Economic viability of used agricultural equipment

Begagnade lantbruksmaskiners ekonomiska bärighet

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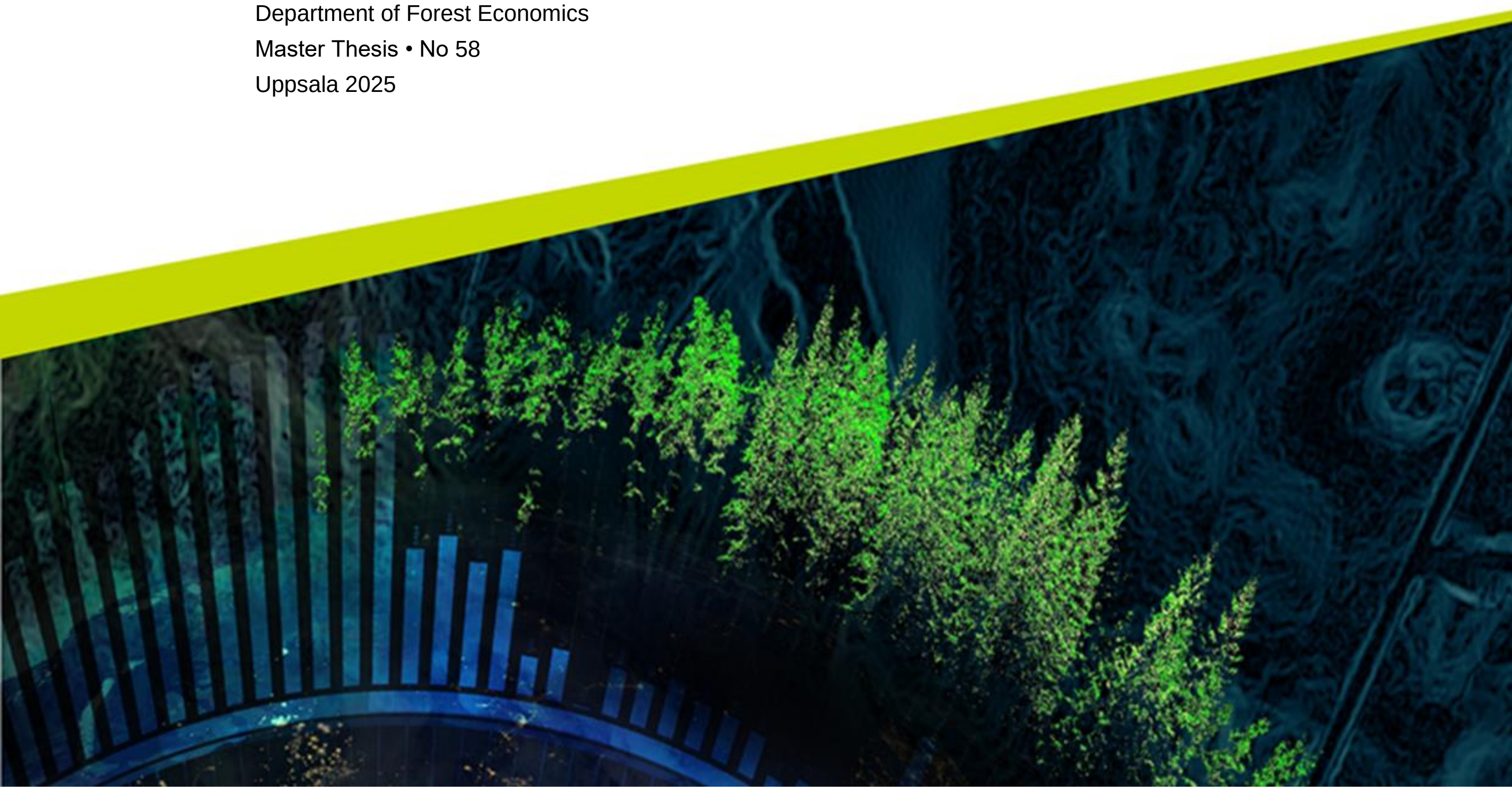

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Summary

As agricultural margins tighten, farmers are considering strategies to minimize costs to create a greater revenue, one being optimizing machinery costs (Zwilling 2021). Niléhn (2023:1) discusses the significant price development on agricultural equipment, where the prices have increased 30-50% from 2020 to 2023. It would therefore presumably be more cost-effective to utilize used agricultural equipment, none where however written on the subject. The aim of this study was therefore to identify the economic viability of used agriculture machinery as part of a cost-effective equipment strategy in a Swedish context.

The study approached the aim by conducting machinery cost calculations on seven different common agricultural machines found on a grain farm of roughly 300 hectares. The calculations were conducted on the individual machines, and as part of a machinery system. When compared, the system with the older machines gave a lower annual cost than the new. The cost minimized system did, however, contain a combination of new and old machinery, notably older tractors and combines and newer implements.

The results did prove the economic viability of older agricultural equipment as part of a cost-effective equipment strategy. The results are however, based on contextual variables as interest rates and grain prices that may change over time, which may alter the outcome.

Keywords: economic viability, equipment strategy, machinery-cost calculations, used agricultural equipment

Sammanfattning

När jordbrukets marginaler minskar överväger lantbrukare strategier för att minimera kostnader och därigenom skapa högre intäkter, varav en strategi är att optimera maskinkostnader (Zwilling 2021). Niléhn (2023:1) diskuterar den betydande prisutvecklingen på lantbruksutrustning, där priserna har ökat med 30–50 % från 2020 till 2023. Det därför presumtivt vara mer kostnadseffektivt att använda begagnad lantbruksutrustning, dock finns ingen tidigare forskning på ämnet. Syftet med denna studie var därför att identifiera den ekonomiska bärigheten för begagnade lantbruksmaskiner som en del av en kostnadseffektiv maskinstrategi i en svensk kontext.

Studien närmade sig syftet genom att utföra maskinkostnadsberäkningar på sju vanligt förekommande lantbruksmaskiner som används på en spannmålsgård om cirka 300 hektar. Beräkningarna utfördes på de enskilda maskinerna och som en del av ett maskinsystem. Vid jämförelse visade systemet med de äldre maskinerna en lägre årlig kostnad än det nya. Det kostnadsminimerade systemet innehöll dock en kombination av nya och gamla maskiner, särskilt äldre traktorer och skördetröskor samt nyare redskap.

Resultaten visade den ekonomiska lönsamheten hos äldre lantbruksmaskiner som en del av en kostnadseffektiv maskinstrategi. Resultaten baseras dock på kontextuella variabler som räntor och spannmålspriser, vilka kan förändras över tid och påverka utfallet.

Nyckelord: ekonomisk lönsamhet, maskinstrategi, maskinkostnadsberäkningar, begagnad lantbruksutrustning

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1 Introduction

Chapter one introduces the problem's background and the reasoning behind the chosen subject. It also presents the thesis problem as well as the aim and delimitations.

1.1 Problem background

The Swedish agricultural sector has in recent years experienced historically high costs of operational expenses. This phenomenon is partly due to input costs but has more recently been overtaken by interest as a cost-driven factor (Stärn, 2023). As a result, 48% of farmers in Sweden perceives the profitability in farming as “quite bad” (Ludvig & Co *et al.*, 2024:3). These developments have consequently led to financial pressure on the Swedish farmers, something that can be observed in the agricultural machinery demand (Stork, 2024).

In an article from May 2024 in the agriculture industry magazine ATL, Stork (2024:1) writes about the Swedish manufacturer of agricultural machines Väderstad. They propose a sales forecast that indicates a decline in revenue generated from machine sales of 25% compared to the previous year. Niléhn (2023:1) discusses the significant price development on agricultural equipment, where the prices have increased 30-50% from 2020 to 2023. In contrast, the Producer Price Index (PPI) for the same period only increased by 5,7 percentage points (The Swedish Agency of Agriculture, 2023). This disparity in price growth likely contributes to reduced equipment sales.

As agricultural margins tighten, farmers are considering strategies to minimize costs to create a greater revenue (Zwilling, 2021). One of these ways would be to assert the optimal or close to optimal cost of agricultural machinery in accordance with the individual farm´s needs and conditions. A report by Carlsson *et al.* (2006:2) states that machinery costs could be estimated to be 36% of the total expense, something farmers can influence to a great degree and is therefore a possible way to better the farms’ margin. As Zwilling (2021) proposes, lower equipment costs tend to generate greater profitability for farmers.

A good equipment strategy is according to Axenbom *et al.* (1988) to find the optimal capacity for farm equipment when taking the farm's size and needs into account. Figure 1 displays how the cost per hectare changes in proportion to the capacity of the farm's machinery. The machines capacity dictates how much labor is needed to perform a field operation and is expressed as machinery and labor cost.

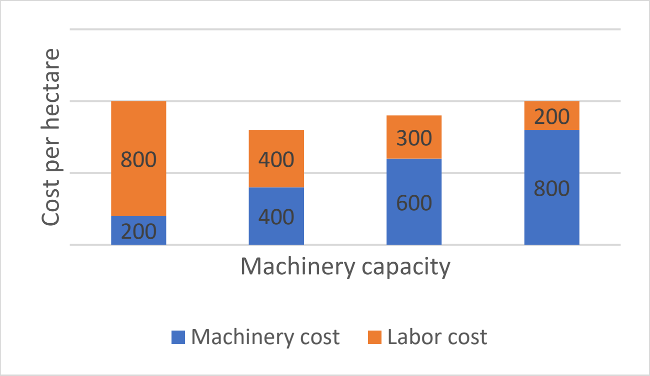


Figure 1. Example of the correlation between machinery- and labor cost (Axenbom et al, 1988).

The value of machinery capacity can be expressed as timeliness cost (Axenbom *et al.*, 1988). It represents the total revenue losses experienced completing field operations at a sub-optimal moment. The total equipment cost can therefore be expressed as the combination of machinery costs, labor costs and timeliness costs. The foundation for a well-calculated equipment strategy is therefore according to Axenbom *et al.* (1988) to find the point where the sum of these components is the lowest. Figure 2 Showcases the relationship between these factors where the third column achieves the lowest total cost.

