the study are explained in Chapter 1. Chapter 2, 3. handles the literature review of basic investment planning theory, replacement models, life-cycle costs theory, and the theory of the cost of quality. Chapter 4. contains the presentation of the case company, and empirical research of the study. The structure and use of the life-cycle cost model are presented in Chapter 5. Chapter 6. handles the results of the research. The summary and conclusion are given in Chapter 7.

Table 2. Structure of the study

INPUT	CHAPTER	OUTPUT
Intrduction of the topic	INTRODUCTION	Objective of the research, deliminations, research questions, construction, methodology
Basic investment theory	INVESTMENT PLANNING	Basic investment methods
Replacement time and life-cycle costs theory, backround, history	REPLACEMENT MODELS FOR MACHINERY	Advanced investment methods
Target company	CASE PHILLPIS MEDISIZE OY	Injection molding lifecycle costs, different perspective of the cost development
Life-cycle costs of injection molding machine	MODEL	Annual costs development
Results of the research, and previous research	RESULTS	Analysis of the results found in in the research
Important results, theory used	CONCLUSION	Abstract of the content, results found, and suggestions

2 INVESTMENT PLANNING

The development of the company's operations requires different investments. Investment decisions are an essential part of strategic planning to ensure the company's operating condition and development in the long term. (Järvenpää 2017, 373)

Investment refers to the use of assets for targets that generate a return in the long term, commonly over one year. Investment can refer to tangible assets, such as buildings, machines, and equipment, or intangible assets, such as long-term training of the personnel, research, and product development. Investment referring to IT infrastructure or management systems can include tangible and intangible assets. (Järvenpää 2017, 373-374)

2.1 Investment process

The investment process can be divided into stages, which helps to manage the investments. Latest models basis on the strategy of the company. Pellinen (2018, 87-90) represents seven stages of the investment process that can be divided as follows:

1. *Field of strategy.* With the help of strategy, the relevant standard competitive weapons are determined the way that business management believes that the company will succeed. The owners must approve the chosen strategy.

2. *Find an investment idea.* Implementing the general strategy policy requires investing money in long term projects. To make sure that the investment opportunities are represented from the perspective of the chosen strategy, the management needs to adequately inform the whole company about the strategy and goals of the company.

3. *Prepare the investment proposal.* When someone notices a problem in the organization, it can lead to an investment idea. There must be budget orientated leaders participating in the proposal preparation. Economically and strategically argued proposals are forwarded to the person in the management who is authorized to make decisions.

4. *Value the investment proposal.* It is good practice to prepare more investment proposals than can be implemented in a year. Investment proposals can then be sorted from best to worse.

5. *Plan the implementation of the investment.* Most profitable valued investment costs a lot of money in the short term. It is an essential part of ensuring the sufficiency of the funds. A small investment can be fund with income financing, but large investments can need new capital. When raising new money, it is essential to assess whether it is more profitable to borrow or raise the necessary capital from new or old shareholders.

6. *Approval of investment.* When an investment has been discovered profitable, financing organized, technical planning, and project organization specified, the investment decision can be made. This is the last step to retreat. When the decision is made, usually, the project will be accomplished.

7. *Supervising investments.* Supervising is needed when implementing the investment and after the implementation. Vital areas to monitor are the sufficiency of the money reserved for the project and the project's progress. When the investment project is completed, it can be evaluated economically, technically. An unpredictable number of lessons can be learned from the evaluation of an investment for future investments.

Regarding Götze (2008, 9), capital investments should not be made on an ad hoc basis but should be passed through the company's existing and planned investment program. There are many investment appraisal procedures introduced in investment literature; few mentioned are Mott (1997, 3) and Götze (2008, 10). In the Figure 1. the typical investment process is described by Götze (2008, 10) as a flow chart.

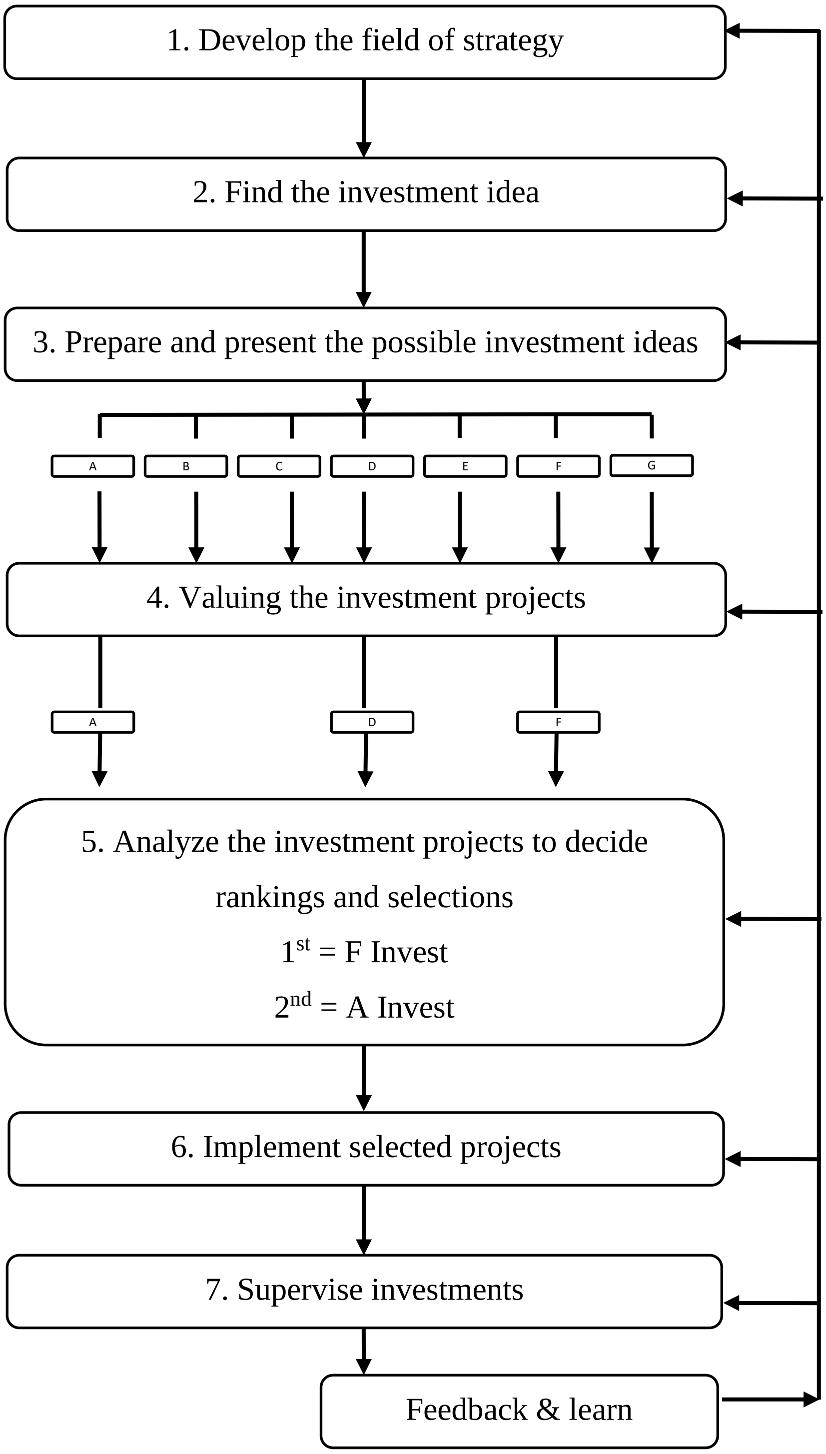

Figure 1. Investment decision making process

2.2 Classification of the investments

Finding the right investment ideas and assessing the investment proposals can be led by various company-based investment classifications. Main investment classifications can be divided as expenses are divided: type of investment, area of responsibility, and purpose of the investment. More accurate classification is always company-based. Type-based classification could example include real estate investments, equipment and machinery investments, company buyout, immaterial investment, and human resources investments. (Götze 2008, 3-26)

Responsibility based classification follows the responsibility map of the company. Essential for the perception of the investments is to determine which areas of responsibility are responsible for the rate of return on investment, and what is the amount of money that investment units can decide on investments. A common practice is that small investment decision can be made in a cost center or production facility, and in large investments, the decisions must be made in the board of directors. (Götze 2008, 3-26)

The purpose of the investment-based classification is example dived to mandatory investments, ensuring position on the market, repair investments, rationalizing investments, extension investments. (Pellinen 2018, 89)

Classifications can be used when informing about the investments' priority if the organization is aware of what investments are essential and what investments are at the bottom of the line. The effort can be steered to more desirable investments. The company may agree that it will only make repair investments in Switzerland and extension investments to Finland in the coming years. (Pellinen 2018, 89)

2.3 Basic discounted cash flow investments analysis

There are various analysis to assess the profitability of an investment. In this context, the word profitability stands for a positive economic return from an investment project. (Götze 2008, 31) This chapter considers basic analysis to assess the profitability of an investment.

2.3.1 Hurdle rate

The hurdle rate is an estimated interest rate used rather than the traditional interest rate associated with debt. The hurdle rate is used; as a result, the conventional rate does not precisely follow the real market rate of interest, or there is no traditional rate at all. The hurdle rate estimates the price that is used for the debt that haves an independent borrower and banker and with comparable conditions of the contract. It is a common situation that arises when assets are loaned between related parties, and the interest rate is not charged. The hurdle rate of return can be considered as a required rate of return because the financial capital is never free. Rate is expected to be paid for borrowed money, and dividends are expected to be paid for the owners. The required rate of return and the rate of interest forms the cost of capital. The average price that a company is expected to pay to all its security holders to finance its assets is called: the weighted average cost of capital (WACC). A common practice is that the hurdle rate is chosen to be higher than the weighted average price of money. Tax effects can also be integrated into the calculations. The company can deduct the payments of the borrowed money. WACC can be calculated with the equation 1. (Saaranen 2016, 326)

$$WACC = \frac{E}{V} \times r_E + \frac{D}{V} \times r_D \times (1 - T_c) \tag{1}$$

where
E = Market value of the company's equity
V = Total market value of the company's financing (E + D)
r_e = Cost of equity
D = Market value of the company's debt
r_d = Cost of debt
T_c = Company's tax rate

The hurdle rate is also used to calculate the time value of the money. The returns and costs are dated to a different period, and the imputed interest rate is used to make the transactions comparable. Comparing the present and the future value can be done by discounting the prospective transaction with the agreed hurdle rate.

2.3.2 Net Present Value Method

The net present value (NPV) method calculates the expected financial loss or gains from a project by discounting all estimated future incomes and outcomes to the current point in time, using the required hurdle rate (Horngren 2006, 727). Projects with zero or positive NPV are profitable and acceptable because the returns from the projects are equal or higher than the cost of capital. Projects with high NPV are better. NPV is a widely used method in theory and practice. Because the arithmetic calculations are enough, the computational effort is low. Data collecting might be challenging because several predictions are necessary. Initial investment outlay includes all future cash flows, the project's economic life, the liquidation value at the end of economic life, and the applicable discount rate. The total time of the investment project's economic life is also included. It is not likely that all the necessary data is 100% certain. For the effect of uncertainty, additional analyses should be made. Net present value can be calculated with the equation 2. (Götze 2008, 54)

$$NPV = \sum_{t=0}^{T} (CIF_t - COF_t) \times q^{-t} \qquad (2)$$

Where:
t = Time index
T = The last year when cash flows take place
CIF_t = Cash inflows in t
COF_t = Cash outflows in t
q^{-t} = Discounting factor in t ($q^{-t} = \frac{1}{q^t} = \frac{1}{(1+i)^t}$)

The benefit of the NPV method is that it shows the computations in currency value, not percentages. (Horngren 2008, 730)

2.3.3 Annuity Method

The annuity method (AN) uses discounted cash flow model like the NPV method, but the target measure is the annuity. The total planning period can be divided to series of equal amount cash flows, that is called annuity. The annuity is amount that can be withdrawn in every period when launching an investment project. The NPV and annuity of an investment project are equal and can be both calculated mathematically. An investment project is considered to be profitability when annuity of the investment is greater than zero. Determining relative profitability of the investment projects, the project which has higher annuity than the alternative investment project is preferred, however the annuity method is not fully suitable when determining relative profitability. (Götze 2008, 65)

Calculating an annuity of the investment the cash flows are commonly targeted to end of particular period, and the economic life of the project is the time interval used. Regarding Götze (2008, 65), the annuity can be calculated with the equation 3.

$$ANN = NPV \times \frac{(1+i)^T \times i}{(1+i)^T - 1} \tag{3}$$

Where:
i = Discount rate
T = Economic life

From equation 3, we can witness that the annuity method leads to the same estimation of absolute profitability as the NPV. When i and T are higher than zero, the capital recovery factor is higher than zero as well. A positive or negative annuity is the result of positive or negative NPV. When comparing the investment projects, and the projects have identical economic life interval, the recovery factors are also identical. (Götze 2008, 65)

The calculation of the annuity method is similar, but somewhat more difficult than NPV. In many cases, the annuity method is unnecessary. When analyzing the absolute profitability of the projects, the NPV method leads to the same result. (Götze 2008, 67)

2.3.4 Internal Rate-of-Return Method

The internal rate of return (IRR) is similar to the NPV method. The IRR is the discount rate that causes the NPV of the investment project to be zero. The IRR estimates the investment's future return rate, and it is the sum of the annual rate of return earned on an investment project. Both methods need the same data. Regarding Götze (2008, 67), the calculation of an approximated IRR is slightly more complicated than the NPV analysis.