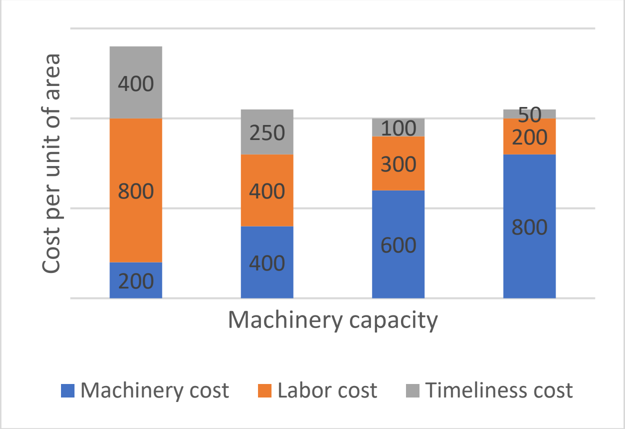


Figure 2. Example of the correlation between machinery-, labor- and timeliness cost (Axenbom et al.,1988).

1.2 Problem

To achieve lower equipment costs, it is sensible to have a cost-effective machinery strategy (Hallefält & Nilsson, 2006:1). Hallefält and Nilsson (2006) conducted an extensive report on equipment cost strategies in potato production. The authors presented ways to calculate both general and implement specific costs to quantify the economic effects behind different equipment strategies. Andersson *et al.* (2017) present in their thesis an optimal time to change a combine harvester. Their thesis concludes that by using calculation models constructed from equipment cost theories, an optimal replacement time can be calculated. The authors add that to create more validity in the results, more research needs to be conducted on complementing factors such as technical development and maintenance costs, as they are relying on outdated data. Both reports present a foundation of calculations needed for creating a cost-effective equipment strategy, however, neither of these reports take older or used farm equipment into account. This is prevalent in most reports conducted on the subject of machinery cost calculation.

Lundberg and Magnusson (2013) wrote about the economic viability of investing in a new combine, the authors put this in relativity to contracting. They demonstrated a viability to invest in a new combine, depending on the scale of the farm. The authors included that to add depth to the study, older or used equipment should be considered in a following study.

Used agricultural equipment is under-represented in the existing literature as part of equipment strategy calculations. This thesis will therefore explore when and if used equipment is a viable consideration for an equipment strategy.

1.3 Aim and research questions

The aim of this project was to identify the economic viability of used agriculture machinery as part of a cost-effective equipment strategy. The objective was to contribute a comprehensive strategy for managing operational costs.

To reach the aim of the thesis, the following research questions were addressed:

- Is used agricultural machinery economically and operationally viable as part of a cost-effective equipment strategy?
- What advantages and disadvantages do used agricultural equipment have compared to newer equipment when conducting an equipment strategy?

1.4 Delimitations

As this thesis aims to identify the economic viability of used agricultural equipment, all relevant factors should be addressed. To do this, some delimitations need to be made.

As the timeliness factor varies across Sweden due to geographical conditions, the thesis will focus on one geographic locations of the country. This delimitation is made partly because of simplification, but also as this region are one of the main agricultural regions in Sweden. The thesis will therefore presume the conditions present in Gns (Götalands norra slättbyggder, region 3).

To further simplify, the calculations will only be conducted on grain production, meaning the result will be transferable to grain only. The thesis will also not take machine breakdown insurance or labor costs into consideration, along with technical development.

2 Method

Chapter 2 presents the literature review conducted at the beginning of the thesis. It also addresses the method and quality criteria, along with the empirical method for conducting the calculations.

2.1 Literature review

To develop an understanding of the subject and to examine how previous literature addressed the topic, a literature review was conducted. The relevant literature was sourced from different academic databases such as the SLU library database Primo, Science Direct and Google Scholar, as well as from the SLU library in the form of reports and institutional reports.

Bryman and Bell (2011, 94) state that a review should be performed to understand differences in existing material to develop a research aim, in the case of this thesis, the economic viability of used equipment in equipment cost strategies.

The literature review did not only highlight the under-representation of used equipment in cost strategies but did also identify themes that had been thoroughly addressed in previous research. Various studies (Lundberg & Magnusson, 2013; Ibendahl & Griffin, 2021; Weersink, 1984 etc.) focuses on replacement strategies where the emphasis lies on the change from old to new equipment. Multiple studies have been performed on calculations for evaluating the cost of machinery (Axenbom *et al.*, 1988; Hallefält & Nilsson, 2006; Svensson, 1987 & 1988 etc.), although they have been under-utilized on the calculation of used machinery. Andersson *et al.* (2017) explored when the optimal time to change a combine was, where they utilized Axenbom *et al.* (1988) etc. calculations on older equipment, but did not explore the economic viability of the used equipment.

As Bryman and Bell (2011) state, the literature review contributes to a deeper understanding of the disparities in the current literature and has aided to establish the thesis aim. In addition to gaining a fundamental understanding of the subject in the beginning of the research, the literature review was a continuous part of the thesis, serving as a foundation to further refine the research.

2.2 Research method

When conducting an academic study, three methods could be used (Bryman & Bell, 2011), quantitative, qualitative or a mixed method. To quantify and generalize the results of the study, the quantitative method is suitable. The quantitative method is grounded in the belief that there exists an objective reality, and by studying this reality, an objective truth can be reached. The quantitative method is characterized by positivism and objectivism which presumes that knowledge can be derived from an observable phenomenon and that the researchers can reach an objective truth (*ibid.*).

In contrast, the qualitative method is grounded in the understanding of a social reality and its continuous change. The qualitative method is characterized by interpretivism and constructivism which presumes that reality is subjective and socially constructed, it also recognizes the author´s role in the interpretation of the data (Bryman & Bell, 2011).

The mixed method utilizes both quantitative and qualitative research methodologies to provide a comprehensive understanding of a problem (Bryman & Bell, 2011). The combination of methods enables the author to utilize the strengths of both methods while compensating for their individual weaknesses (*Ibid.*). To enable a generalization and quantification of the results in this study, the quantitative method was used.

There are primarily two approaches to understanding the relationship between empirical evidence and theory in research, the deductive and inductive approach (Bryman & Bell, 2011). The deductive approach begins with established theories or principles and aims to apply them to specific cases. In this approach, the researchers formulate hypotheses based on existing theoretical frameworks and conduct studies to test if these hypotheses are correct in accordance with the empirical data. The goal is to draw conclusions about the chosen research subject that either supports or challenges the existing theory. This structured investigation allows for the refinement or modification of the original theory based on the study's findings (Bryman & Bell, 2011).

The inductive approach is generally more oriented towards exploring, starting with observations and experiences to develop new theories. This method emphasizes gathering data through interviews, focus groups, and observations. Researchers analyze this data to identify patterns, themes, and relationships, ultimately leading to the formulation of new theoretical frameworks. Inductive reasoning allows for flexibility and adaptability, as it highlights the importance of understanding the complexities of real-world phenomena (Bryman & Bell, 2011). To support and develop the existing theories regarding equipment strategies in relation to used equipment the deductive approach was used.

Epistemology is important when shaping research approaches (Bryman & Bell, 2011). The researchers must consider how their perspectives and experience influence the way knowledge is understood and constructed. Bryman and Bell (2011) describe two central epistemological positions, positivism and interpretivism.

Positivism assumes that an objective reality can be measured through empirical observations and quantitative methods (*Ibid.*). It aims to uncover objective truths based on observable facts and data. Interpretivism views reality as subjective and shaped by individual interpretations and social contexts. This approach focuses on understanding these subjective realities through qualitative methods, focusing on the individuals' experiences and how they interpret them (Bryman & Bell, 2011).

The study of social phenomena and how they are perceived by the world is called ontology, which includes two main perspectives: objectivism and constructionism (Bryman & Bell, 2011).

Objectivism claims that social phenomena exist separately from social actors and that there is no interaction between them and the phenomena. In contrast, constructionism argues that social phenomena are continuously shaped by interactions with social actors and are in constant change (Bryman & Bell, 2011).

The author of this thesis had a positivistic approach as the aim of the study was to apply existing theories to an empirical example with quantitative methods.

2.3 Quality criteria in research

The reliability criteria in research are the basis of credibility and dependability in measurements, this ensures that the study measures what it is supposed to be measured, and that the information should be reliable. Reliability is dependent on how the information in a thesis is processed and the accuracy of calculations, therefore, the precision of the measurements. This is important because reliability is the degree to which it is possible to duplicate the study and obtain similar results, thus, a good description of the methodology of the study needs to be given (Bryman & Bell, 2011). In this study, the author had a high focus on the study's reliability, the calculations are based on well-established formulas in order to achieve this. The author acknowledges that the results are sensitive, due to the critical values of the parameters on which the calculations are based, and also, that some parameters may be on the verge of being outdated.

Validity relates to the clarity and accuracy of what is being studied in order to truly test its supposed subject. Validity is one of the most important quality criteria in research according to Bryman and Bell (2011). A reflexive approach is characterized by reflecting on the methods concerning how to ensure that the results deviate as little as possible from reality (*Ibid*). The validity of such results may be seen from either an internal or external perspective. Internal validity refers to the existence of a supposed link between several variables, while external validity is a matter of establishing whether such findings can be applied in any other context other than the one that was used during the study (*Ibid*). In order to ensure the validity of the study's findings, various methods were used. When possible, the collected data were triangulated, the calculations were reviewed by an advisor and the findings were critically reflected on.

2.4 Empirical method

As the thesis is focused on a Swedish setting, it does therefore make assumptions that relate to those conditions. The replacement prices for the machines used in the calculations is derived from a compilation of machinery costs from Maskinkalkylsgruppen (2023), were the authors collected prices from the biggest machinery-brands present on the Swedish market. This compilation was also the source for average hours of usage per year, field capacity, fuel price and fuel consumption for all machines.

The calculated values of maintenance- and timeliness cost are given as future values, meaning they need to be adjusted to inflation. The thesis assumes an annual inflation rate of 2%, based on data from the years 2010 to 2023 (SCB, 2024). The interest cost do not need to be adjusted as the equation utilizes a real interest rate. Different rates are presented by Agriwise (2009) and Maskinkalkylsgruppen (2023) as 7% and 2% respectively, the thesis chooses to use a real interest rate of 5%, a bit higher than the median. The calculation period is set to 8 years for all machines where the categorization of new machines corresponds to year 1-8 and old machines 9-16, these are referred to as the new system and the old system.

The calculations were conducted for each of the machines separately, and as part of a system which is based on the equations presented in chapter 3. The thesis focuses on some of the essential equipment for a grain farm with roughly 300 hectares of farmland (Farmer A, 2024), this includes:

- 150-horsepower tractor
- 300-horsepower tractor
- 30-foot combine
- 4-meter combi seed drill
- 5-bottom switch plow
- 8-meter harrow
- 24-meter sprayer

3 Theory

Chapter 3 introduces the theories which the thesis is based on. The groundwork for the thesis was different investment-, equipment-, and timeliness calculations.

3.1 Investment theory

An investment is the act of procuring an asset that contributes to higher revenue, lower costs or results in better quality of the products generated (Bergknut *et al.,* 1993). As an investment often binds a substantial amount of the firm's capital, it is important to plan the expected outcome thoroughly. Before committing to an investment, an extensive assessment of the investment's benefits and drawbacks needs to be conducted, as well as to compare different alternatives to the investment (Ljung & Högberg, 1996). Bergknut *et al.* (1993) describes different types of investments, where the most common reasoning is to rationalize the current operation. Investments could also occur to ensure the current operations continuation, if new technology creates rationalizing effects on the operation or if the cost of maintenance on the current equipment can't be justified.

3.1.1 Present value

Present value (PV) is a common method in investment calculation to make accurate assessments regarding future investments. When using the present value method, all in- and outflows are discounted to a point in time using a discount rate. This enables future investments or cashflows to be compared to the present as the value of money changes over time (Fernando, 2024). The formula used in the calculation is presented in Equation 1.

$$PV = \frac{FV}{(1+r)^n}$$

Equation 1. Present value formula, Present value = PV, Future value = FV, r = Discount rate and n = Number of periods.

3.1.2 Annuity method

The annuity method is commonly used in investment theory to distribute payment streams evenly over time (Olsson, 1998). This distribution is made in proportion to the discount rate and the duration for which the payment streams occur. The method converts a present value into a series of equal periodic payments, ensuring that the total present value of all payments equals the future value as seen in Equation 2.

$$A = PV * \frac{r}{1-(1+r)^{-n}}$$

Equation 2. Annuity formula, A = annual payment (annuity), Present value = PV, r = Discount rate and n = Number of periods.

3.2 Equipment cost calculations

Equipment costs mainly consist of six different cost aspects; depreciation, interest, maintenance, cost of storage, fuel and insurance (Pettersson & Davidsson, 2009:9). These costs can then be divided into fixed and variable costs (Hallefält & Nilsson, 2006:2). The fixed cost is independent of the usage of the equipment, such as depreciation, interest, insurance and storage. Variable cost is dependent on the usage of the equipment, such as maintenance and fuel consumption, as well as the timeliness cost. As Hallefält and Nilsson (2006) states, the categorization between fixed and variable costs is dependent on the equipment. If a machine that isn't used still needs maintenance, it can be categorized as a fixed cost. Figure 3 displays the cost of machinery depending on usage in relation to fixed or variable costs.

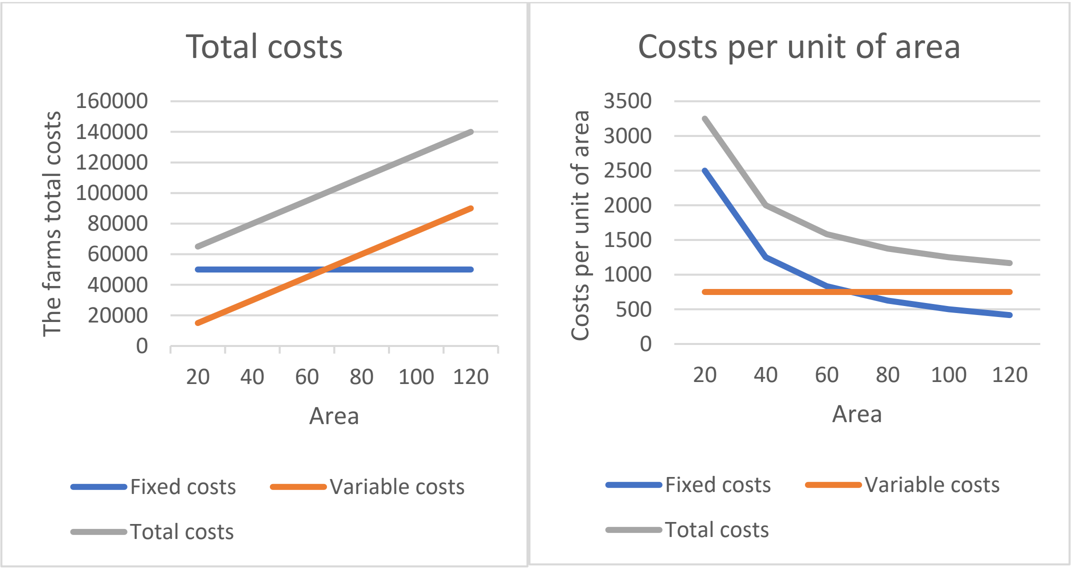


Figure 3. Example of how the fixed and variable costs differentiate between the farms total cost and the cost per hectare (Hallefält & Nilsson, 2006).

These cost aspects will be the foundation of the machine's total costs and are covered in the following chapter. The storage cost will, however, not be included in the thesis calculations as the machinery will be of the same sizes, resulting in equal costs for each machine, despite its age. It can also be added that depreciation and interest, although being categorized as a fixed cost, depends on the machines' use. If the machine is used an extensive amount, it could deteriorate faster, resulting in a greater depreciation.

3.2.1 Depreciation

Depreciation can be described as the value a machine loses over the time of utilization (Axenbom *et al.,* 1988). This refers to a machine’s actual depreciation which is grounded in a machine’s usage, deterioration and age, not the accounting variation of depreciation, which is based on different accounting principles. The classic calculation for depreciation was presented by Axenbom *et al*. (1988) and is shown in Equation 3.

$$D = \frac{PVm - RV}{t}$$

Equation 3. Classic depreciation equation, D = Depreciation, PVm = Present value of the machine, RV = Residual value of the machine and t = Time

Svensson (1988) estimated a way of calculating a machine’s residual value, this model is derived from collected data that originates from different machinery calculation groups. The model is based on the age of the machine, one depreciation factor, one machine specific depreciation factor and the machine’s replacement cost, Equation 4. Eriksson (1986) found that the average price increase of the equipment dealer was roughly 20%. By reducing the replacement cost (the cost of a machine that is bought new at an equipment dealer) by 20 %, it gives the current value of the machine. This is represented by the depreciation factor (*Df)* and is a constant of 0,833, resulting in a high depreciation cost the first year.

$$RVn = RC * Df * SDf^{t}$$

Equation 4. Residual value equation, RVn = Residual Value at year n, RC = The machines replacement cost, Df = Depreciation factor, SDf = Machine specific depreciation factor and t = Age of the machine -1

A depreciation formula can be derived from the classic depreciation equation and Svensson’s (1988) model, as seen in Equation 5. The Present value of the machine is calculated as a percentage of the replacement cost and represent the current market value year n, this gives the cost of depreciation at year n. The denominator of time will not be needed as the calculation will be conducted on each separate year.

$$D = PVm - RC * Df * SDf^{t}$$

Equation 5. Compound equation derived from the classical depreciation equation and Svensson (1988).

3.2.2 Interest

The act of committing capital to equipment over a period of time is calculated as an interest cost. As the value of the machine changes due to depreciation, the mean amount of capital changes accordingly. The interest rate used in the calculation needs to be adjusted for inflation; hence, the real interest rate should be applied. Axenbom *et al*. (1988) proposed the following way to calculate the interest cost, Equation 6 and 7.

$$Mean\ capital = \frac{(PVm + RVn)}{2}$$

Equation 6. Equation for calculating the mean committed capital.

$$Ic = \frac{(PVm + RVn)}{2} * \frac{i}{100}$$

Equation 7. Equation for calculating interest cost, calculating, Ic =Total interest cost, i = real interest rate.

3.2.3 Insurance

A machine's insurance cost can according to Axenbom *et al.* (1988), be calculated by using a machine's replacement cost (Rc) and template-based values. Pålsson and Rydheimer (2005) displayed the viability of the template-based values regarding combines in their thesis. The template-based values are displayed in Table 1 as a percentage of the machine's replacement cost.

Table 1. Template-based values for insurance cost (Axenbom et al., 1988)

Machine	Insurance cost (SEK/year)
Tractors	0,003*Rc
Combines	0,002*Rc
Other implements	0,001*Rc

3.2.4 Fuel

The fuel and lubrication costs can be calculated if the fuel usage of the machine per hour is known. Earlier studies have shown that the lubrication cost can be calculated to 10% of the fuel cost (Axenbom *et al.*, 1988). This calculation will only need to be conducted on machines that are self-propelled, such as the tractors and combine due to being the only machines that require fuel. The cost for fuel and grease is calculated by Equation 8.

$$C_{fl} = 1{,}1(h * U_F * P_f)$$

Equation 8. Fuel and luberication equation, Cfl = the cost of fuel and lubrication, h = usage), Uf = Fuel consumption and Pf = Price of fuel.

3.2.5 Maintenance

Svensson (1987) noted that maintenance costs increased in relation to the age of the machine. The maintenance cost increases exponentially to later stagnate due to most of the wearable components being replaced, shown in Figure 4. To adapt the formula in a reliable way, it needs to be done to all machines separately. The formula relies on three parameters: the machines' replacement cost, the machines' age and the usage per year. The calculations also rely on machine specific variables (B0 and B1) that determine the maintenance curve. The maintenance cost is calculated by Equation 9 and the machine specific variables are displayed in Table 2.

$$Mc_t = B0\left(1 - e^{(-B1*t)}\right) * h * \frac{Rc_n}{1000}$$

Equation 9. Maintenance cost equation, Mct = Maintenance cost in relation to replacement cost, usage and age, B0 and B1 = machine specific variables, t = year of the machine, h = usage, Rc = replacement cost at year n.