Estimated cash flows of an investment project are needed, and the NPV must equal to zero when calculating the IRR. The company's hurdle rate is commonly compared to IRR. If the IRR is larger than the cost of capital or hurdle rate, the investment is considered to be profitable. The equation 4 represents the mathematical calculation of IRR. (Hayes, 2020)

$$NPV = \sum_{t=1}^{T} \frac{C_v}{(1+IRR)^t} - C_0 = 0 \tag{4}$$

Where:
C_t = Net cash income during period t
C_0 = Total cost of investment
IRR = Internal rate of return
t = The number of time periods

When using the IRR method, managers commonly assume the discounted rate is equal to the rate of return earned of the projects, and such investment opportunities may not be available. (Horngren 2008, 730)

2.3.5 Sensitivity analysis

NPV and IRR methods assume that the expected cash flows are certain. Life-cycle analyses also contain risks and uncertainties. When discussing risks, the probabilities of future events are known, and when talking about uncertainties, the likelihood of future events is unknown. In this context, the risk is measurable uncertainty. (Neilimo & Uusi-rauva 2005)

Managers can use a "what-if" technique to examine how the outcome will change if a critical assumption changes. Sensitivity analysis examines how the result will change if one or more variables are changed, and the effects of evaluation errors are found when the analysis is done to all variables and components. (Horngren 2008, 730)

For example, determining NPV of the investment Götze (2008, 274-280) represents the following input variables that can be used for sensitivity analyses:

- The initial investment outlay
- The sale price of the production
- The volume of the sales or production
- The economic life of the investment
- The discount rate
- The cash outflows of production

Many variations arise as a result when input measures are used in isolation or combination with other measures. (Götze 2008, 280)

Sensitivity analysis can be used with any method for appraising an investment project; it can be applied to optimum economic life determination and the visualization of financial implications. For investment decision making under uncertainty, sensitivity analysis is a valuable tool. (Götze 2008, 280)

Sensitivity analysis has some disadvantages as well. The measures that are not analyzed, certainty is assumed. This expectation is often incorrect because input values rarely change independently. If two or more values are changed simultaneously, it can lead to interpretation difficulties. Another disadvantage is that not many input values can be clearly analyzed, and the probability of their deviation is ignored. (Götze 2008, 280)

Sensitivity analysis intends to examine the relationship between the current data and the target variables of an investment appraisal. If data is available, the profitability of different options as well. Its focus is to study the uncertainty in the output of a mathematical model. Götze (2008, 274) presents the following two questions that sensitivity analysis is trying to find answers:

- How does the target data change with different input variables?
- What are the input variables that give the desired output data?

The target data changes can be analyzed by starting with the original data and changing it using different possible input data. The implementation of sensitivity analysis is based on constructing the replacement model and resolving its input variables. Götze (2008, 274)

Sensitivity analysis examines the effects of uncertain model data and gives an observation into the structure of a model. Sensitivity analysis does not contain any decision rules, and the decision-maker will make the final decision to select an investment alternative based on the result received. Götze (2008, 280)

3 REPLACEMENT MODELS FOR MACHINERY

3.1 Lifetime

The lifetime of an investment project means the period for which it operates. A project's lifetime can be hindered for many reasons. For example, agreements in contracts or legal matters can set up an upper limit on economic life, or technical aspects can limit how long a project can maintain its function. In some cases, technical life can be increased with proper maintenance and repairs of the equipment. (Götze 2008, 131)

Götze (2008, 131 - 133) has found that technical life often should not be wholly exhausted to maximize financial success. The product market can change and make the existing equipment uneconomic with the project. Or the development of technology can present alternative investment opportunities that can fulfill the needed requirements at lower costs or higher qualities.

Economic aspects also control the optimum economic life. Economic life is always shorter or equal to the project's technical life. (Götze, 132)

3.2 Life-cycle costs

3.2.1 History of life-cycle modeling

The history of life-cycle costing first begun in the 1960s when the US Department of Defense determine the continuing cost effects of military equipment when making investment decisions. Commonly, the acquisition price is used to make decisions about investments. This is, however, considered bad practice because it usually leads to an economically bad decision. The total costs of ownership usually are bigger than the acquisition itself. In life-cycle costing, the total costs of ownership are also considered to make decisions about the investments. (Lindholm & Suomala 2002)

3.2.2 Life-cycle costing economics

Economics is one of the critical factors in life-cycle costing. Various economic-related information is required to calculate different life-cycle cost items. It is also necessary to consider the time value of money when calculating the life-cycle's potential costs. The time value of money considers interest and inflation rates. In life-cycle costing, all the future costs, including operation and maintenance costs of the item, must be discounted to their present values before adding them to the cost of acquisition. Many formulas and models have been developed for converting money from one point of time to another. These formulas are essential in life-cycle costing. Typical parts of life-cycle costs are presented in Figure 2. (Dhillon 2010, 11-25)

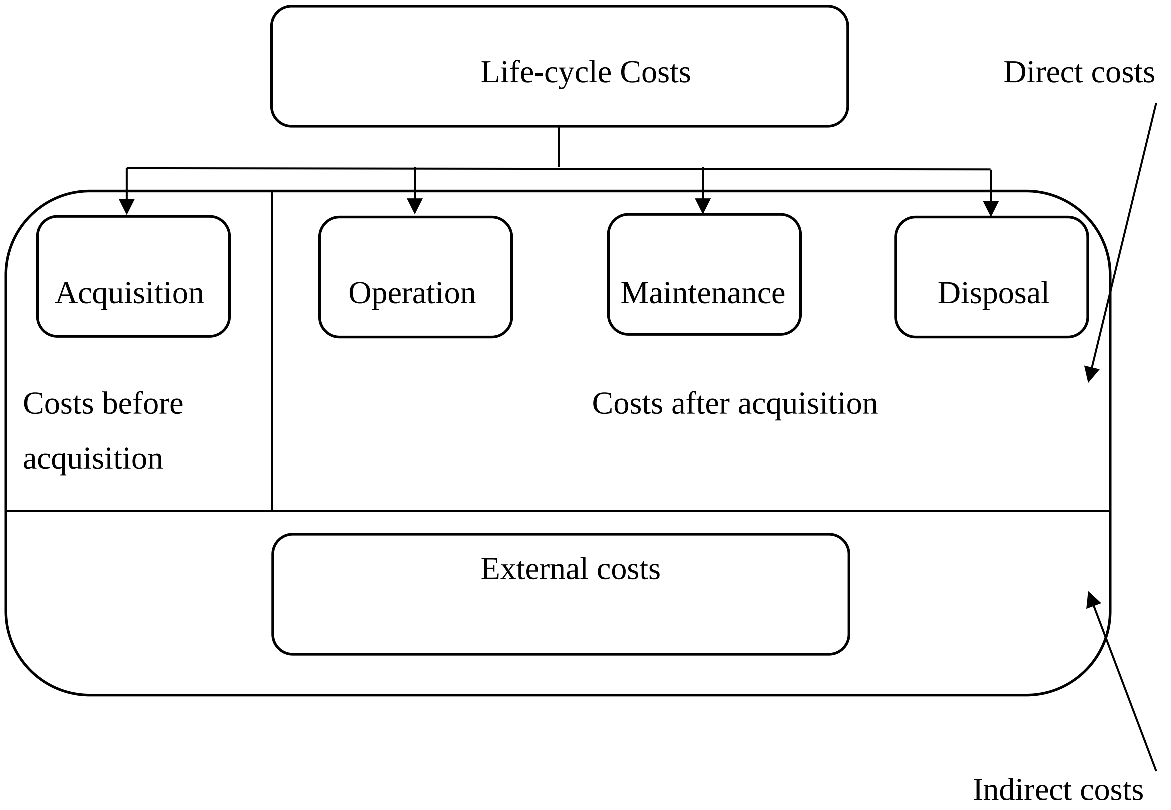

Figure 2. Direct and indirect costs

Categories of total costs

According to Tenhunen (2013), the most common classification, a company's costs are divided into fixed costs and variable costs. Other standard cost categorizations are direct and indirect costs (Horngren 2006, 30-37).

The rate of operation of a company determines whether the cost is a fixed cost or variable cost. The operating rate points to the actual production volume in a unit of time. Capacity refers to the company's maximum performance in a unit of time. If the operating rate is proportionate to capacity, the answer is a percentage describing the company's operating ratio. If the costs increase or decrease as the level of activity changes, variable costs are involved. Fixed costs remain constant.

Typical variable costs of an industrial company include aspects such as raw materials used in the manufacturing process, parts that are purchased, semi-finished products purchased, subcontracting services, manufacturing labor costs, and other wages that change in relation to production, example, transport, maintenance of equipment, sorting and loading.

Fixed costs do not depend on operating rate changes. Typical fixed costs include interest and depreciation of capital tied up in machinery and equipment, space rents, heating and sanitation, necessary electricity charges, management and staff costs, personnel costs, miscellaneous administrative costs, representation, and computer, and office equipment costs.

Regarding Kärri (2007, 51), Direct costs can be traced to the cost object in an economically reasonable way, as opposed to indirect costs, which are allocated to a particular cost object. Common cost objects are services, customers, brands, activities, departments, and projects.

When assigning total costs, variable costs and fixed costs can be divided into direct and indirect costs. The costs can be direct and variable, direct and fixed, indirect and variable, or indirect and fixed at the same time. (Kärri 2007, 51)

Example an office building is fixed cost, but it is also an indirect cost. Raw materials are considered to be variable and direct. The cost of a complete factory is both fixed and direct. The cost of advertising is variable and indirect. The four possible combinations are shown in the Figure 3. (Cammarano, 2020)

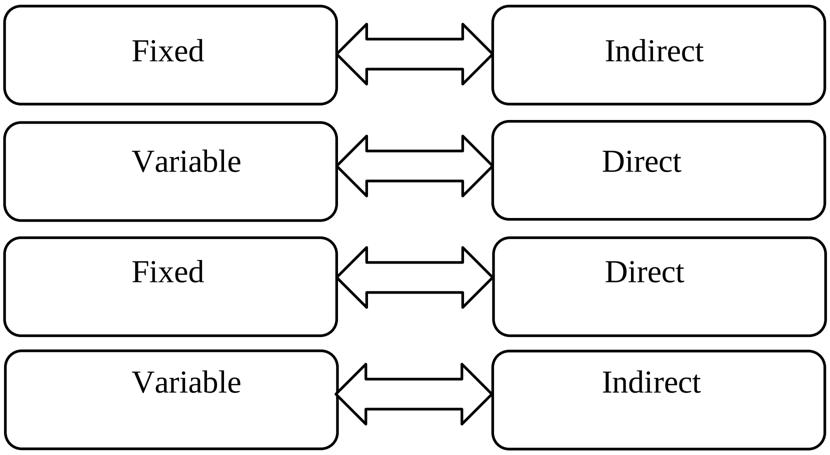

Figure 3. Total costs categorization

3.2.3 Life-cycle costing fundamentals

Experience shows that equipment procured at the lowest cost, not always be that costs the least amount of money over the equipment's lifetime. The total costs of ownership can significantly exceed the procurement cost. The U.S. Departments of Defense observed that in 1974, 27% of the overall budget were operation and maintenance costs, and 20% were procurement costs. Procurement decisions based entirely on the acquisition cost may lead to fatal choices in the long term. (Dhillon 2010, 27-41)

Life-cycle costing is increasingly used in the industrial sector worldwide. Various information is needed when making life-cycle costing research, including the acquisition cost of the item, the operation life of the equipment in years, the annual maintenance costs of the equipment, delivery and installation costs, discount and escalation rates, the annual operation cost of the equipment, disposal cost of the equipment. Dhillon (2010, 30) represents the steps shown in Figure 4 to be considered in life-cycle costing. (Dhillon 2010, 27-30

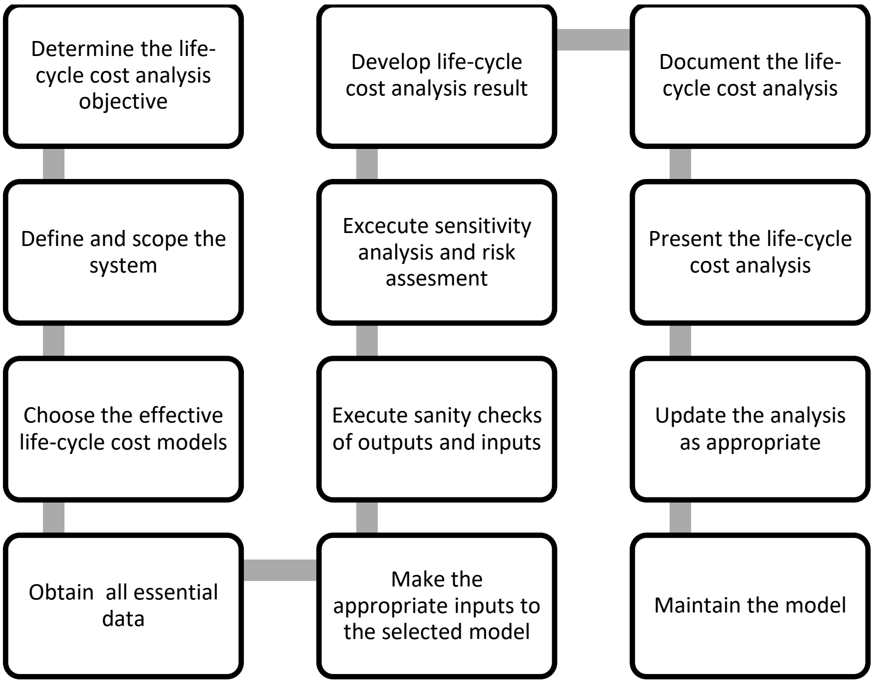

Figure 4. Steps of life-cycle costing

3.2.4 Information sources for Life-cycle-Costing

To develop a quality life-cycle cost analysis, the availability of reliable data is necessary. Good cost data banks are vital. When building a new data bank, it is essential to consider the comprehensiveness, size, uniformity, flexibility, responsiveness, ready accessibility, orientation, and contraction capability. Minimum data to store in data banks would include cost records, operation, and maintenance records, user pattern records. (Dhillon 2010, 32)

Data for life-cycle cost analysis can be collected from many different sources, and their quality and amount can vary significantly. It is necessary to examine aspects such as data bias, data applicability, data availability, data comparability to existing data, data orientation toward the problem under consideration, and coordination with other information. (Dhillon 2010, 32)

When evaluating the equipment’s maintenance costing, various types of cost data are needed. Management decides the types of cost data that should be used for the life-cycle model. Jordan (1990) represents four types of data that related to maintenance costs:

- *Labor costs* are normally collected from timesheets, job tickets, and maintenance work orders.

- *Spare parts* and supplies costs are normally collected from maintenance work orders and propositions.

- *Fixed costs* are normally collected from the company accounting department.

- *Equipment costs* information is normally collected from purchase orders, propositions, or suppliers' invoices.