Table 2. Maintenance variables, (Svensson, 1987)

Machines	B0	B1
150-horsepower tractor	0,122	0,203
300-horsepower tractor	0,122	0,203
30-foot combine	0,697	0,065
4-meter combi seed drill	1,099	0,099
5-bottom switch plow	0,900	0,273
8-meter harrow	1,959	0,071
24-meter sprayer	1,194	0,287

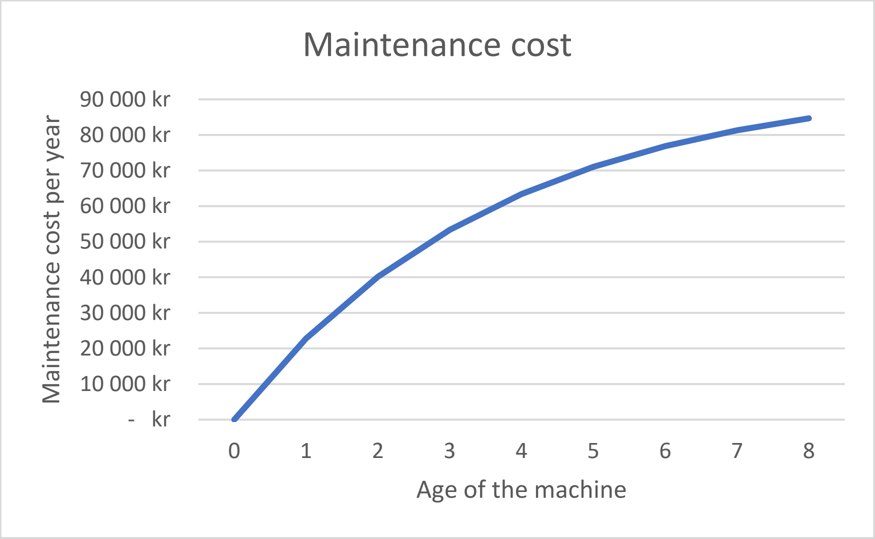


Figure 4. Example of the development of the maintenance cost (own processing of Svensson, 1988).

3.3 Timeliness cost

Timeliness costs arise when field operations are conducted at a sub-optimal time, causing a negative impact on the potential yield or quality (Axenbom *et al.*, 1988). Timeliness costs can therefore be expressed as the value of having adequate machine capacity to complete fieldwork at a close to optimal time. The timeliness cost is therefore not a real cost, as it is a loss of revenue, but is generally treated as a cost during calculations (Hallefält & Nilsson, 2006). Figure 5 shows how the timeliness factor contributes to a loss in yield and the formula is seen in Equation 10.

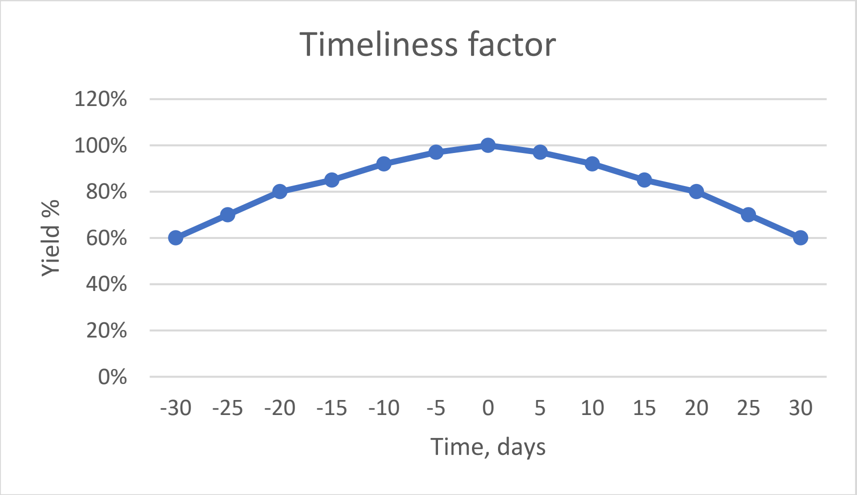


Figure 5. Example of timeliness costs development (Axenbom et al., 1988)

$$Tc = \frac{Tf * Pg * A * Td}{2}$$

Equation 10. Timeliness equation by Axenbom et al. (1988), Tc = timeliness cost, Tf = timeliness factor, P = price of grain, A = area and Td = expected time of the fieldwork -1 day

The timeliness factor is derived from compiled data by Axenbom *et al.* (1988) and represents the quantity and quality losses due to sub-optimal timing of field work. This is presented in Table 3, where the value of seeding will be used for all machines, except the combine.

Table 3. Timeliness factor in Gns (Axenbom et al., 1988)

Production region	**Crop**	**Tf, seeding (kg/ha)**	**Tf, harvesting (kg/ha)**
Gns	Grain	35	40

As the thesis compares equipment of the same capacity, the timeliness cost will arise from breakdown time and are not due to an absence of suitable machinery capacity. The formula used for timeliness cost will therefore exchange the variables *A* and *Td* for the probability of a breakdown, *Pt* (as presented in chapter 3.4), the amount of days the breakdown lasts, *Dt* (also presented in chapter 3.4), and the capacity of the machine, *Cm*. The new formula will therefore be used as in Equation 11. This formula estimates the probability of a breakdown occurring, and how much the breakdown would cost per hectare, to then calculate how many hectares that would not be worked during the breakdown.

$$Tc = Pt * Dt * Tf * Pg * C(Pt * Dt * Wh)$$

Equation 11. The timeliness cost due to machinery breakdown. Pt = Probability of a breakdown in relation to the machines age (Value given as %), Dt = The mean days a breakdown lasts, C =The field capacity of the machine and Wh = The number of workhours in a day.

3.4 Breakdowns

Weersink (1984) describes the rising probability of a breakdown in relation to a combines age. A breakdown is described as an event in which the machine is stopped from conducting its intended fieldwork due to an accident or breakage, until it is repaired. The study is based on compiled empirical data from Montana, USA. Weersink (1984) further explains that the probability for a breakdown is the same during the whole season but is greater each season the machine is used. If a breakdown occurs the probability of another breakdown shrinks. The probability of a breakdown is shown in Figure 6 and the formula in Equation 12.

$$Pt = \frac{1}{(1 + e^{-(-4{,}59512+0{,}51057*t)}}$$

Equation 12. Pt = Probability of a breakdown on a machine in relation to t, years (Weersink, 1984).

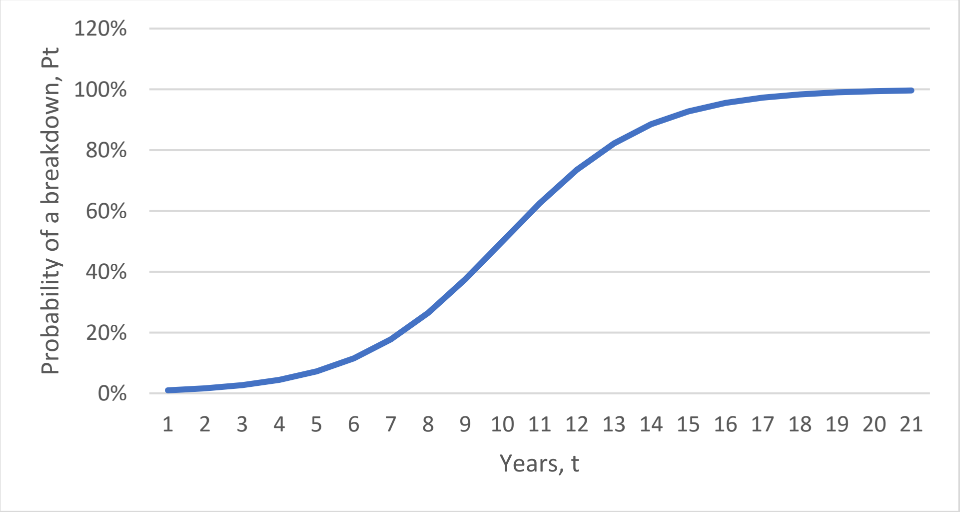
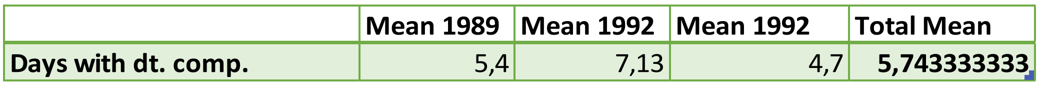


Figure 6. The probability of a breakdown in relation to machine age (Weersink, 1984).

Bohm (1994) compiled breakdown frequency and how long each breakdown event lasted on the “average tractor”, which were expressed in downtime compensation. Three averages were presented depending on the year and where the data was derived. These averages will be used when calculating the downtimes effect on the timeliness factor for all machines and is presented in Table 4.

Table 4. Mean days with downtime compensation (Bohm, 1994)



	Mean 1989	**Mean 1992**	**Mean 1992**	**Total Mean**
Days with dt. comp.	5,4	7,13	4,7	**5,743333333**

4 Empirical results

The following chapter presents the empirical results found during the calculations which laid as a foundation for the analysis.

4.1 Individual calculations

The following chapter will present the individual calculations for each machine, forming the basis for evaluating their performance as part of a cost-effective machinery strategy. The results will be presented in a table, but also as a graph to find the year for which the machine has the lowest annual cost, as seen in Figure 7. This indicates the optimal age of the machine for cost-minimizing, essential for finding a cost-effective equipment strategy (Axenbom *et al.*, 1988).

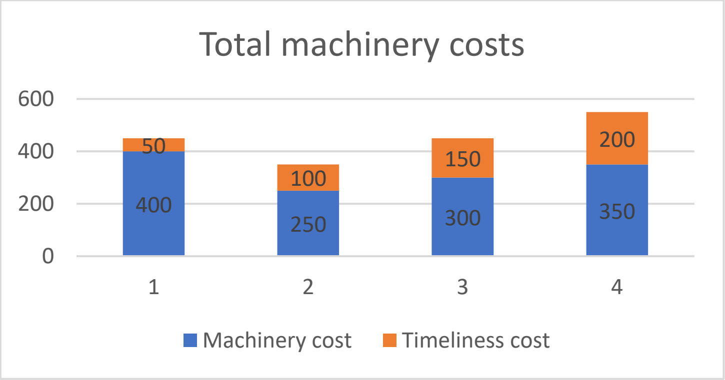


Figure 7. Example of machinery- and timeliness costs compound effect (Axenbom et al., 1988).