3.2.5 Life-cycle Costing Advantages and Disadvantages

Life-cycle costing is not perfect, and various professionals have identified many advantages and disadvantages of life-cycle costing. Dhillon (2010, 33) presents a few essential advantages and disadvantages shown in Table 3.

Table 3. Life- Cycle Costing Advantages and Disadvantages

Advantages	Disadvantages
• Useful to reduce the total cost of ownership • Useful to control programs • Useful when comparing the costs of multiple competing projects • Useful tool for making decision regarding equipment replacement planning, and budgeting • Excellent tool for comparing competing manufacturers	• It is time consuming • Is costly • Data accuracy can be problematic • Collection of data can be difficult

3.2.6 Life-cycle profits

The life-cycle profits stand for the total potential profit for equipment over its lifetime. Bengtsson & Kurdve (2016) found that having low Life-cycle Costs (LCC) does not inevitably mean having a high Life-cycle Profit (LCP). Reducing LCC can be one option to achieve higher LCC. However, Increasing LCC sometimes reduce or eliminate losses that will increase LCP more than rises LCC. Allocating extra on acquisition or maintenance to increase capacity or life length gives higher LCC but may improve LCP, although it depends on the market. Figure 5 visualizes the life-cycle profit concept. (Bengtsson & Kurdve 2016)

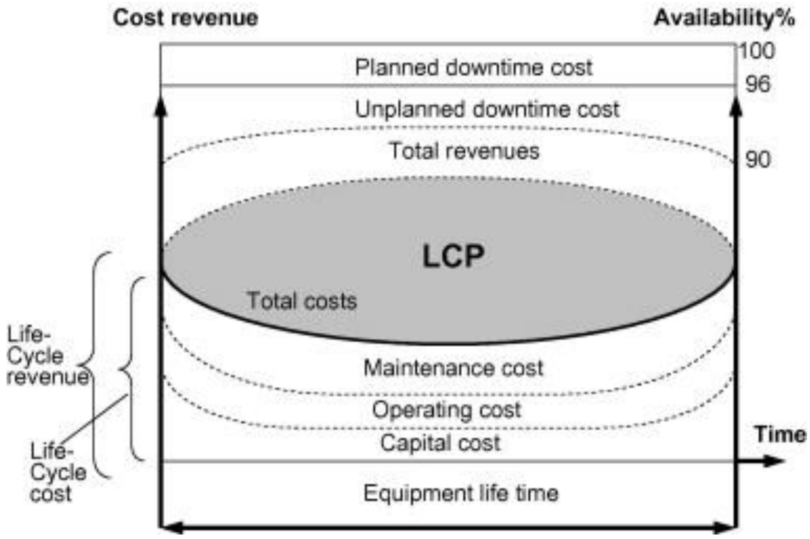

Figure 5. life-cycle profit concept. (Räsänen et al. 2007)

Operations running time and production volumes profoundly influences the LCC and LCP. A company that runs their machines only daytime will have a different situation from a company with running machines 24/7. The needs of the operations command the trade-off between LCC and losses. (Bengtsson & Kurdve 2016)

In a stable market, it is essential to work with lowering costs and losses while maintaining the objects of utilization. In a booming market, with increasing product capacities, it might be necessary to increase life-cycle costs, such as life support costs, to improve the goal levels. In some cases, it might be wise to decrease goal levels so that also life-cycle costs can be reduced. (Bengtsson & Kurdve 2016)

3.3 Different models for machinery replacement

It is common that decision-makers balance between the question “Should we replace a piece of equipment we own now or later.” The Replacement Theory is a decision-making process of replacing old equipment with a new alternative substitute. The replacement might be a necessary cause of malfunction or breakdown of the equipment. Replacement theory is used in cases when equipment has outlived, or it may not be economical to continue their lifetime. The life of equipment commonly follows the same U-shaped bathtub curve represented in Figure 6.

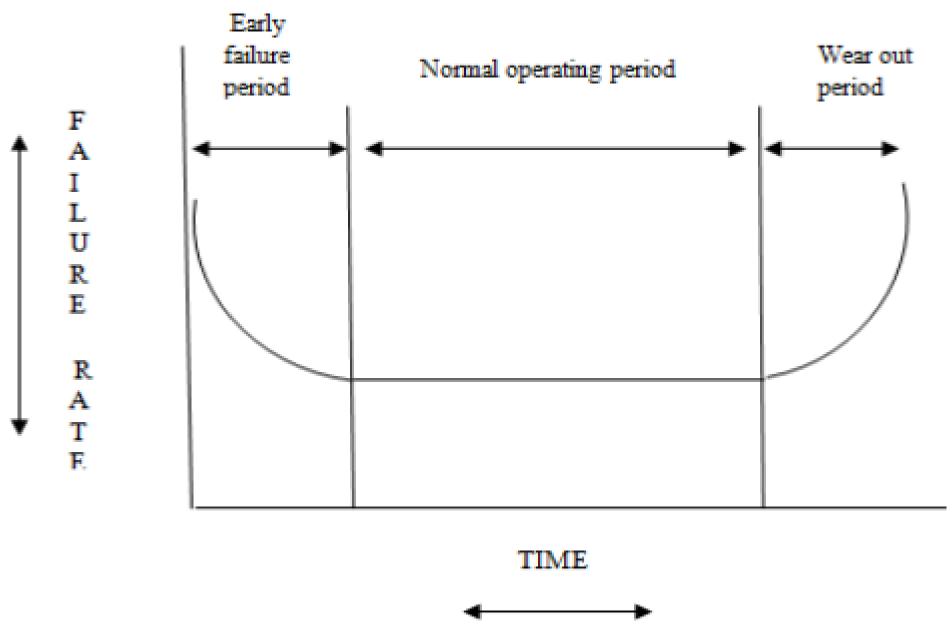

Figure 6. U-curved failure rate (Sahu etc. 2010)

Luckily, many researchers have studied the machinery replacement problem, and there are large numbers of models developed for the purpose of machinery replacement.

There is a large number of factors to replace the equipment before the end of its lifetime. Sahu etc. (2010) lists various possible reasons requiring the replacement of equipment and machinery:

- major depreciation of the equipment
- increasing costs of maintenance
- increasing labor costs
- unavailability of spare parts
- possible new operations of new equipment
- technological development
- profit reduction
- competitive strengthening
- product design change
- improving the quality of the products produced
- improving safety and reliable of the equipment
- reducing energy consumption
- reducing down time of existing equipment
- improving the efficiency of space utilization.

3.3.1 Age dependent replacement

The traditional age replacement method is presented by Barlov etc. (2012), and its main concept is that the system is replaced at failure or at age T, whichever occurs first. Sheu (2010) presents a more advanced version of the age-replacement model, where the system is completely replaced whenever it reaches age T (planned replacement). If the system fails before age T (unplanned replacement), it is replaced by a new system or repaired with minimum effort. The choice between minimal repair or replacement depends on the age of that unit. The time variable T depends on company policy.

3.3.2 Preventive Maintenance Models

Maintenance planning is essential for many industries. To companies that own diverse sets of equipment, planning is a crucial aspect of maintenance to ensure that all equipment is kept properly maintained. (Lofti tec. 2011, 129)

Lofti etc. (2011) presents three types of maintenance: corrective maintenance (CM), preventive maintenance (PM), and condition-based maintenance (CBM). CBM is gathering more and more attention in academic researchers and industrial practitioners. CBM might be unrealistic to some equipment, such as water pipes that are geographically widespread to install any conditional monitoring equipment to monitor the whole pipeline. In various facilities, such as nuclear power plants, planes, and trains, condition monitoring equipment is essential.

CM is the maintenance operation performed after fault recognition, and the objective is to put the equipment into the state; it can function the required operation. PM is the maintenance performed predetermined intervals intend to reduce the probability of failure. (Lofti tec. 2011, 129)

3.3.3 Challenger and Defender

One of the commonly used methods for equipment replacement is the so-called challenger and defender method. The capital equipment currently in use is called the defender, and the possible alternative equipment that will potentially replace the current equipment is called challenger. The defender will be replaced if there is no need for the existing equipment, or the challenger option is superior. Various potential options are compared against each other when selecting the challenger. This method is initially designed for equipment replacement but is also relevant for non-replacement decisions. (Herbst 2003, 77)

If the challenger is a better option than the defender and presently available rivals, it can still be a more inferior option to future choices. The present challenger is the best option if there are no future challenger’s worth waiting for. (Herbst 2003, 77)

3.4 Quality

The managers are focusing increasingly on improving the quality of their products, services, and activities. In the pharmaceutical device industry, the high quality of the products is vital. This chapter discusses how to determine the cost of quality and steps for the activity-based costing method for determining the quality costs. The life-cycle model constructed in this thesis does not include quality costs from a direct viewpoint, and the activity-based costing method is not considered. Still, the activity-based method can be attached to the model in the future development of the model. As a result, a short introduction to the cost of quality is presented.

3.4.1 Cost of Quality

The cost of quality (COQ) refers to the cost incurred to prevent or the cost rising due to the production of a low-quality product. Horngren (2006, 661) classifies the costs into four categories:

- Preventive costs are incurred to prevent the manufacture of products that do not conform to specifications.

- Appraisal costs are incurred to discover which of the specific units of products do not correspond to specifications.

- Internal failure costs are incurred on faulty products before they are shipped to customers.

- External failure costs are incurred on faulty products after they are shipped to customers.

Horngren (2006, 661) presents the items of quality costs across all business functions shown in Table 4.

Table 4. Quality cost items (Horngren 2006, 661)

Preventive Costs	**Appraisal Costs**	**Internal Failure Costs**	**External Failure Costs**
Design engineering Process engineering Supplier evaluations Preventive equipment maintenance Quality training Testing of new materials	Inspection Online product manufacturing and process inspection Product testing	Spoilage Rework Scrab Machine repairs Manufacturing\process engineering on internal failures	Customer support Manufacturing\process engineering for external failures Warranty repair costs Liability claims

3.4.2 Activity-Based Cost of Quality

The cost item listed in table 4 come from all business functions of the value chain, and they are more extensive than the internal failure costs of spoilage, rework, and scrap. Horngren (2006, 662) presents a seven-step activity-based costing approach for determining costs of quality.

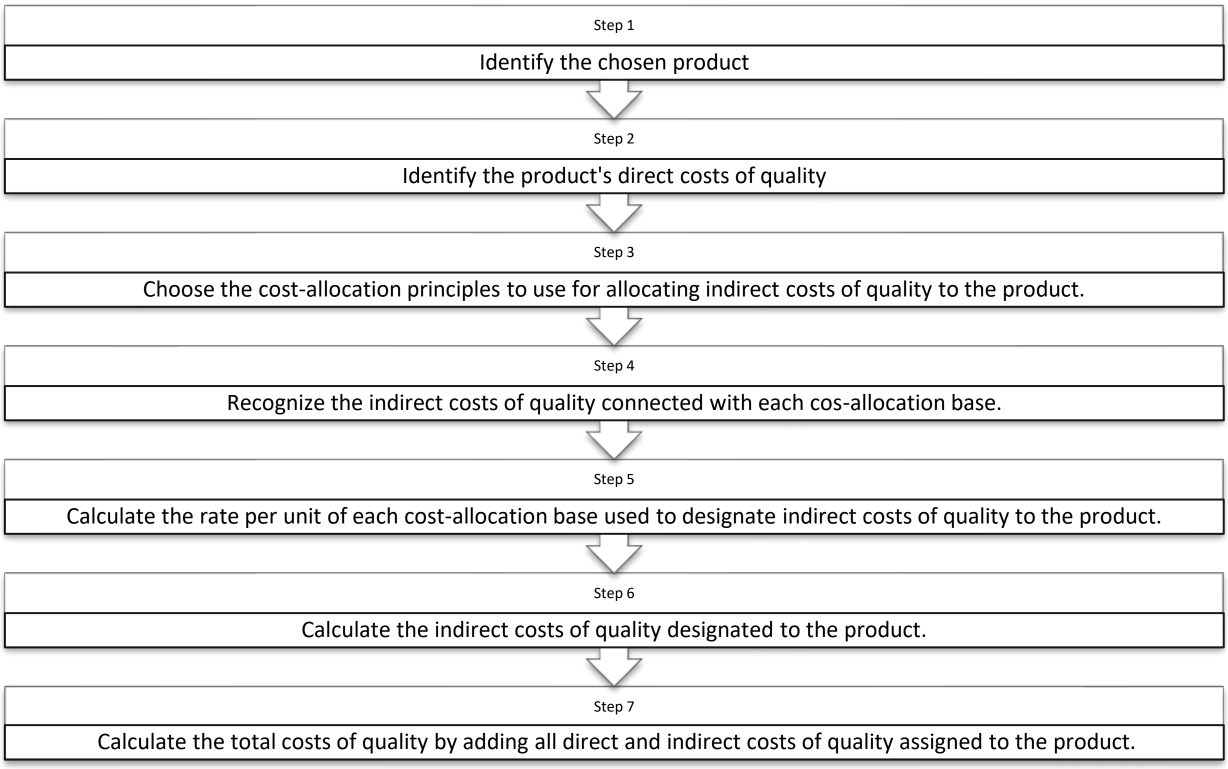

Figure 7. Activity-Based Cost of Quality steps (Horngren 2006, 662)

4 CASE MEDISIZE OY

4.1 Company and research case

This thesis's objective was to create a life-cycle model of an injection molding machine for the case company Medisize Oy and find the essential cost driving factors of the machine to give a deeper understanding of the injection molding machine life-cycle costs. In Kontiolahti factories, there are more than 100 injection molding machines, and the number is continuously growing as a result of new investments and growth of the company. After the recent corporate acquisition in 2006, the new owner's strategy has been to invest in long-term development and manufacturing, instead of short-term profits. The company's present vision is to be the number one service provider choice for the customer to produce pharmaceutical equipment.

The following chapters consider empirical research, introduction of injection molding machine, and cost-driving factors that effect to the costs of the injection molding machines within the case company.

4.2 Empirical research

4.2.1 Interviews

Interviews were chosen as one research method to assess the case company's needs for the injection molding machine's life-cycle model. The interviews' object was also to gain a more precise vision of aspects that needs to be considered when constructing the model and collect different perspective of the cost driving factors of injection molding machine. All the interviews were semi-structured and with open questions. The meetings often led to more in-depth conversations about the subject, and specially inside the case company the interviews were more like meetings with no predefined questions. The interviews were held between 6/2020 – 10/2020. The duration of interviews was typically one hour, and total 12 interviews were held.

In the case company, the following persons were interviewed:

- Pekka Korhonen, Operation excellence, Six Sigma Black Belt
- Olli Honkanen, Pre-Production Controller
- Harri Karvinen, Production Technician Injection molding
- Marko Järviö, Maintenance & Development engineer
- Simo Pitkänen, Maintenance Mechanic
- Perttu Huovinen, Plant General Manager
- Ilari Varhimo, Operations manager

Interviews were also held with the injection molding machine vendor and injection molding consultant from the vendor company. The interviews to the vendor company were predefined and the questions were sent to the company before the actual interview session. The templates of the questions to the vendor and the consultant are presented in the appendices.

Following persons were interviewed in the vendor company:

- Esa Mikkonen, Injection molding technical support
- Patrik Jensen, Injection molding sales manager

The conversational type of interview with the case company was recorded with a mobile application. Permission to record the conversations was asked before the discussions. Interviews with the injection molding machine vendor and the consultant were recorded by writing notes manually. Analyzation of the interviews was done by listening to the recorded conversations and by reading the notes. The summary of the interview results is found in the chapter seven.

4.2.2 Quantitative data analysis

The data analysis objective was to examine how the maintenance of the injection molding machine develops over time. Regarding the literature review, the maintenance needs and failure rate exponentially decrease when the machine is new and exponentially increases when the machine reaches a specific point in time and starts to wear out. This is discussed as a U-shaped bathtub curve in chapter 3. The data analysis's objective was also to inspect the machine's running hours and age and investigate if there is a relation to the maintenance hours and is the U-shaped curve real in this case.

Recognize the objective of this thesis, the construction of the life-cycle model. The data analysis objective was to examine can a percent variable be used in the model to define the growth annual maintenance expenses, or does it need to be implemented some other way.

Quantitative data was available from the old maintenance management software from 2009 until the end of 2018. In 2019 the maintenance management software was changed to a different system. The new maintenance management system's data was examined separately from the old data because of its distinct design.

One excel spreadsheet included all the machines that are in use and the year of purchase. The machines' ages were determined together with the average yearly age of the injection molding machine fleet.

There was also data available concerning the running hours and shots of the machines. The needed information was gathered from the production monitoring system. The time interval observed was the same as was in the maintenance management system, from 2009 until the end of 2018.

The old maintenance data included two large excel spreadsheets with 73 831 rows of information. The data was cleaned and prepared for the necessary analysis with the help of the Python programming language. All the yearly maintenance hours spent on each machine were summed and examined how the hours developed during ten years. The data shows that the maintenance hours have grown as the capacity of the plant has grown. Still, the dataset needs to be examined with high criticism because it does not include how many maintenance specialists have been working on specific tasks recorded, and. the information on the used spare parts was mostly missing.

The new maintenance management system's data was not comparable to the old system's data because of its different design. The new system dataset included maintenance information from the period of less than one year, and it also had lots of data from the testing of the system. Therefore, it does not provide a comprehensive picture of the yearly maintenance service done to the injection molding machines when this research is done.

The data analysis results are discussed and shown in the form of figures more in chapter 7.

4.3 Injection molding machine

The life-cycle model developed in this thesis is for a specific machine called injection molding machine, so it is essential to give a quick review about the machine itself. This chapter provides a short introduction to different injection molding machines available in the market.

An injection molding machine is a machine for manufacturing plastic products. In the injection molding process, molten plastic material is injected from a heated cylinder into a closed mold, where the plastic cools down and solidifies. The finished product is then ejected from the mold. The main machine parts are an injection unit to inject the material, and a clamping unit used to hold the mold closed during the injection phase. (Dominick, Donald & Marlene 200, 4-6)

The primary purposes of the injection unit and the clamp unit are separate, and they complete each other. The machine can be purchased and built with any injection unit solution and clamp because they depend on each other.

Figure 8. Fanuc injection molding machine (Fanuc 2020)

The types of injection molding machines are divided into hydraulic, mechanical, electrical, and hybrid machines. Most of the new machines acquired to Kontiolahti factories after the year 2000 are either fully electrical or hybrid machine. The older machines are fully hydraulic. Figure 8 presents an injection molding machine manufactured by Fanuc.

Hydraulic

In a hydraulic injection molding machine, the machine's relevant movement is executed with hydraulic pistons or motors. Fully hydraulic injection molding machines were the only machine type until the 1980s. In the beginning of 1980s MILACRON-FANUC begin to develop all-electric injection molding machine. (Plastic Technology 2020)

Mechanical

In mechanical machines, building up the tonnage on the clamp side of the machine, a toggle system is used. In all machine types, the tonnage is required, so the clamp side stays closed and holds the injection pressure. There is a risk of creating flash in the plastic product if the pressure is not accurate. (Dominick, Donald & Marlene 200, 28-40)

Electrical

The electric press lowers the costs of operation by reducing the energy consumption and cutting off some of the environmental trouble surrounding the hydraulic press (Dominick, Donald & Marlene 200). Regarding (Järviö 2020) They are proven to be quieter, faster, and more accurate than hydraulic machines, but more expensive as well.

Hybrid

The hybrid injection molding machines share the best features of the hydraulic machine and electrical machines. Regarding Bryce (2000, 41) the main disadvantage of hybrid machine is the cost. Commonly the machine is manufactured using standard technology, then upgraded to meet the hybrid specification.

In the case company, the future needs of injection molding machines are highly focused on fully electric injection molding machines. The electric injection molding machine's efficiency is better than the hydraulic injection molding machine's and the possible hydraulic oil leakages that could cause contamination to the process producing pharmaceutical equipment disappear when choosing an electric injection molding machine.

The production line for producing plastic parts for pharmaceutical devices also contains several accessory types of equipment, such as robotic arms, inserters, etc. This research is limited, particularly to the injection molding machine, and the life-cycle costs for accessory equipment are not studied.

4.3.1 Cost driving factors of injection molding machine

The cost factors for the injection molding machine in the case company are based on the literature review, and the interviews held. The most challenging factor to examine is the variables that affect the quality of the produced products. The maintenance history was examined trough the maintenance history data discussed in chapter 5.2.2 which helped to estimate how the maintenance costs develop during the injection molding machine's lifetime.

Figure 9 presents the cost driving factors of the injection molding machine, and in the next chapters, each element is explained more detailed.

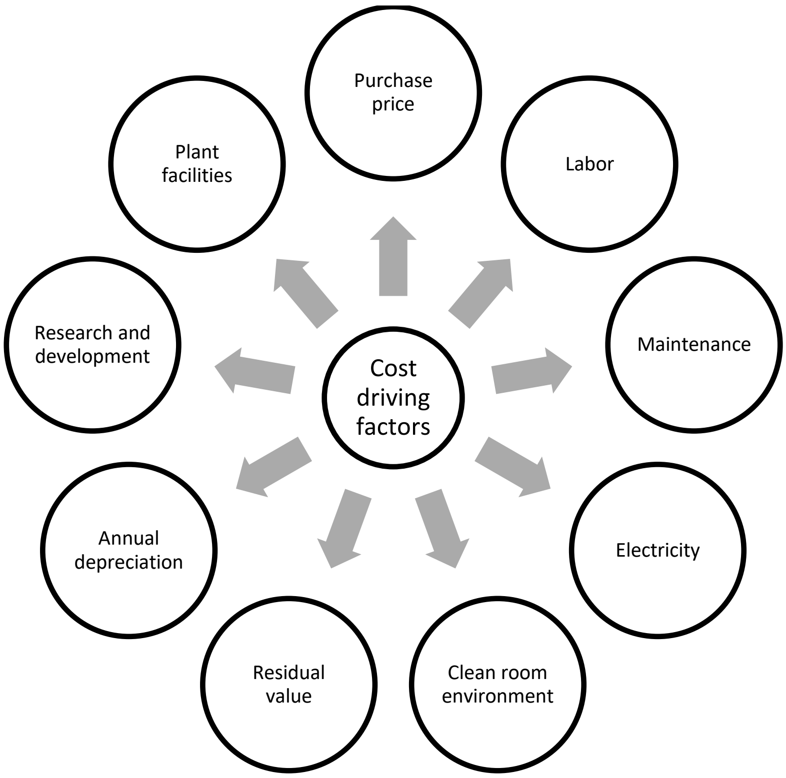

Figure 9. Cost driving factors of injection molding machine

Purchase price

The initial investment expense for an investment project is a cash outflow resulting from the project's purchase. The purchase price also includes any discount received, freight, and custom/import duties.

When analyzing the acquisition cost of the injection molding machine, it is not easy to work out the costs of additional in-company activities correlated with the purchase or production of an investment project. Especially indirect costs caused by the common use of indivisible assets (staff, capital assets, etc.) makes determining the acquisition costs difficult.

Labor costs

The cost of labor is the total of all payments paid to employees and the cost of employee benefits and salary taxes paid by an employer. In this research, the labor costs indicate to the costs of the employees who operate the injection molding machines, and the possible supervision and management of work are included in the other fixed costs. In Medisize Oy Kontiolahti factories' typical theoretical arrangement is that there is one operator in a shift for ten injection molding machines. The machine's maintenance labor costs are analyzed separately.

Maintenance

Regarding Manzini, R. et al. (2010), maintenance is the function that monitors and keeps plants, equipment, and facilities working. It must design, organize, carry out, and check the work to guarantee nominal functions of the equipment along its working time, and minimize the stopping intervals caused by failures. In Medisize, Kontiolahti, the maintenance team consists of total 5 employees, and the quartermaster. The mechanics are specialized in mechanical and automation engineering. When determining the costs of maintenance in the model constructed in this thesis, the labor costs of maintenance are included to maintenance costs, and the quarter costs are included to other fixed costs.

When considering the life-cycle cost of an injection molding machine, the maintenance costs are one of the critical factors. The hypothesis is that the maintenance costs will grow exponentially during the machine's lifetime. The target company's maintenance development was examined through data collected from the maintenance management system.

As discussed in chapter 5.2.2, all the maintenance events have been recorded to the maintenance management system. The data that was used for this research is from the year 2009 to 2019. Each recorded event consists of a date, working hours spend on the event, and description. The primary variable that was examined was the working hours. The objective was to investigate if there is exponential growth in a particular machine's maintenance hours. Results are discussed more in the chapter 7.2.

Electricity

An injection molding machine's energy efficiency is an important consideration, but regarding Bryce (2016, 101), determining electrical costs can be complicated due to variations in fees charged based on peak need and usage, and various power factors. Power requirements should be based on peak operation conditions, but normal operations use about 60% of that number at any given time.

Clean room environment

A cleanroom is a controlled area where pollutants such as dust, airborne microbes, and aerosol particles are filtered to arrange the cleanest environment. In particular, every industry where small particles can negatively affect the process uses cleanrooms, such industries as manufacturing electronics, pharmaceutical products, and medical equipment. The number of particles allowed in the environment per cubic meter determines the classification of the cleanroom environment. Temperature, airflow, and humidity are the variables monitored in the cleanroom environment. (Pharmabiz 2017)

The cost of a cleanroom environment can vary considerably. The price per cubic meter represents the price of the environment.

Both factories in Kontiolahti have cleanroom environments. In this case, the cleanroom environment price is part of the total costs of ownership because it is mandatory when producing medical equipment. In Kontiolahti factories, it is common practice to calculate other plant facilities costs to be part of the cleanroom environment costs. For that reason, it must be part of the life-cycle costs calculations as well.

Residual value

Residual value is defined as the estimated resale value of the equipment at the end of its lifetime. The residual value is usually a positive amount but can also be negative, thus sometimes called "salvage value". (Shillingglaw 1995). Predicting the equipment's residual value is necessary to subtract the estimated costs of disposing of the equipment. Residual value is used when calculating the depreciation of equipment, and it includes a lot of uncertainty. In the case company a common practice is that the bookkeeping residual value is determined as zero.

Annual depreciation

Depreciation is an accounting technique of allocating the cost of an asset over its estimated useful life. Depreciation shows how much of an asset's value is already used up. Companies need to earn income from an asset while expensing a part of its value each year the asset is in use. If depreciation is not used, it can significantly influence profits. (Tuovila 2020)

Companies can depreciate long-term assets tax and accounting purposes. (Tuovila 2020)

Because production equipment is expensive, and instead of completing the total expense in year one, depreciation allows businesses to separate that price and generate income from it. (Tuovila 2020)

Lawrence (2013) represents the following factors to be considered in choosing depreciation:

- When determining the historical cost of the asset, other costs directly related to the acquisition of the machine are added up to the purchase price, like agreement cost, installation cost, improvement cost, etc.

- Similar to the historical cost is the asset that needs to have an economic life span.

- Salvage value is predominant in defining the value of depreciation.

- The nature and type of assets differ from one asset to another, even in the same organization.

- Usage and capacity of the asset may vary from one machine to another as some provision for depreciation is made based on volume or capacity.

- Improvement and development costs are related to direct costs associated with the purchase price of the equipment.

Research and development

Research and development include activities in which businesses begin to innovate and introduce new products and services. It is usually the first step in the development process. The purpose is typically to take new products and services to market and add to its competitiveness in the industry. (Kenton 2020)

The research and development department also plan and implement new production lines and improve existing production lines. In the research and development projects of the company, there are no expectations of quick profit. Instead, there are expectations of proving the long-long term profitability of the company.

The research and development costs cause indirect costs to injection molding machine's total costs of ownership, and therefore must be considered when planning the life-cycle costs analysis.

In Medisize Oy, there is no separate research and development department, and the possible costs of research and development projects are included in administrative expenses.

Plant facilities

A plant facility means a single place that is particularly dedicated to manufacturing or processing product activities. Plant facility costs include factors such as rent, HVAC, electricity, and water. In this research, the electricity costs are examined separately because of the large energy consumption of injection molding machines, and other plant facilities are included in cleanroom environment costs.