Figure 7 displays the total annual cost of a machine in respect to its age where year two has the lowest cost. This illustrates how the relationship between machinery costs and timeliness cost affects the total cost, where the aim is to find the period where this relationship amounts to the lowest total cost. With the prerequisite of utilizing the machines for 8 years, the cost-minimized period is where the 8 consecutive years amounts to the lowest annualized cost. This will be explored in the following chapter.

4.1.1 150-horsepower tractor

Table 5 presents the total annual cost, for both the new and old tractor, as well as the annual cost of the different cost aspects. The tractor is kept for 8 years and has an annual usage of 500 hours. The new tractor is bought without previous owners and has a price of 1 350 000 kr. The old tractor is bought when it is 8 years old for a price of roughly 581 000 kr. Figure 8 shows how the different cost aspects change over time and indicates a minimum point in year 9.

Table 5. The annual cost of a new and old 150-horsepower tractor

150-hp Tractor	Annuity year 1-8	Annuity year 9-16
Depreciation	104 959,16 kr	42 024,37 kr
Interest	41 079,42 kr	19 134,38 kr
Insurance	4 422,92 kr	4 422,92 kr
Maintenance	45 782,21 kr	65 261,74 kr
Timeliness cost	2 605,36 kr	46 949,31 kr
Fuel and grease	153 163,99 kr	153 163,99 kr
Total	**352 013,06 kr**	**330 956,71 kr**

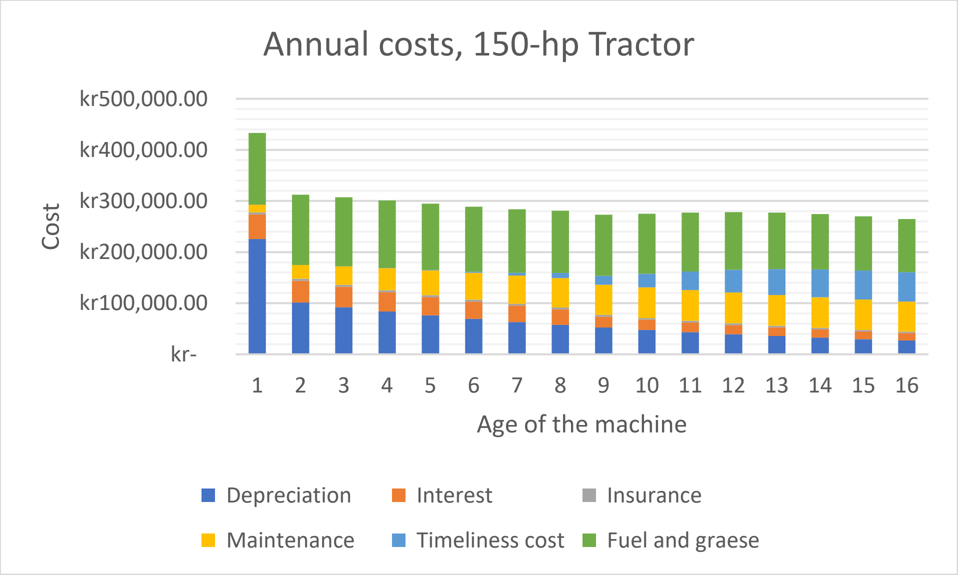


Figure 8. Development of the 150-hp tractors annual cost.

The results displayed in Table 5 give a cost difference of roughly 21 000kr in annual cost between the new and old tractor. This occurs mainly as the financial costs in the earlier period are substantially higher than the variable costs in the older period, especially the depreciation cost in year 1. This is common on all machines and is the result of the findings by Eriksson (1986), this effect arises because of the depreciation factor which correlates to the dealership's price increase.

4.1.2 300-horsepower tractor

Table 6 presents the total annual cost, for both the new and old tractor, as well as the annual cost of the different cost aspects. The tractor is kept for 8 years and has an annual usage of 500 hours. The new tractor is bought without previous owners and has a price of 2 580 000 kr. The old tractor is bought when it is 8 years old for a price of roughly 1 110 000 kr. Figure 9 shows how the different cost-aspects change over time and indicates a minimum point in year 16.

Table 6. The annual cost of a new and old 300-horsepower tractor

300-hp Tractor	Annuity year 1-8	Annuity year 9-16
Depreciation	200 588,62 kr	80 313,25 kr
Interest	78 507,33 kr	36 567,92 kr
Insurance	8 452,69 kr	8 452,69 kr
Maintenance	87 494,89 kr	124 722,44 kr
Timeliness cost	2 605,36 kr	46 949,31 kr
Fuel and grease	297 318,34 kr	297 318,34 kr
Total	**674 967,23 kr**	**594 323,94 kr**

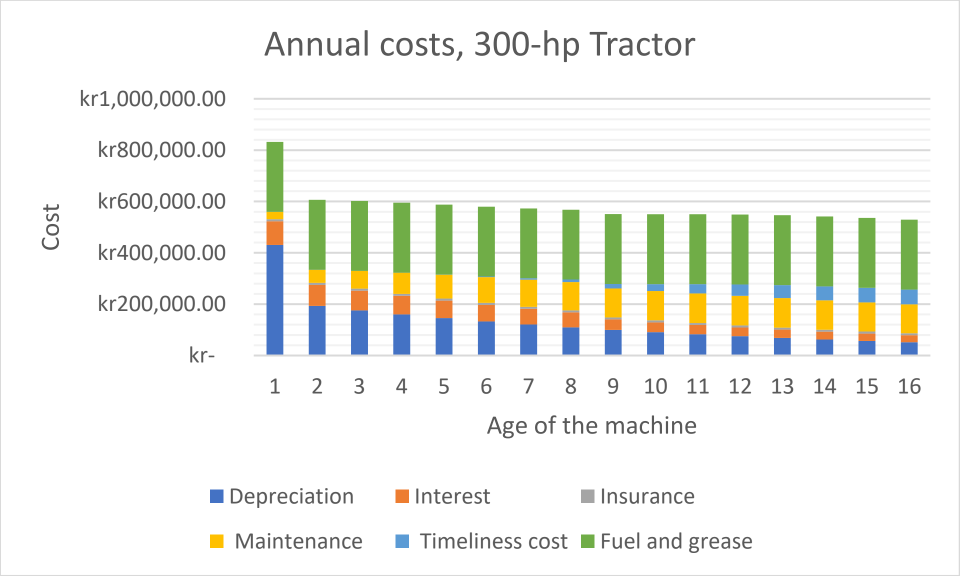


Figure 9. The development of the 300-hp tractors annual cost.

The results displayed in Table 6 give a cost difference of roughly 80 000kr in annual cost between the new and old tractor, this occurs mainly as the financial costs in the earlier period are relatively higher than the variable costs in the older period, especially the depreciation cost at year 1. After the first year, there is a steady decline in annual cost.

4.1.3 30-foot combine

Table 7 presents the total annual cost, for both the new and old combine, as well as the different cost aspects annual cost. The combine is kept for 8 years and has an annual usage of 150 hours. The new combine is bought without previous owners and has a price of 4 600 000 kr. The old combine is bought when it is 8 years old for a price of roughly 1 861 000 kr. Figure 10 shows how the different cost aspects change over time where there is a great decline in the total machinery costs in the first 8 years, mostly due to depreciation and interest costs. The combine reaches its lowest annual cost in year 16.

Table 7. The annual cost of a new and old 30-foot combine

30-ft Combine	Annuity year 1-8	Annuity year 9-16
Depreciation	**373 840,54 kr**	**142 761,08 kr**
Interest	**135 135,28 kr**	**58 687,33 kr**
Insurance	**10 047,12 kr**	**10 047,12 kr**
Maintenance	**117 838,90 kr**	**229 559,06 kr**
Timeliness cost	**2 242,84 kr**	**40 416,47 kr**
Fuel and grease	**108 115,76 kr**	**108 115,76 kr**
Total	**801 278,31 kr**	**643 644,70 kr**

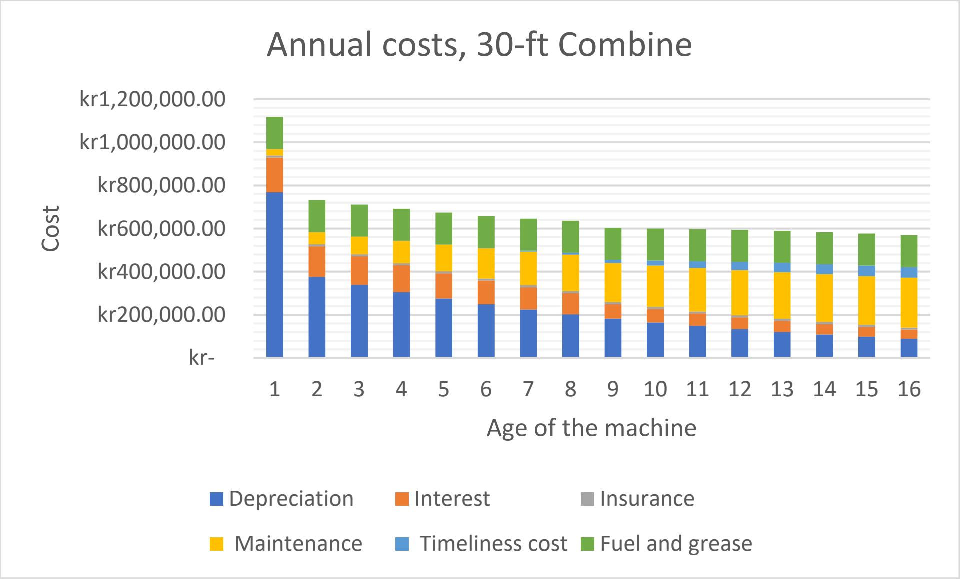


Figure 10. The development of the 30-ft combines annual cost.

The results displayed in Table 7 give a cost difference of roughly 157 000kr in annual cost between the new and old combine. This occurs mainly as the financial costs in the earlier period are substantially higher than the variable costs in the older period, especially the depreciation cost in year 1. This is common with all machines but is especially pronounced on the combine, given its high replacement cost. The use of Eriksson's (1986) depreciation factor (an initial value loss of 20%) results in a large monetary depreciation cost compared to the monetary value of the other cost aspects.

4.1.4 4-meter combi-seeder

Table 8 presents the total annual cost of the new and old seeder, as well as the different cost aspects annual costs. The combi-seeder is kept for 8 years and has an annual usage of 150 hours. The new seeder is bought without previous owners and has a price of 700 000 kr. The old combi-seeder is bought when it is 8 years old for a price of roughly 292 000 kr. Figure 11 displays how the different cost-aspects change over time where the combi-seeder has a steady annual cost for the first nine years, excluding year one. The lowest annual cost is reached in year 2 and later experiences a local peak in year 14, after which the total machinery costs slowly decline.

Table 8. The annual cost of a new and old 4-meter combi-seeder

4m Seeder	Annuity year 1-8	Annuity year 9-16
Depreciation	55 672,35 kr	21 778,20 kr
Interest	20 928,15 kr	9 413,34 kr
Insurance	764,45 kr	764,45 kr
Maintenance	39 570,51 kr	70 254,01 kr
Timeliness cost	1 421,11 kr	25 608,71 kr
Fuel and grease	162 173,64 kr	162 173,64 kr
Total	**118 356,58 kr**	**127 818,72 kr**

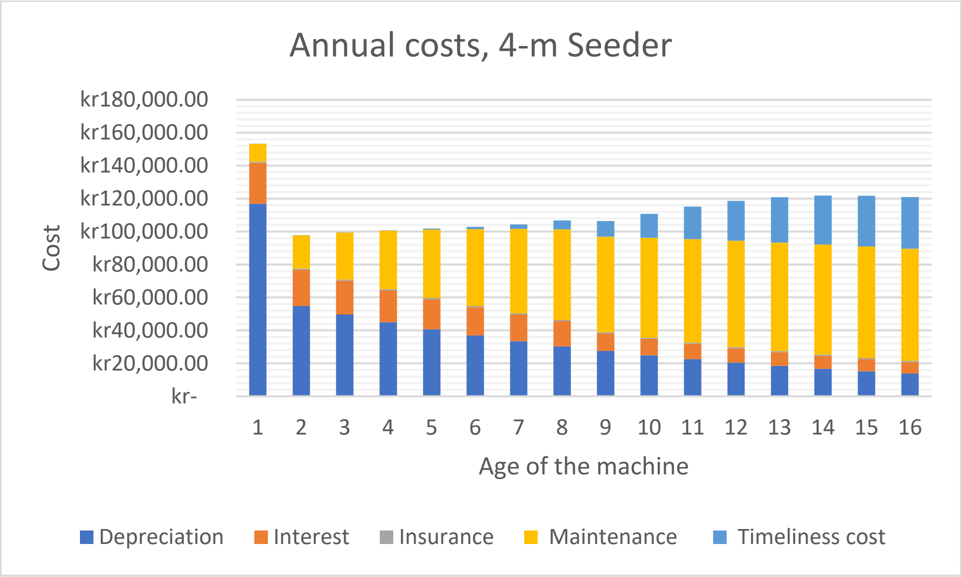


Figure 11. Development of the 4-m seeders annual cost.

The results displayed in Table 8 give a cost difference of roughly 10 000kr in annual cost between the new and old seeder. The new seeder has a lower annual cost, despite the relatively large depreciation cost on year one, as maintenance- and timeliness cost greatly increases after year 9.

4.1.5 5-bottom switch plow

Table 9 presents the total annual cost of both the new and old seeder, and the different cost aspects annual costs. The plow is kept for 8 years and has an annual usage of 150 hours. The new plow is bought without previous owners and has a price of 700 000 kr. The old plow is bought when it is 8 years old for a price of roughly 180 000 kr. Figure 12 shows how the different cost-aspects change over time where the plow experiences the lowest annual cost in year 2 and reaches a local cost-peak in year 8.

Table 9. The annual cost of a new and old 5-bottom switch plow

5-b Plow	**Annuity year 1-8**	**Annuity year 9-16**
Depreciation	34 787,25 kr	13 527,59 kr
Interest	12 948,31 kr	5 773,28 kr
Insurance	475,05 kr	475,05 kr
Maintenance	50 896,42 kr	65 381,04 kr
Timeliness cost	676,72 kr	12 194,63 kr
Total	**99 783,76 kr**	**97 351,58 kr**

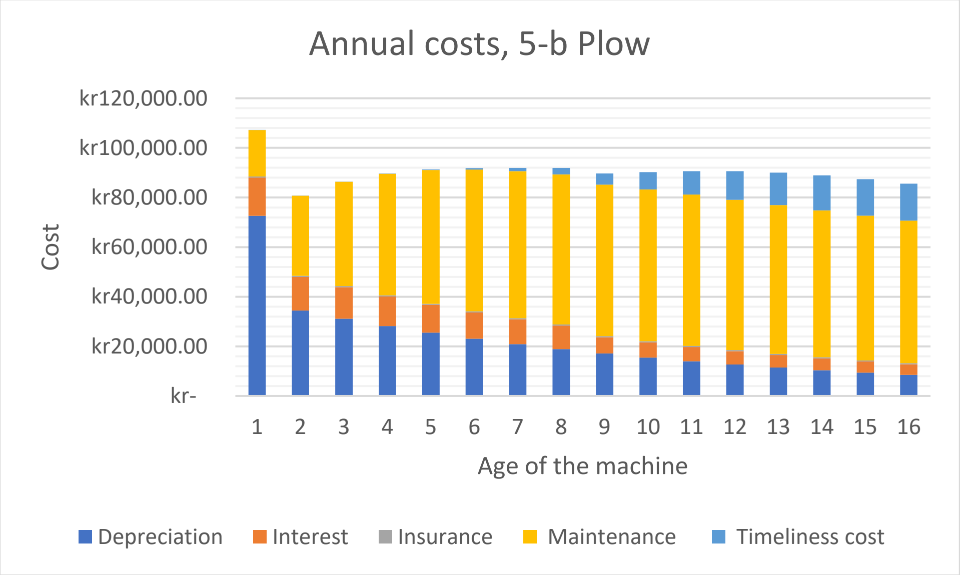


Figure 12. Development of the 5-b plows annual cost.

The results displayed in Table 9 give a cost difference of roughly 2 400kr in annual cost between the new and old plow. The new plow has a higher annual cost by a small margin, mainly because of the relatively large depreciation cost on year one. As maintenance- and timeliness costs increase after year three, the plows annual cost stagnate, to later decrease in year 15.

4.1.6 8-meter harrow

Table 10 presents the total annual cost of the new and old harrow, and the different cost aspects annual costs. The harrow is kept for 8 years and has an annual usage of 70 hours. The new harrow is bought without previous owners and has a price of 420 000 kr. The old harrow is bought when it is 8 years old for a price of roughly 133 000 kr. Figure 13 shows how the different cost aspects change over time where the harrow reaches the lowest annual cost at year 6, to later reach its cost-peak at year 16.

Table 10. The annual cost of a new and old 8 meter harrow

8-m Harrow	Annuity year 1-8	Annuity year 9-16
Depreciation	39 171,22 kr	12 146,59 kr
Interest	10 801,67 kr	3 557,25 kr
Insurance	458,67 kr	458,67 kr
Maintenance	15 181,68 kr	29 070,02 kr
Timeliness cost	3 248,24 kr	58 534,20 kr
Total	**68 861,48 kr**	**103 766,73 kr**

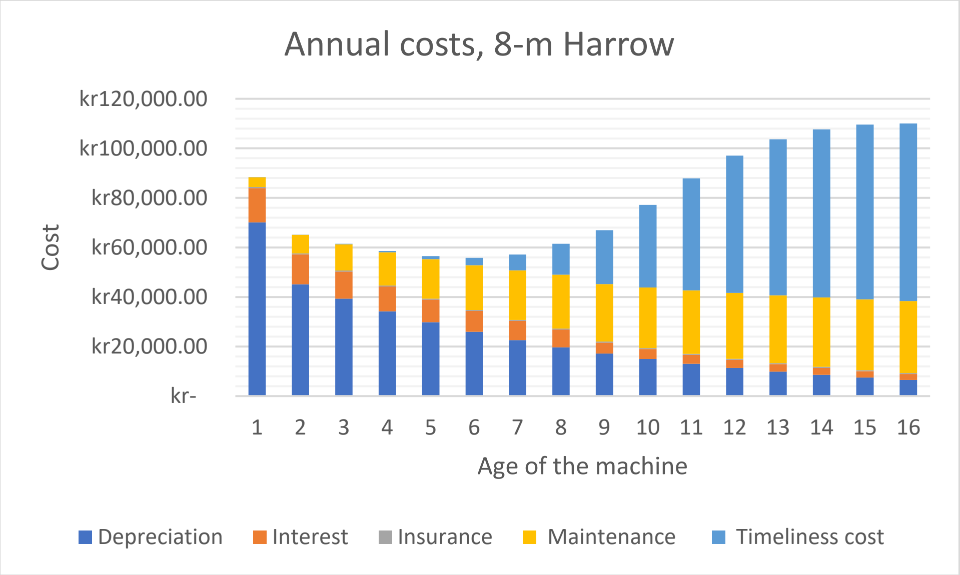


Figure 13. Development of the 8-m harrows annual cost.

The results displayed in Table 10 give a cost difference of roughly 35 000kr in annual cost between the new and old harrow. The new harrow has a lower annual cost by a relatively great margin, mainly because of the rise in timeliness cost as it rapidly increases after year 7. This happens as the harrow has a great field capacity, which is also true for the sprayer.

4.1.7 24-meter sprayer

Table 11 presents the total annual cost of the new and old sprayer, and the different cost aspects annual cost. The sprayer is kept for 8 years and has an annual usage of 100 hours. The new sprayer is bought without previous owners and has a price of 700 000 kr. The old sprayer was bought when it was 8 years old for a price of roughly 260 000 kr. Figure 14 shows how the different-cost aspects change over time where the sprayer reaches the lowest annual cost at year 2, to later reach its cost-peak at year 15.