4.3.2 Machine Hour Rate

After the annual depreciation costs and the yearly operating expenses are found, the machine hour rate can be determined. The machine hour rate is a rate displayed as a cost per hour assigned to each molding machine. (Bryce 1999)

The machine hour rate (MHR) can be calculated using machine-specific data, such as electrical fees, maintenance reports, depreciation, etc. Two numbers are essential when determining the MHR. They are depreciation and annual operating costs, as discussed earlier. Dividing the sum of those two numbers by the yearly production hours available to the plant will represent the MHR, as shown in equation 5. (Bryce 1999)

$$MHR = \frac{A_d + A_o}{A_m} \tag{5}$$

A_d = annual depreciation
A_o = annual operating costs
A_m = annual manufacturing hours available

The individual MHR is the value used for determining what cost per hour to mold plastic products is. (Bryce 1999)

5 MODEL

5.1 Planning

The primary objective of this study was to build life-cycle cost model of injection molding machine. The model's planning started based on the interviews held within the company and representative of the injection molding machine vendor. The model should be able to convince investment decision-makers, and the aspect that they are interested in should be emphasized most. The interviews definitely proved a need for the model to determine the life-cycle costs of the machine because the investment needs can be challenging to argue without an appropriate tool. The model's purpose is to give a deeper understanding of the injection molding machine life-cycle costs.

5.2 Construction

When constructing the model, the objective was to gather all cost-driving factors that affect an injection molding machine's life-cycle costs to an excel spreadsheet and estimate how the costs develop over time. The model is constructed with Microsoft excel, and it is planned the way that it can be used in another similar situation.

The model consists of four excel sheets, the operating costs sheet, life-cycle costs sheet, sensitivity analysis I and II sheets.

The operating costs sheet is the sheet where the necessary data is inputted. The input variables of the model are divided into initial data, variable costs, and fixed costs. Table 5 shows how input variables are divided into sections.

Table 5. Input variables

Initial data	Variable costs	Fixed costs
• Depreciation in years • Hurdle rate • Machines purchase price • Average annual maintenance cost increase • Indirect employees' costs multiplier • Annual operating hour	• Labor costs • Maintenance costs • Electricity costs	• Cleanroom environment costs • Research and development • Administrative costs • Other Utilities

The life-cycle costs sheet shows how the costs develop in the function of time. There are two separate sections, one where all the cash flows are discounted, and one where the discount factor is not considered. The cash flows are also presented in figures.

The sensitivity analysis I sheet shows the sensitivity analysis of the maintenance costs and the electricity costs. The Sensitivity analysis II sheet shows the cash flows with different hurdle rate.

The numbers used in this report are not absolute, and their purpose is to demonstrate the functioning of the model.

5.2.1 Initial data

In the model's initial data section, the user enters the number of depreciation years, the hurdle rate, machine acquisition price, an estimated average yearly increase of maintenance costs, indirect employees cost multiplier, and annual operating hours of single injection molding machine.

Table 6. Model initial data

Initial Data	
Depreciation in years	10
Hurdle rate	4,00 %
Machine purchase price	100 000,00 €
Average annual increase of maintenance costs	10,00 %
Indirect employees costs multiplier	1,5
Annual operating hours	5000

5.2.2 Variable costs

Labor costs

The labor section objective is to determine the yearly labor costs of a single injection molding machine. The labor costs are incurred when the user enters the number of employees that operate the machine and the employee's annual average earnings.

Table 7. Model labor costs

Labor	
Number of employes	0
Employees average yearly earnings	0,00 €
	0,00 €

Maintenance costs

In the maintenance costs section, the goal is to gather all the annual costs that originate from maintaining the machine. They include the costs of spare parts and maintenance work. The inputs for the user to enter consists of the number of employees maintaining the machine, the number of annual maintenance hours, the average hourly earnings of the maintenance worker, and the yearly spare parts and supplies costs. The maintenance costs are summed and presented how the costs develop as a function of time in the life-cycle costs sheet, multiplying the total costs with the percentage of the annual increase in maintenance costs. The fixed foreman's yearly earnings are handled in the fixed costs section.

Table 8. Model maintenance labor costs

Maintenance	
Number of maintenance employees	0
Number of maintenance hours	0
Employees average hourly earnings	0,00 €
Total employees costs	0,00 €
Spare parts and supplies	0,00 €
	0,00 €

Electricity costs

In this section, the cost of electricity is calculated multiplying the operating hours, power consumption and electricity price. The user inputs the estimated annual operating hours of a single injection molding machine, the power of the machine, and the electricity price.

Table 9. Model electric costs

Electricity	
Power comsuption of the machine kW	0
Electricity price €/kWh	0,00 €
	0,00 €

5.2.3 Fixed costs

Cleanroom environment costs

The effect of the cleanroom to cost development of the injection molding machine is considered in this section. The user inputs are the cost of the area per square meter and the total area that the equipment requires. The cleanroom environment costs include other plant facilities costs, such as HVAC, rent etc.

Table 10. Model cleanroom costs

Cleanroom environment	
Cost of the cleanroom environment €/m2	0,00 €
Area needed for the machine m2	0
	0,00 €

Other

This section consists of all the other costs that are related to the injection molding machine. The user inputs a single annual amount that includes management salaries, possible research and development costs, and other utility costs.

Table 11. Model other costs

Other	
Research and development	
Administrative costs	
Other utilities	
	0,00 €

5.2.4 Life-cycle costs

This section is an individual spreadsheet and the costs are automatically calculated based on the initial data. The model calculates the costs for 15 years, taking into account the hurdle rate and possible annual increase in maintenance cost rate. The costs are presented in the cells and the form of a figure. Figure 10 shows the annual machine hour rate (MHR), and Figure 11 shows the total yearly costs.

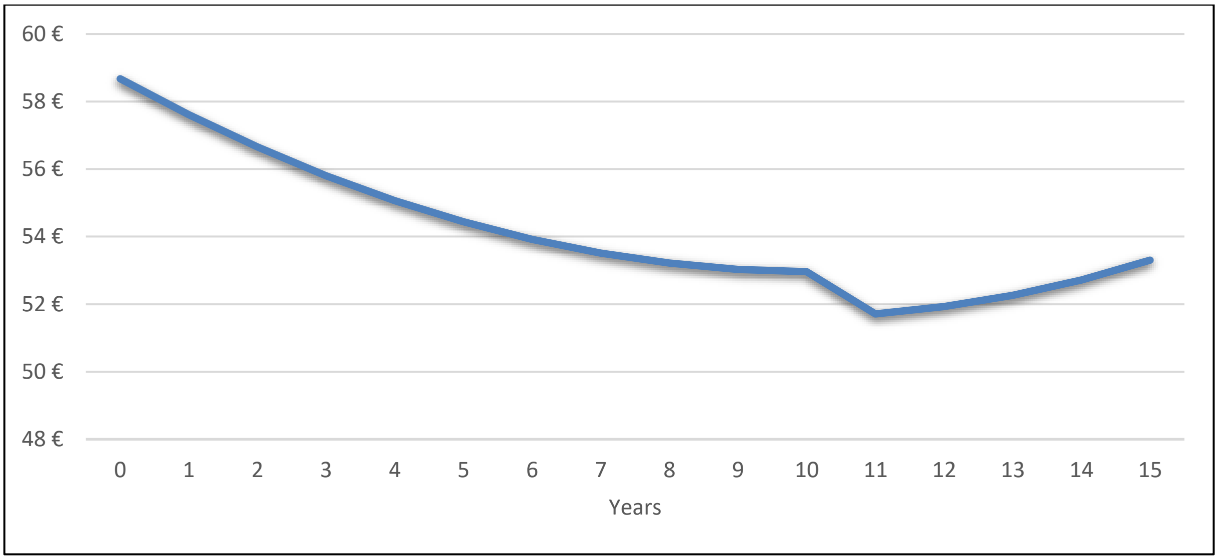

Figure 10. Annual machine hour rate (MHR)

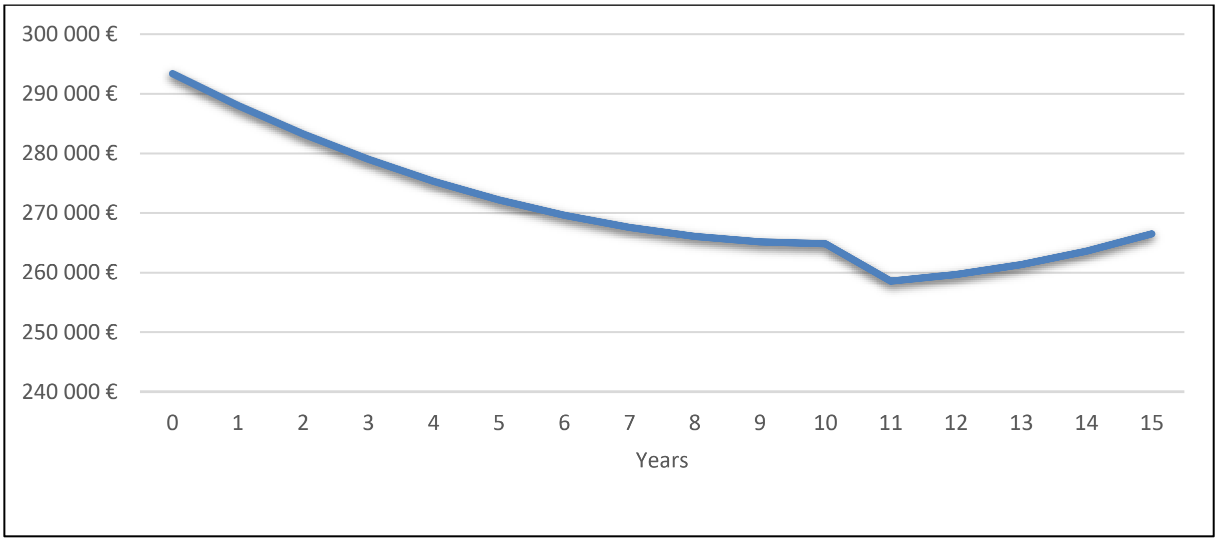

Figure 11. Total annual costs

5.2.5 Sensitivity analysis

As discussed in chapter 2.3.5 sensitivity analysis examines how the result will change if one or more variables are changed. The total maintenance cost was chosen as one variable for sensitivity analysis because the maintenance needs can vary a lot over the machine's lifetime. Another variable that was chosen for sensitivity analysis is the price of electricity. Sensitivity analysis of electricity shows how electricity costs change if the machine's power consumption changes, and the maintenance sensitivity analysis shows how the annual costs of maintenance change if the volume of the maintenance change. Figure 12 presents how the annual maintenance and electricity costs change if the parameters are changed between -25% and 25%. Separate sensitivity analysis was done with a hurdle rate and total operating costs. Figure 13 shows the net present value change of the operation costs if the hurdle rate is changed between 2% and 16% every two percent. Operation costs include all the costs inputted to the model.

Figure 12. Maintenance and electricity cost sensitivity analysis

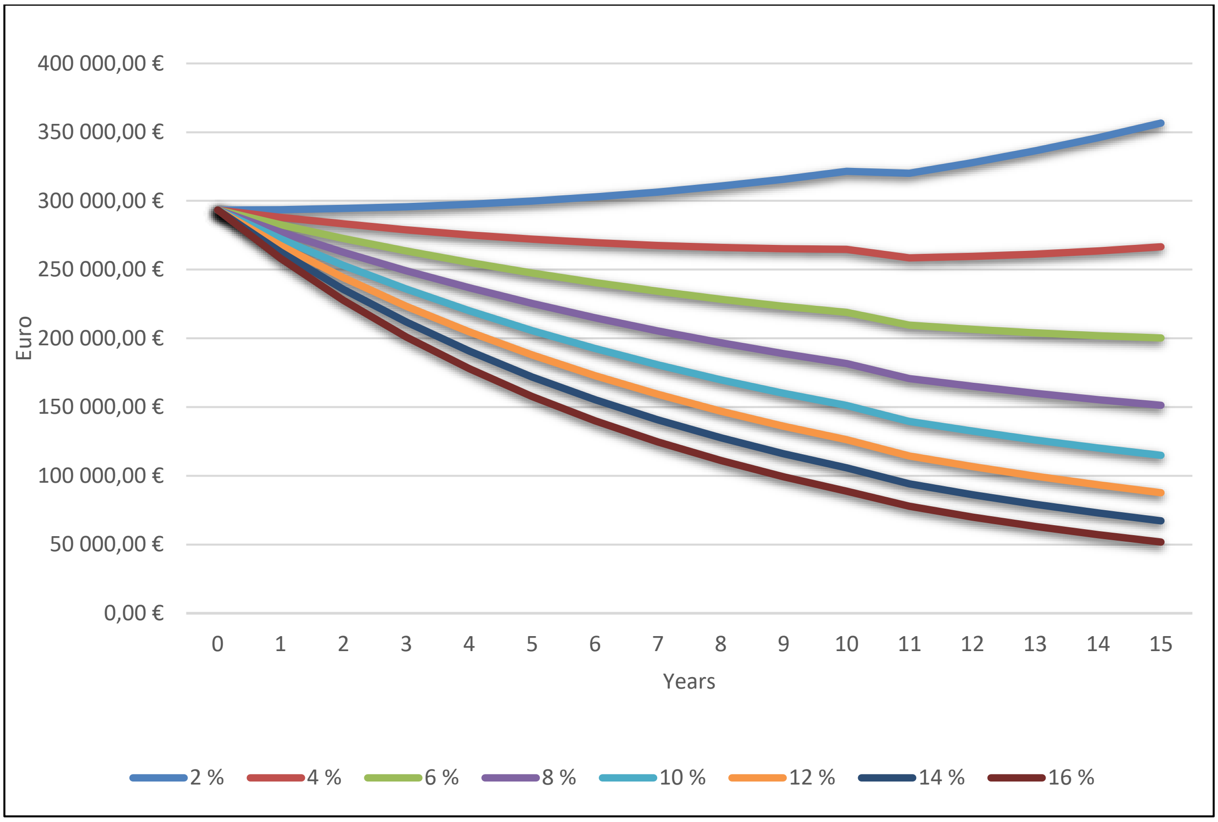

Figure 13. Hurdle rate sensitivity analysis

5.3 Further development of the model

The model needs to be continuously updated as the company makes new investments, and the business develops over time. In the pharmaceutical equipment industry, the quality of the products is essential for the company's success, and one of the critical aspects that need to be considered is the cost of quality. The activity-based cost of the quality model discussed in chapter four could be attached to the life-cycle model. The model activity-based cost of the quality model gives a more detailed picture of the price of producing high-quality products.

Another improvement proposal would be to make the model more interactive with the enterprise resource planning system. Especially the maintenance costs could be monitored more detailed and detect the possible increasing growth of the maintenance costs, and other anomalies. The model could also be expanded the way that it is suitable for other production equipment, such as robotic arms, etc.

6 RESULTS

6.1 Summary of interviews

This chapter summarizes the interviews held inside the case company and the machine vendor company.

Based on the case company's interviews, there has not been a tradition for significant machinery replacement investments. There have been new machinery investments due to the extension of the manufacturing capacity. The older injection molding machines have been reused for manufacturing different products, and their utilization rate is reduced. Regarding the case company's maintenance team, the machine's conditions more aged than ten years must be monitored with extra care.

All the maintenance of the injection molding machine is done with the Medisize own maintenance team. The vendor company also provides maintenance services for robotic arms, injection molding machines, and other machine tools. The machine manufacturer Fanuc provides a detailed maintenance plan, but naturally, it does not consider spontaneous machinery failures.

In the past twenty years, the new machines acquired to the Kontiolahti factories have been fully electric injection molding machines. Compared to the hydraulic injection molding machine, the fully electrical machine reduces the contamination possibility, which is essential when producing pharmaceutical equipment in a cleanroom environment. The fully electrical machine also consumes less energy than the fully hydraulic machine, which reduces the plant's annual electricity costs. The machine manufacturer Fanuc claims that fully electrical machine uses up to 50-70% less energy than hydraulic machines (Fanuc 2020). The size of the electrical machine is also smaller than the size of the hydraulic machine.

The constant technical development also influences the machine fleet, the increasing automation in production lines and more complicated plastic products force the company to keep production lines up to date.

The availability of spare parts can be challenging, and it can lead to machinery replacement. A possible delay in spare part delivery can lead to significant production loss if the machine needs to stand and wait for the vital spare part. The injection molding machine vendor Flextek promises an excellent spare part delivery for the Fanuc brand machines they sell. They keep a stock of the most consumed spare parts in Finland, and more rare spare parts must be delivered from Central Europe. However, spare part delivery for an older machine can challenging if the spare parts are no longer produced.

Based on the interviews held in the machine vendor company, the most common reason for machinery replacement is wearing the machine's mechanical parts, for example, joints, servo systems, etc. And their perspective of a typical economic lifetime of the injection molding machine is approximately 10 to 15 years, depending on the machine's running hours and shots. In this context, a shot is an action when the machine injects the melted plastic into the mold. Also, the weight of the mold used in the machine influences the wearing of the mechanical parts of the machine. The machine vendor states that the used machines resale value can be up to 25% price of the new electric injection molding machine, and the accuracy of the machine stays even if it is an old machine. However, the experts from the case company see the resale value of the machine lower.

6.2 Summary of the data analysis

One of the objectives of this thesis was to investigate the maintenance history data. As discussed in chapter 5.2.2, the maintenance history data analysis objective was to examine how the maintenance events develop overtime. A total of 104 machines maintenance events was considered. The total amount of maintenance hours has increased in the review period, as shown in Figure 14. The maintenance hours are increased as the production capacity has grown in both factories.

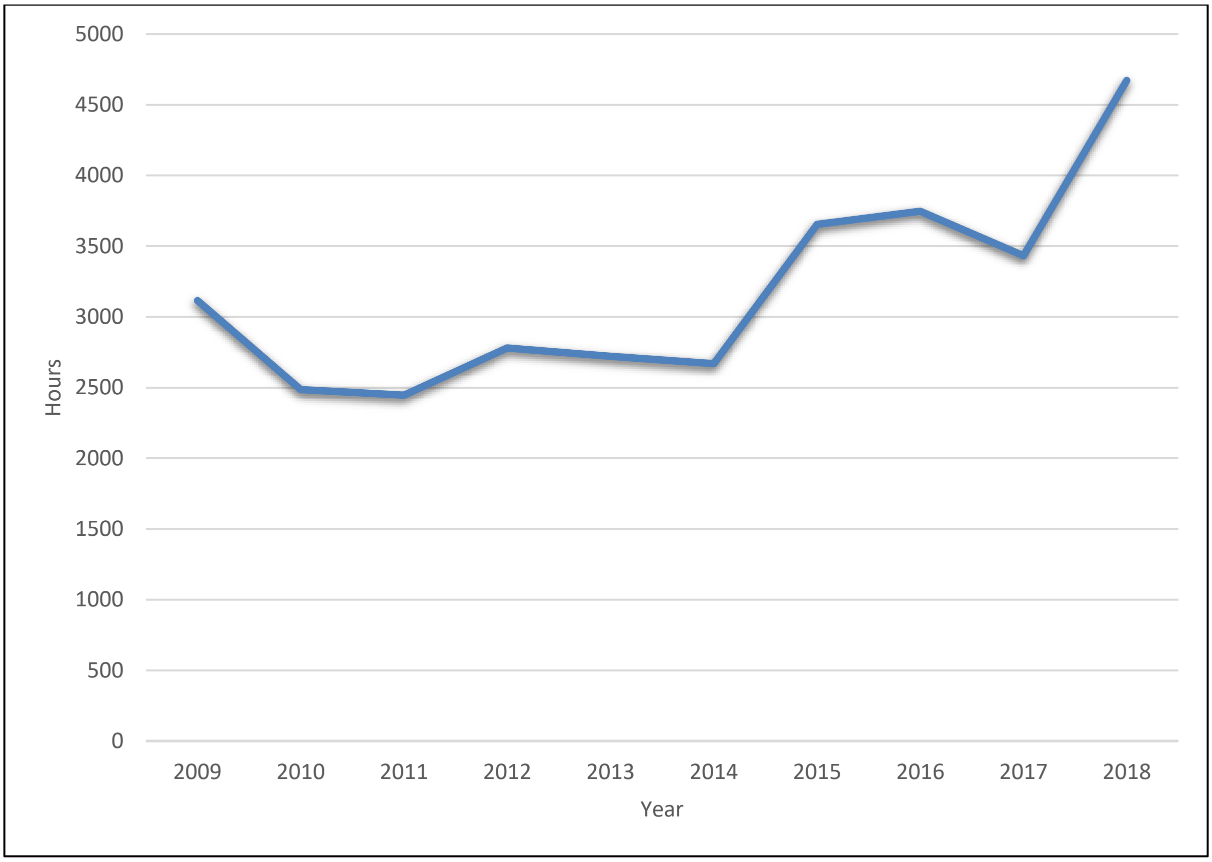

Figure 14. The maintenance hours of injection molding machine fleet 2009 - 2018

When looking at an individual machine, the maintenance hours vary a lot. It is hard to give an explicit assumption that there is a significant growth of maintenance hours in a single injection molding machine. It is also difficult to estimate the total cost of the maintenance event when considering only the maintenance hours and not knowing the price of the spare parts that have been used for the maintenance event. Some expensive spare parts can be somewhat easy to change and do not require lots of human resources, and some maintenance events do not require significant spare parts but require lots of human resources. Figure 15 shows the maintenance hours of 11 individual machines that are acquired in 2009.

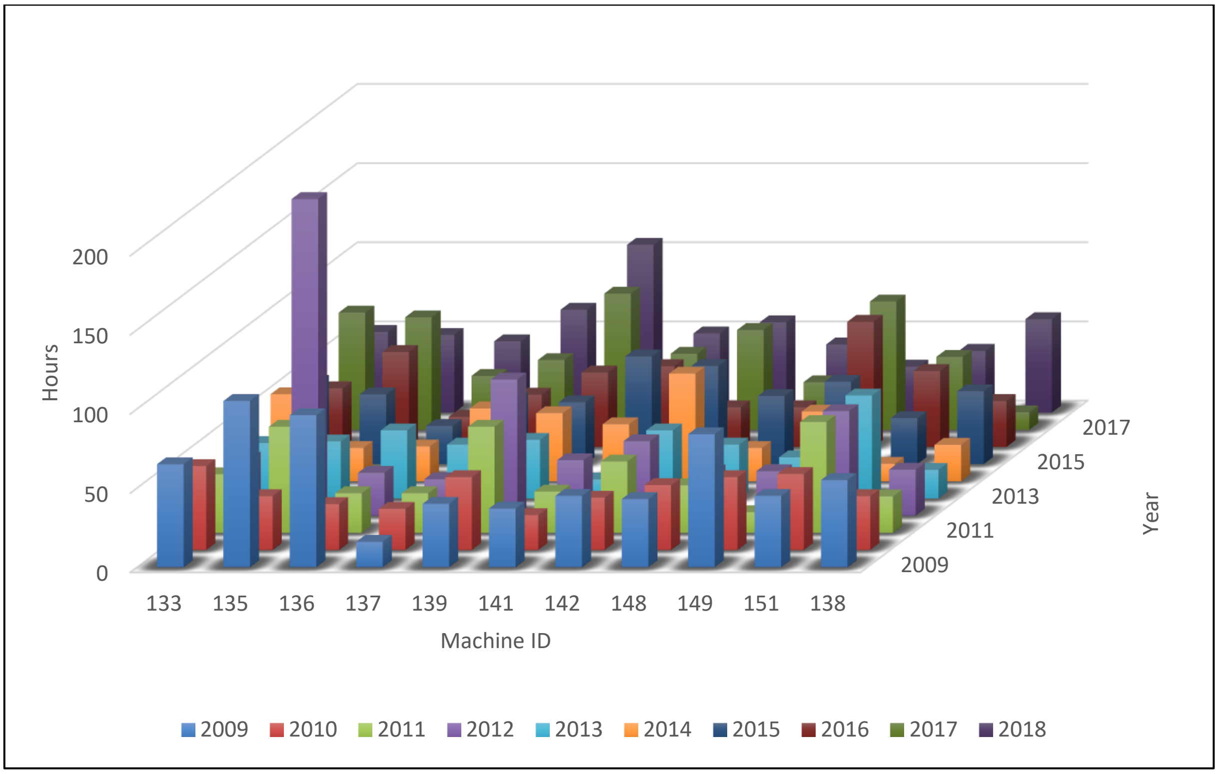

Figure 15. Individual injection molding machine maintenance hours 2008 - 2018

Average ages of the injection molding machine fleet

A total of 107 injection molding machines age was examined in this research. 61 machines in the Ensolantie factory and 46 in the Lammintie factory. The total average age of the machines in 2020 is 11,4. 10,6 in the Ensolantie factory, and 12,5 in the Lammintie factory. Figure 16 shows the average age development from the year 1997. The figure shows the aging of the machine fleet. The average age of the machine fleet was calculated for each year separately. The linear growth can be partly explained cause there have been new machine investments, but the old machines were reused for further production instead of replaced. Anyhow the figure must be analyzed with criticism because it does not consider the older machines that are acquired before 1997 and later disabled.

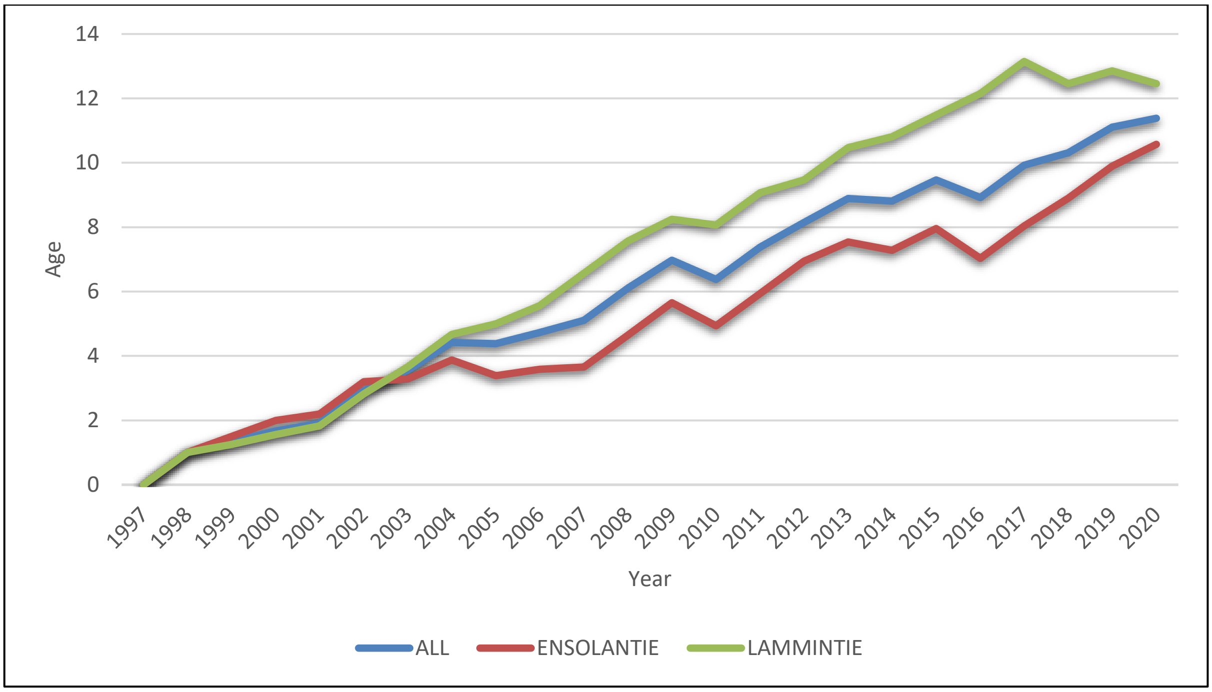

Figure 16 Average age of injection molding machine fleet

Maintenance hours compared to running time

When examining the relationship between the running time of the machine and maintenance hours, the hypothesis is that the more running hours the machine has, the more maintenance it needs.

Figure 17 shows the average running time and average maintenance hours of the 11 injection molding machines purchased in 2009. Machines commissioning requires time and workforce, so the machine's average maintenance hours appear high in the first year of the machine's lifetime. After the machine's first year, some relationships between the average running time and average maintenance hours can be seen.