Table 11. The annual cost of a new and old 24 meter sprayer

24-m Sprayer	Annuity year 1-8	Annuity year 9-16
Depreciation	60 071,37 kr	21 390,25 kr
Interest	19 603,77 kr	11 960,01 kr
Insurance	764,45 kr	764,45 kr
Maintenance	55 625,70 kr	70 216,17 kr
Timeliness cost	5 075,38 kr	91 459,69 kr
Total	**141 140,67 kr**	**195 790,58 kr**

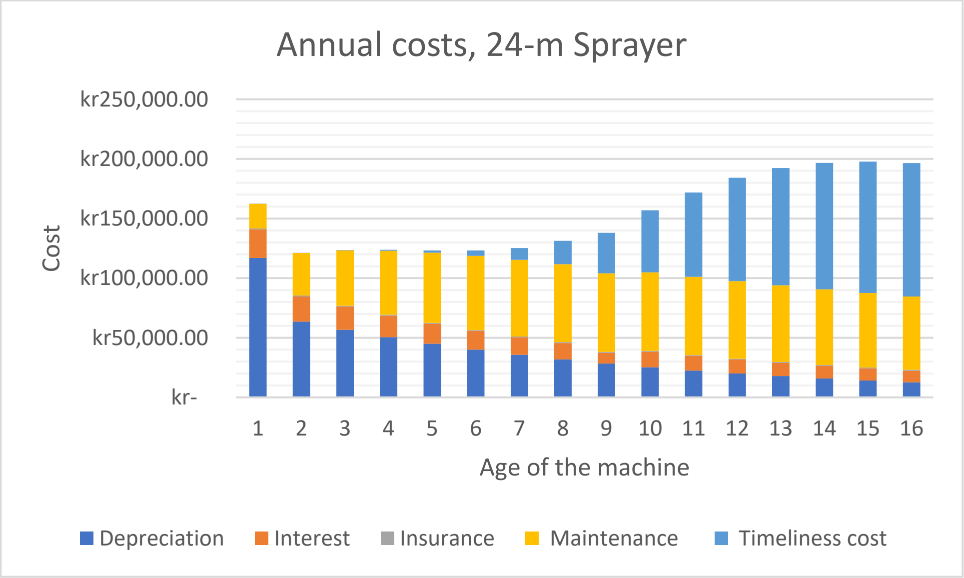


Figure 14. Development of the 24-m sprayers annual cost.

The results displayed in Table 11 give a cost difference of roughly 55 000kr in annual cost between the new and old sprayer. As in the case of the harrow, the new sprayer gives a lower annual cost by a relatively great margin, mainly because of the rise in timeliness cost as it rapidly increases after year 7.

4.2 Equipment systems

For evaluating if used agricultural machinery is economically and operationally viable as part of a cost-effective equipment strategy, the machines will be compared as part of a system. As the calculation period for all machines is 8 years, the new machines will be bought new, without previous owners, and then being kept for 8 years. The system with old machines is bought when the machines are 8 years old and are then kept for 8 years. The summary in Table 12 displays the annuity of all machines, as well as the total annuity for each system. The calculations proved that the tractors, combine and plow is more costly in the new system than the old, while the opposite is true for the seeder, harrow and sprayer. Figure 15 shows how the total machinery costs change over time, where the total annual cost reaches the minimum point in year 9, and a maximum in year 1 due to a high depreciation cost.

Table 12. Summary of the new and old systems annuities

Machine	**Annuity year 1-8**	**Annuity year 9-16**
150-hp Tractor	352 013,06 kr	330 956,71 kr
300-hp Tractor	674 967,23 kr	594 323,94 kr
30-ft Combine	801 278,31 kr	643 644,70 kr
4-m Seeder	118 356,58 kr	127 818,72 kr
5-b Plow	99 783,76 kr	97 351,58 kr
8-m Harrow	68 861,48 kr	103 766,73 kr
24-m Sprayer	141 140,67 kr	195 790,58 kr
Total	**2 256 401,10 kr**	**2 093 652,96 kr**

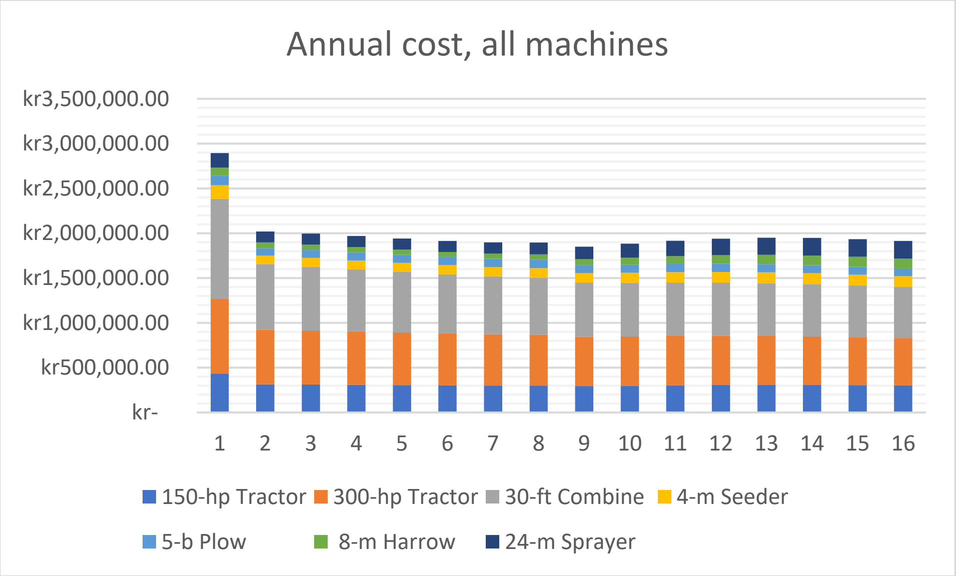


Figure 15. The development of the combined annual cost.

Figure 15 shows the development of the total annual costs, where the first year is significantly higher. This illustrates the major impact of Eriksson's (1986) depreciation factor and its major effect on purchasing new equipment. Notably, the annual cost reaches its minimum in year 9, primarily because the maintenance- and timeliness cost is yet to have a substantial effect.

As the annual cost of the machine’s changes, so does the cost distribution. For the machines in the newer system, the greatest contribution to annual cost is depreciation as it constitutes 39% of the total cost, this value is only 16% in the older system. The reasoning is that the formula for depreciation relies on both the present and residual value of the machine, which peaks in year 1, to then exponentially decline. The same conditions are true for the interest cost, as it relies on the same variables.

The maintenance cost, contrary to depreciation and interest, rises over time. It shifts from constituting 18% of the machinery cost for the newer system to 31% in the older system. It is important to note that this does not necessarily mean that the maintenance cost for the older system (31%) is greater than the interest cost for the newer system (14%). The values depict a percentage of the system’s total machinery cost, they are therefore not directly comparable in monetary terms, they only display the change of the cost distribution.

Similar to the maintenance cost, the timeliness cost also rises over time. This happens as the function is based on an exponentially growing probability of a breakdown occurring, in relation to the age of the machine. In the newer system this constitutes 1% of the total machinery cost, and 16% of the older system, the greatest percentual change over time. Both the fuel and insurance cost stay static in monetary terms but represent a different percentage of the total cost. The change in cost distribution across the two systems is shown in Figure 16 and 17.

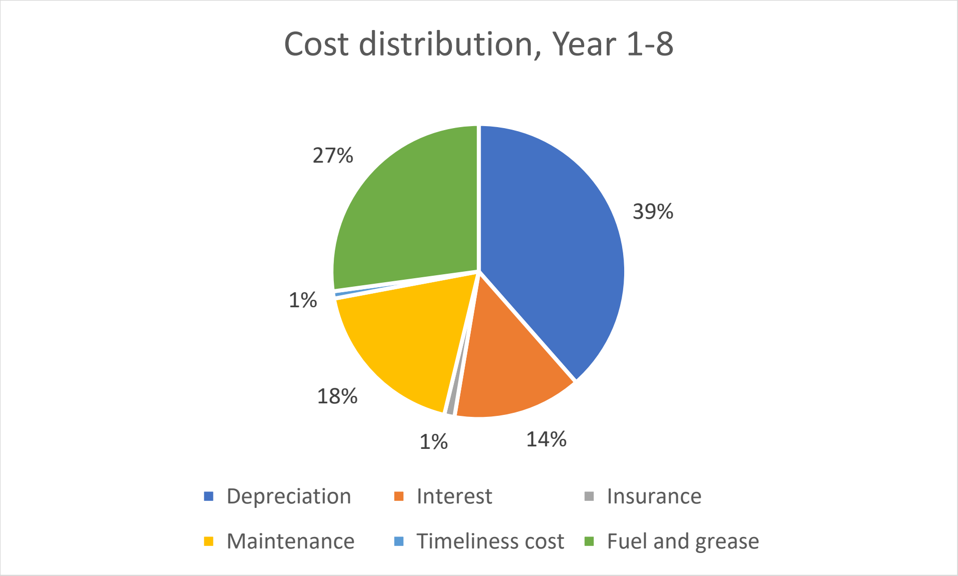


Figure 16. The cost distribution for the new system.

It is clear from Figure 16 that the financial costs are the greatest contributor to the new system’s total cost, primarily depreciation, as it constitutes 39%. It is also clear how minimal the timeliness cost is in the new system, mostly as the cost increases substantially around year 8.

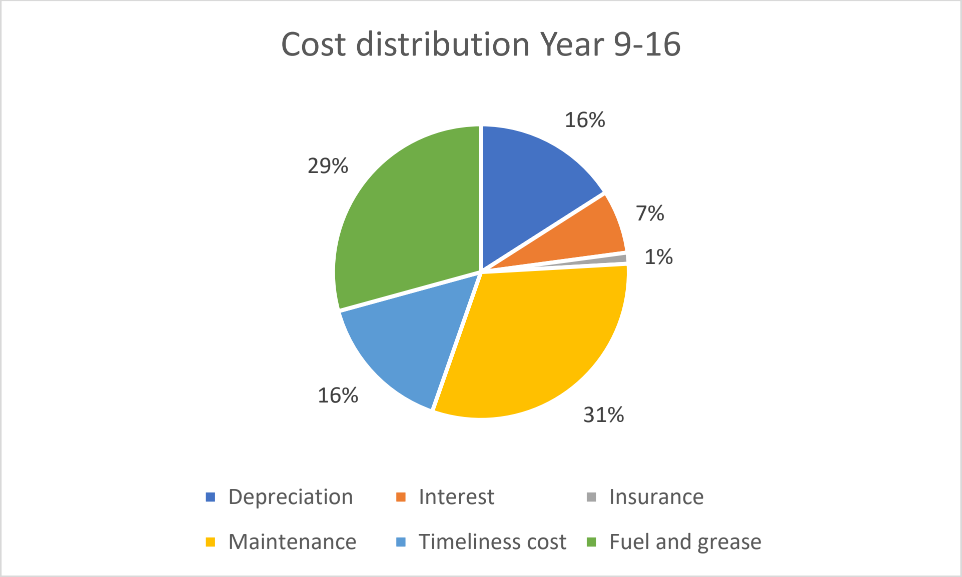


Figure 17. The cost distribution for the old system.