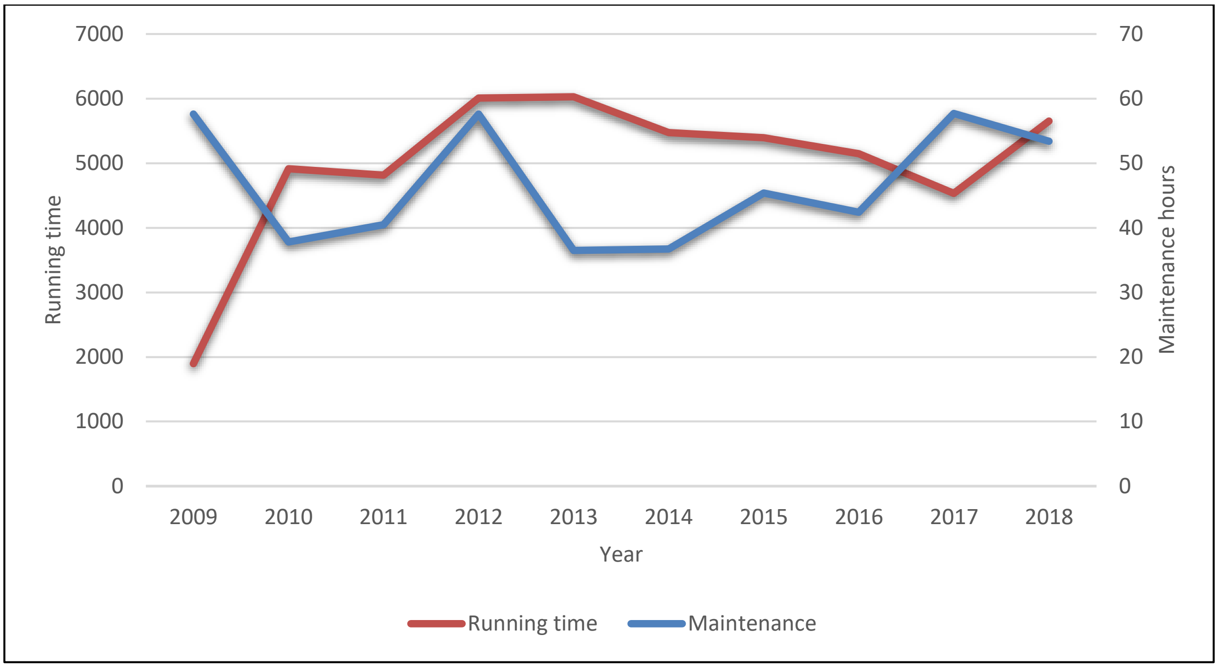

Figure 17. Average running time & average maintenance hours of 11 machines

For comparison, Figure 18 shows the running time and maintenance hours of one individual injection molding machine.

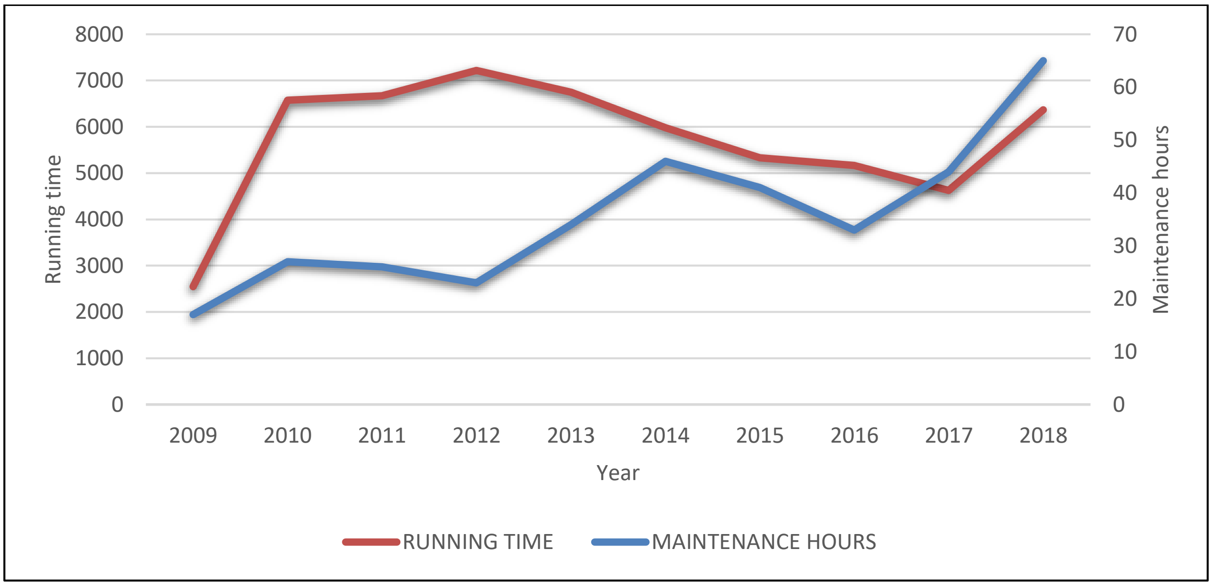

Figure 18. Individual machine running time & maintenance hours (machine id 139)

6.3 Evaluation of the model

The research objective was to investigate the cost driving factors, and maintenance history data of the injection molding machine and develop life-cycle cost models that can be used to assess new injection molding machine investments. The model also shows how the life-cycle costs develop during the time, taking into account the time value of many and depreciation.

The actual model was constructed with Microsoft excel, the goal was to make it as simple as possible for the end-user, and it was designed only for the use of the target company, and it will not be hand over to third party vendors.

The calculations for the inputs of the model require critics as assessing the costs can be challenging. For example, the annual maintenance expenses can be challenging to predict, and the usage of the equipment and volume production can change significantly during its lifetime. The quality of the costs data available in the case company was poor and for the simplicity and to usability reasons a percent variable was chosen to show the annual maintenance increase, instead of separately listing the annual costs of maintenance.

6.4 Conclusion and discussion

The study's objective was to design and create a life-cycle cost model and investigate the cost driving factors of injection molding machines. An additional goal was to calculate the machine's hourly rate. The study includes the life-cycle model, which includes the machine our rate output calculated based on the literature review. The cost-driving factors of the machine are listed based on the interviews and literature review. The maintenance history data is analyzed and shown in the form of figures.

The research had three research questions to support the objectives of the study. The first question was: What are the main aspects influencing an injection molding machine's total costs of ownership? The second question was: What is the construction and logic of the life-cycle model? And the third question was: What is the machine hour rate of the injection molding machine? The three research questions are handled below.

What are the main aspects influencing an injection molding machine's total costs of ownership?

The total costs of ownership of an injection molding machine consist of various aspects. The machine's purchase price is the purchased machine's cash flow, including all the freight and custom/import duties. The purchase costs are relatively easy to determine, but it can include unusual indirect costs that make the definition of the purchase price more difficult. The operator of the injection molding machine determines the labor costs of the machine. The labor costs include any taxes and benefits paid to the employee. In the pharmaceutical equipment industry, the quality of the products is essential. The cost of quality can be challenging to determine. The proper maintenance of the equipment is crucial to ensure the high quality of the produced products. The costs of maintenance include the price of the workforce and the price of the spare parts used. The machine's electricity costs can be calculated with nomination power, annual machine running hours, and electricity price. A cleanroom is a controlled area to reduce the possibility of contamination of the products, and it is essential in the medical device industry. In the case company, other plant facilities such as rent, HVAC, etc. are included in the cleanroom environment costs. Residual value and annual depreciation also need to be taken into account when calculating the machine's life-cycle costs. The research and development costs also affect the total costs of ownership. However, there is no separate research and development team in the case company, but standard development work still exists.

What is the construction and logic of the life-cycle model?

When planning the model, the objective was to list all the cost-driving factors to an excel spreadsheet and use the basic discounted cash flow analysis and life-cycle cost methods to provide a working model for the case company. The model construction consists of four excel spreadsheets. The first page is where the user enters the annual costs of the injection molding machine. The second spreadsheet shows the machine's life-cycle costs taking advantage of the basic discounted cash flow analysis presented in the literature review. The third spreadsheet includes a sensitivity analysis of how different maintenance and electricity costs affect the cash flows. The fourth spreadsheet is also a sensitivity analysis with different hurdle rates used.

The objective was to develop a usable model with a simple user interface. Technically almost everything is possible with new high-quality software and tools, and the difficult question is what the customer wants and what adds more value to the company.

The further development of the model would include more aspects of the cost of quality. And like all tools, the life-cycle model needs a constant update and re-evaluation.

One of the aspects found during the research was the importance of detailed data when determining the equipment's life-cycle costs. The electricity price can be relatively easy to calculate from the nomination power and electric price, and the acquisition price is determined in the purchasing moment. The cost of maintenance, though, can be more challenging to determine.

In this research, the maintenance history was examined from the maintenance management system. The data that was used included all the maintenance transaction between 2009 and 2019. Each transaction included information on the machine's id, date, time, duration, actions taken, and additional information. The information provided was relatively easy to calculate the maintenance hours for each machine, and detailed information provided the information about what has been done to the machine. However, from the researcher's perspective, some necessary information was missing. How many mechanics have been working on the specific task, and what spare parts and materials have been used? With that additional information, the transaction price could then be calculated by multiplying the working hours by the hourly wage and evaluating spare parts' costs.

Considerably detailed maintenance life-cycle cost could be determined if each maintenance transaction would include the discussed information.

What is the machine hour rate of the injection molding machine?

The machine hour rate question was one of the first questions raised when started this study. The problem is more or less technical and can be calculated from the machine's total annual costs and running hours. Bryce (2009) presented a simple equation in his book (Plastic Injection

Molding, Manufacturing Startup, and Management) to determine the machine hour rate of the injection molding machine used in this study.

6.5 Limitations and future research opportunities

The research's most significant challenges were the subject's delimitation and the lack of data available. The model gives an excellent overall picture of the life-cycle costs. Still, it turned out that Dhillion (2010) judgment that when constructing a life-cycle model of the machine, it is impossible to build an accurate model without good quality historical data of the machine is correct. The different opinions about the possible cost-driving factors were easy to gather from the interviews but their actual costs impossible to prove without data. Scientific publications about life-cycle costs and machinery replacements are widely available. Even though the machinery replacement theory and life-cycle theory have been well-studied, the literature lacks publications about injection molding machines. The research does not include life-cycle profits. It would be complicated to track down the sales for an individual machine, and it is out of this research range.

The case company is a growing pharmaceutical equipment producer, and all the recent new investments can be classified as extensions investments presented by Pellinen (2018, 89). The prior machinery replacement has followed more or less age-dependent replacements presented by Barlov etc. (2012). Therefore, future research could be focusing more on the implementation of data-based preventive maintenance and replacement models of injection molding machines. Also, one interesting future research could be the possibilities provided by the Internet of Things. For example, the opportunity to connect the information of raw materials and accurate maintenance data good be a game-changing technology to produce high-quality products.

7 SUMMARY

This thesis's objective was to develop a life-cycle cost model of the injection molding machine and investigate the cost driving factors, maintenance history and the machine's total cost of ownership. The research also aims to determine the machine's hour rate. Typical practice for firms is to compare investment projects payback period and initial procurement costs. However, this is not always the ideal method for comparing different investment choices. The life-cycle model provides a more in-depth view of the injection molding machine costs for the purpose of the investment planning process. The model was constructed with Microsoft Excel, and it allows the user to observe the machine's life-cycle costs with different variables.

The study is a combination of qualitative and quantitative research. Several books and articles regarding the investment process and life-cycle costing were used for the literature review. Interviews were held with the employees inside the case company and with the injection molding machine vendors' representatives. Also, data regarding the injection molding machine maintenance was collected from the case company and further analyzed. The data must be examined with criticism in mind because not all information for in-depth analysis was available.

As a result of this thesis, a life-cycle model of the injection molding machine was developed, and the cost driving factors of the machine were listed. The machine hour rate is calculated in the model with other essential information. The model is designed for the use of the case company's investment planning process.

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Interviewees

Olli Honkanen, Pre-Production Controller

Perttu Huovinen, Plant General Manager

Harri Karvinen, Production Technician Injection molding

Pekka Korhonen, Operation excellence, Six Sigma Black Belt

Marko Järviö, Maintenance & Development engineer

Simo Pitkänen, Maintenance Mechanic

Ilari Varhimo, Operations manager

APPENDICES

APPENDIX 1. Interview questions for the injection molding machine vendor and injection molding consultant

1. What services does your company provide?
2. Does your service include life-cycle modelling?
3. What is your point of view about the expected economic life of an injection molding machine?
4. What are the recommended maintenance intervals for injection molding machine?
5. Does your company provide maintenance services?
6. Are the replacement times monitored by your company?
7. What is the most common reason for replacing the used machine?
8. What are the markets for used machines? Disposal value?
9. What is your opinion of hydraulic vs. electric machine?
10. What is your opinion in future markets of injection molding machine?
11. What is the biggest competitor of Fanuc?

APPENDIX 2. Model life-cycle model

LIFE CYCLE MODEL OF INJECTION MOLDING MACHINE

Phillips Medisize a molex company

Initial Data		
	Depreciation in years	10
	Hurdle rate	4,00 %
	Machine purchase price	100 000,00 €
	Average annual increase of maintenance costs	10,00 %
	Indirect employees costs multiplier	1,5
	Annual operating hours	5000
VARIABLE COSTS		
	Labor	
	Number of employes	1
	Employees average yearly earnings	60 000,00 €
		60 000,00 €
	Maintenance	
	Number of maintenance employees	6
	Number of maintenance hours	200
	Employees average hourly earnings	15,00 €
	Total maintenance employees costs	27 000,00 €
	Spare parts and supplies	30 000,00 €
		57 000,00 €
	Electricity	
	Power comsuption of the machine kW	150
	Electricity price €/kWh	0,07 €
		52 500,00 €
FIXED COSTS		
	Cleanroom environment	
	Cost of the cleanroom environment €/m2	1 000,00 €
	Area needed for the machine m2	20
		20 000,00 €
	Other	
	Research and development	
	Administrative costs	
	Other utilities	
		150 000,00 €
TOTAL		**439 500,00 €**
Machine Hour Rate (MHR)		87,90 €

(continues)

APPENDIX 2. Life-cycle costs spreadsheet (continue)

LIFE CYCLE COSTS OF INJECTION MOLDING MACHINE

Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676	0,650	0,625	0,601	0,577	0,555
VARIABLE COSTS																
Labor	60 000 €	57 692 €	55 473 €	53 340 €	51 288 €	49 316 €	47 419 €	45 595 €	43 841 €	42 155 €	40 534 €	38 975 €	37 476 €	36 034 €	34 649 €	33 316 €
Maintenance	57 000 €	60 288 €	63 767 €	67 445 €	71 337 €	75 452 €	79 805 €	84 409 €	89 279 €	94 430 €	99 878 €	105 640 €	111 734 €	118 181 €	124 999 €	132 210 €
Electricity	52 500 €	50 481 €	48 539 €	46 672 €	44 877 €	43 151 €	41 492 €	39 896 €	38 361 €	36 886 €	35 467 €	34 103 €	32 791 €	31 530 €	30 317 €	29 151 €
FIXED COSTS																
Clean room environment	20 000 €	19 231 €	18 491 €	17 780 €	17 096 €	16 439 €	15 806 €	15 198 €	14 614 €	14 052 €	13 511 €	12 992 €	12 492 €	12 011 €	11 550 €	11 105 €
Other	150 000 €	144 231 €	138 683 €	133 349 €	128 221 €	123 289 €	118 547 €	113 988 €	109 604 €	105 388 €	101 335 €	97 437 €	93 690 €	90 086 €	86 621 €	83 290 €
Annual operation costs	339 500 €	331 923 €	324 954 €	318 587 €	312 819 €	307 647 €	303 069 €	299 086 €	295 699 €	292 911 €	290 725 €	289 146 €	288 183 €	287 843 €	288 135 €	289 072 €
Machines annual depreciation	10 000 €	9 615 €	9 246 €	8 890 €	8 548 €	8 219 €	7 903 €	7 599 €	7 307 €	7 026 €	6 756 €	0 €	0 €	0 €	0 €	0 €
TOTAL	**349 500 €**	**341 538 €**	**334 199 €**	**327 477 €**	**321 367 €**	**315 866 €**	**310 972 €**	**306 685 €**	**303 006 €**	**299 936 €**	**297 480 €**	**289 146 €**	**288 183 €**	**287 843 €**	**288 135 €**	**289 072 €**
Machine Hour Rate (MHR)	70 €	68 €	67 €	65 €	64 €	63 €	62 €	61 €	61 €	60 €	59 €	58 €	58 €	58 €	58 €	58 €

NO DISCOUNT FACTOR INCLUDED

Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VARIABLE COSTS																
Labor	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €	60 000 €
Maintenance	57 000 €	62 700 €	68 970 €	75 867 €	83 454 €	91 799 €	100 979 €	111 077 €	122 185 €	134 403 €	147 843 €	162 628 €	178 890 €	196 779 €	216 457 €	238 103 €
Electricity	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €	52 500 €
FIXED COSTS																
Clean room environment	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €	20 000 €
Other	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €	150 000 €
Annual operation costs	339 500 €	345 200 €	351 470 €	358 367 €	365 954 €	374 299 €	383 479 €	393 577 €	404 685 €	416 903 €	430 343 €	445 128 €	461 390 €	479 279 €	498 957 €	520 603 €
Machines annual depreciation	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	0 €	0 €	0 €	0 €	0 €
TOTAL	**349 500 €**	**355 200 €**	**361 470 €**	**368 367 €**	**375 954 €**	**384 299 €**	**393 479 €**	**403 577 €**	**414 685 €**	**426 903 €**	**440 343 €**	**445 128 €**	**461 390 €**	**479 279 €**	**498 957 €**	**520 603 €**
Machine Hour Rate (MHR)	70 €	71 €	72 €	74 €	75 €	77 €	79 €	81 €	83 €	85 €	88 €	89 €	92 €	96 €	100 €	104 €

(continues)

APPENDIX 2. Sensitivity analysis I spreadsheet (continue)

SENSITIVITY ANALYSIS

Change in maintenance hours & Costs of spare parts(%)	-25 %	-20 %	-15 %	-10 %	-5 %	0 %	5 %	10 %	15 %	20 %	25 %
Number of maintenance employees	6	6	6	6	6	6	6	6	6	6	6
Number of maintenance hours	150	160	170	180	190	200	210	221	232	243	255
Employees average hourly earnings	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €	15,00 €
Total employees costs	20 250,00 €	21 600,00 €	22 950,00 €	24 300,00 €	25 650,00 €	27 000,00 €	28 350,00 €	29 767,50 €	31 255,88 €	32 818,67 €	34 459,60 €
Spare parts and supplies	22 500,00 €	24 000,00 €	25 500,00 €	27 000,00 €	28 500,00 €	30 000,00 €	31 500,00 €	33 000,00 €	34 500,00 €	36 000,00 €	37 500,00 €
TOTAL	**42 750 €**	**45 600 €**	**48 450 €**	**51 300 €**	**54 150 €**	**57 000 €**	**59 850 €**	**62 768 €**	**65 756 €**	**68 819 €**	**71 960 €**

Change in power comsumption of the machine(%)	-25 %	-20 %	-15 %	-10 %	-5 %	0 %	5 %	10 %	15 %	20 %	25 %
Power comsuption of the machine kW	113	120	128	135	143	150	158	165	173	180	188
Electricity price €/kWh	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07
TOTAL	**39 375 €**	**42 000 €**	**44 625 €**	**47 250 €**	**49 875 €**	**52 500 €**	**55 125 €**	**57 750 €**	**60 375 €**	**63 000 €**	**65 625 €**

(continues)

APPENDIX 2. Sensitivity analysis II spreadsheet (continue)

Hurdle rate	2 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,980	0,961	0,942	0,924	0,906	0,888	0,871	0,853	0,837	0,820	0,804	0,788	0,773	0,758	0,743
Operation costs	339 500,00 €	338 431,37 €	337 821,99 €	337 697,23 €	338 084,65 €	339 014,20 €	340 518,36 €	342 632,35 €	345 394,38 €	348 845,80 €	353 031,41 €	357 999,72 €	363 803,20 €	370 498,61 €	378 147,36 €	386 815,81 €
Annual depreciation	10 000,00 €	9 803,92 €	9 611,69 €	9 423,22 €	9 238,45 €	9 057,31 €	8 879,71 €	8 705,60 €	8 534,90 €	8 367,55 €	8 203,48 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**348 235,29 €**	**347 433,68 €**	**347 120,45 €**	**347 323,11 €**	**348 071,51 €**	**349 398,07 €**	**351 337,96 €**	**353 929,28 €**	**357 213,35 €**	**361 234,89 €**	**357 999,72 €**	**363 803,20 €**	**370 498,61 €**	**378 147,36 €**	**386 815,81 €**

Hurdle rate	4 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676	0,650	0,625	0,601	0,577	0,555
Operation costs	339 500,00 €	331 923,08 €	324 953,77 €	318 586,96 €	312 818,76 €	307 646,55 €	303 069,01 €	299 086,08 €	295 699,05 €	292 910,53 €	290 724,53 €	289 146,44 €	288 183,09 €	287 842,82 €	288 135,47 €	289 072,45 €
Annual depreciation	10 000,00 €	9 615,38 €	9 245,56 €	8 889,96 €	8 548,04 €	8 219,27 €	7 903,15 €	7 599,18 €	7 306,90 €	7 025,87 €	6 755,64 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**341 538,46 €**	**334 199,33 €**	**327 476,92 €**	**321 366,80 €**	**315 865,82 €**	**310 972,15 €**	**306 685,26 €**	**303 005,95 €**	**299 936,40 €**	**297 480,17 €**	**289 146,44 €**	**288 183,09 €**	**287 842,82 €**	**288 135,47 €**	**289 072,45 €**

Hurdle rate	6 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,943	0,890	0,840	0,792	0,747	0,705	0,665	0,627	0,592	0,558	0,527	0,497	0,469	0,442	0,417
Operation costs	339 500,00 €	325 660,38 €	312 807,05 €	300 891,84 €	289 869,61 €	279 698,04 €	270 337,55 €	261 751,10 €	253 904,10 €	246 764,26 €	240 301,46 €	234 487,69 €	229 296,90 €	224 704,91 €	220 689,34 €	217 229,50 €
Annual depreciation	10 000,00 €	9 433,96 €	8 899,96 €	8 396,19 €	7 920,94 €	7 472,58 €	7 049,61 €	6 650,57 €	6 274,12 €	5 918,98 €	5 583,95 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**335 094,34 €**	**321 707,01 €**	**309 288,04 €**	**297 790,54 €**	**287 170,62 €**	**277 387,15 €**	**268 401,67 €**	**260 178,22 €**	**252 683,24 €**	**245 885,41 €**	**234 487,69 €**	**229 296,90 €**	**224 704,91 €**	**220 689,34 €**	**217 229,50 €**

Hurdle rate	8 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,926	0,857	0,794	0,735	0,681	0,630	0,583	0,540	0,500	0,463	0,429	0,397	0,368	0,340	0,315
Operation costs	339 500,00 €	319 629,63 €	301 328,88 €	284 483,28 €	268 986,89 €	254 741,66 €	241 656,80 €	229 648,33 €	218 638,48 €	208 555,30 €	199 332,22 €	190 907,62 €	183 224,48 €	176 230,06 €	169 875,56 €	164 115,82 €
Annual depreciation	10 000,00 €	9 259,26 €	8 573,39 €	7 938,32 €	7 350,30 €	6 805,83 €	6 301,70 €	5 834,90 €	5 402,69 €	5 002,49 €	4 631,93 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**328 888,89 €**	**309 902,26 €**	**292 421,60 €**	**276 337,19 €**	**261 547,49 €**	**247 958,50 €**	**235 483,23 €**	**224 041,17 €**	**213 557,79 €**	**203 964,16 €**	**190 907,62 €**	**183 224,48 €**	**176 230,06 €**	**169 875,56 €**	**164 115,82 €**

Hurdle rate	10 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,909	0,826	0,751	0,683	0,621	0,564	0,513	0,467	0,424	0,386	0,350	0,319	0,290	0,263	0,239
Operation costs	339 500,00 €	313 818,18 €	290 471,07 €	269 246,43 €	249 951,30 €	232 410,27 €	216 463,89 €	201 967,17 €	188 788,33 €	176 807,58 €	165 915,98 €	156 014,53 €	147 013,21 €	138 830,19 €	131 391,08 €	124 628,25 €
Annual depreciation	10 000,00 €	9 090,91 €	8 264,46 €	7 513,15 €	6 830,13 €	6 209,21 €	5 644,74 €	5 131,58 €	4 665,07 €	4 240,98 €	3 855,43 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**322 909,09 €**	**298 735,54 €**	**276 759,58 €**	**256 781,44 €**	**238 619,49 €**	**222 108,62 €**	**207 098,75 €**	**193 453,41 €**	**181 048,55 €**	**169 771,41 €**	**156 014,53 €**	**147 013,21 €**	**138 830,19 €**	**131 391,08 €**	**124 628,25 €**

Hurdle rate	12 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,893	0,797	0,712	0,636	0,567	0,507	0,452	0,404	0,361	0,322	0,287	0,257	0,229	0,205	0,183
Operation costs	339 500,00 €	308 214,29 €	280 189,73 €	255 078,55 €	232 570,19 €	212 387,34 €	194 282,38 €	178 034,19 €	163 445,31 €	150 339,41 €	138 559,03 €	127 963,56 €	118 427,43 €	109 838,48 €	102 096,57 €	95 112,25 €
Annual depreciation	10 000,00 €	8 928,57 €	7 971,94 €	7 117,80 €	6 355,18 €	5 674,27 €	5 066,31 €	4 523,49 €	4 038,83 €	3 606,10 €	3 219,73 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**317 142,86 €**	**288 161,67 €**	**262 196,35 €**	**238 925,37 €**	**218 061,61 €**	**199 348,70 €**	**182 557,68 €**	**167 484,14 €**	**153 945,51 €**	**141 778,76 €**	**127 963,56 €**	**118 427,43 €**	**109 838,48 €**	**102 096,57 €**	**95 112,25 €**

Hurdle rate	14 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,877	0,769	0,675	0,592	0,519	0,456	0,400	0,351	0,308	0,270	0,237	0,208	0,182	0,160	0,140
Operation costs	339 500,00 €	302 807,02 €	270 444,75 €	241 887,52 €	216 673,97 €	194 399,21 €	174 707,86 €	157 288,01 €	141 865,84 €	128 200,99 €	116 082,45 €	105 324,94 €	95 765,78 €	87 262,12 €	79 688,48 €	72 934,67 €
Annual depreciation	10 000,00 €	8 771,93 €	7 694,68 €	6 749,72 €	5 920,80 €	5 193,69 €	4 555,87 €	3 996,37 €	3 505,59 €	3 075,08 €	2 697,44 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**311 578,95 €**	**278 139,43 €**	**248 637,23 €**	**222 594,77 €**	**199 592,89 €**	**179 263,73 €**	**161 284,38 €**	**145 371,43 €**	**131 276,07 €**	**118 779,88 €**	**105 324,94 €**	**95 765,78 €**	**87 262,12 €**	**79 688,48 €**	**72 934,67 €**

Hurdle rate	16 %															
Years in service	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discount factor	1	0,862	0,743	0,641	0,552	0,476	0,410	0,354	0,305	0,263	0,227	0,195	0,168	0,145	0,125	0,108
Operation costs	339 500,00 €	297 586,21 €	261 199,46 €	229 590,57 €	202 112,97 €	178 208,66 €	157 395,98 €	139 259,12 €	123 439,09 €	109 625,89 €	97 551,77 €	86 985,47 €	77 727,14 €	69 604,12 €	62 467,14 €	56 187,14 €
Annual depreciation	10 000,00 €	8 620,69 €	7 431,63 €	6 406,58 €	5 522,91 €	4 761,13 €	4 104,42 €	3 538,30 €	3 050,25 €	2 629,53 €	2 266,84 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
TOTAL	**349 500,00 €**	**306 206,90 €**	**268 631,09 €**	**235 997,15 €**	**207 635,88 €**	**182 969,79 €**	**161 500,40 €**	**142 797,42 €**	**126 489,35 €**	**112 255,42 €**	**99 818,61 €**	**86 985,47 €**	**77 727,14 €**	**69 604,12 €**	**62 467,14 €**	**56 187,14 €**