It is apparent how much the financial costs of the older system decrease as it only constitutes 23% of the total cost, compared to 53% in the new system. This shift makes maintenance cost the greatest contributor, as it rises to 31% of the total cost. The figures also show how the impact of the timeliness cost has grown, as it now constitutes 16%. Figure 18 presents the cost distribution in monetary terms.

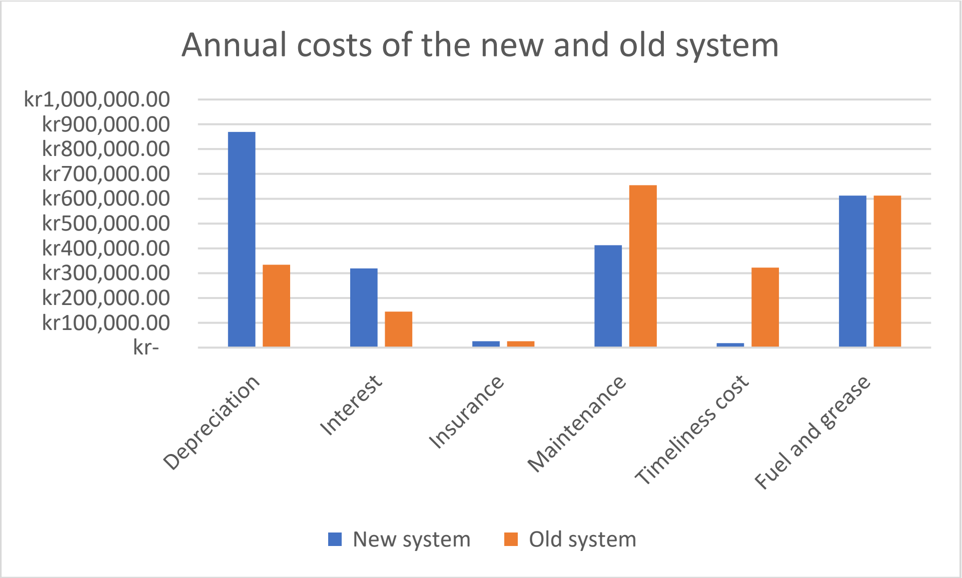


Figure 18. The annuities of each cost aspect in the new and old system.

The new system exceeds the old with roughly 163 000kr in total annual cost. The cost aspects of depreciation and interest are greater in the newer system, the same is true for maintenance- and timeliness cost in the older system. The costs of insurance and fuel remain static across the systems.

5 Analysis

Chapter 5 addresses the research questions raised in chapter one and analyzes the empirical results in relation to the theory and literature presented in earlier chapters. The following chapter does also analyze the empirical results and interpret how they contribute towards the thesis aim.

5.1 Machinery cost aspects

To analyze the empirical findings and their relation to the present literature, the machinery cost aspects will be presented separately. This in combination with the empirical results presented in chapter 4 allows for further discussion on cost minimization and helps to answer the thesis aim.

5.1.1 Depreciation

The calculation of the depreciation function clearly shows an exponential decrease in annual cost (Figure 19), in line with the findings of both Svensson (1987) and Erikson (1986). This creates an exponentially higher cost for newer machines, especially as Eriksson's (1986) depreciation factor is utilized, creating a depreciation cost of 20% in year one. This is clear in the calculations where depreciation is the largest contributor to the total machinery cost in the new system. For the old system it is only 38% of that in the new.

Svensson (1988) notes that as with most calculations conducted on the subject, they are not directly true to reality. The depreciation of machines relies heavily on factors other than the age of the machine that differentiate across regions, firms, and the machines themselves. How much heavy work the machine does annually, the way the machine is operated, the make of the machine and the amount of preventative maintenance to name a few. These are factors that simply cannot directly be accounted for when calculating depreciation as they vary across every individual machine. The function used in the calculations is however based on Svensson (1988) where the machine specific depreciation variable is derived from a regression of empirical data, which loosely takes these contributing factors into account.

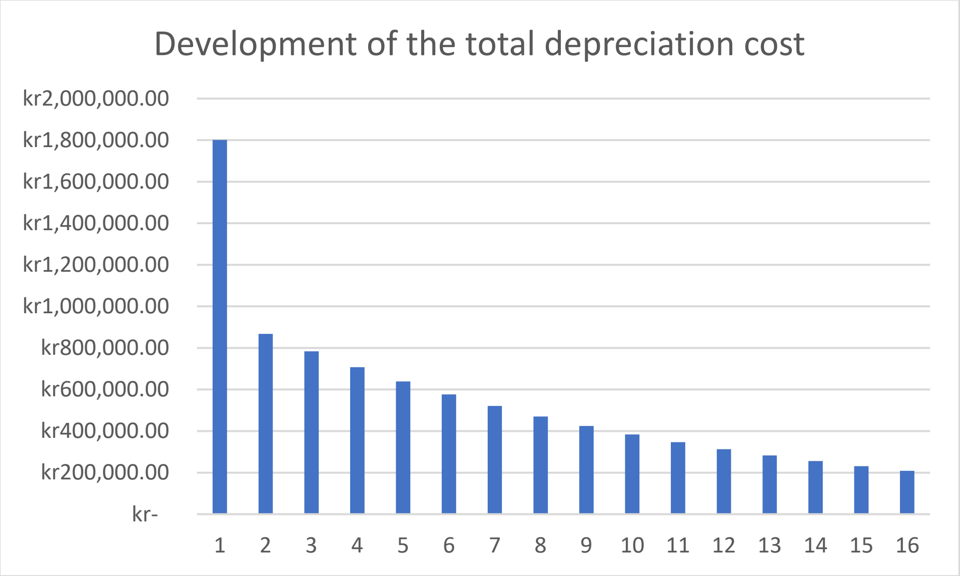


Figure 19. The development of the total depreciation cost.

5.1.2 Interest

Like the calculations regarding the depreciation cost, the interest cost follows an exponential decrease in annual cost. This also creates a significantly higher cost for newer machines where the interest cost for the old machines is 45% of the new, presented in Figure 20. As the calculation is based on the function presented by Axenbom *et al.* (1988), it follows the present and residual value of the machine, much as the depreciation function, hence the similarity. As the formula aims to calculate the mean committed capital in a machine, the residual value used for the new system is based on year 8, while for the old system, it is based on year 16. This explains the jump in cost between the years 8 and 9. Axenbom *et al.* (1988) present the formula using a real interest rate; the thesis did therefore use a real interest rate of 5% as a median of rates presented by Agriwise (2009) and Maskinkalkylsgruppen (2023).

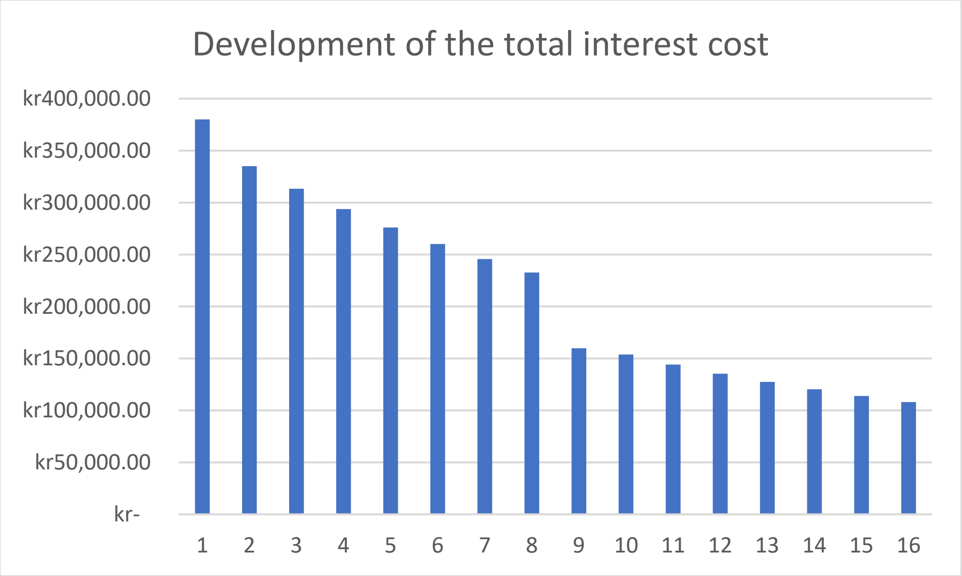


Figure 20. The development of the total interest cost.

5.1.3 Insurance and fuel

The insurance and fuel costs remain static during the whole calculation period as they rely on the same inputs over time. As the fuel prices don’t have a predictable development, at least in a short term (Drivkraft Sverige, 2024), the thesis must rely on a constant fuel price, which may render the fuel calculation slightly uncertain. This could be addressed by changing the fuel price in the calculations to account for a potential increase in fuel prices in the future, with the prerequisite of it remaining static in the calculations. This will, however, not change the relationship between the new and old system as the cost is static over time, it would only change the total annual cost of the machines.

The calculation regarding fuel and grease is only applicable on the tractors and combine and follows the equation presented by Axenbom *et al.* (1988). In this formula, the cost of grease and lubrication is calculated as 10% of the price of fuel, there are however proposals for different percentages e.g. Agriwise (2009) with marginal effects on the results. The insurance cost is based on template-based values presented by Axenbom *et al.* (1988) and is partially confirmed by Pålsson and Rydheimer (2005). The insurance price could be altered in the calculations to address eventual price changes, but as the insurance cost contributes to a minute part of the total costs, a change would barely be noticeable in the total costs.

5.1.4 Maintenance

The calculations conducted on maintenance cost clearly show a rapid increase in annual cost, to nearly stagnate over time, as seen in Figure 21. This creates a high annual cost for the old system, where it is the greatest contributor to the total machinery cost. In the new system, it is only 63% of that in the old. The function used in the calculations is based on Svensson (1987) where the machine specific maintenance constants is derived from a regression of empirical data collected in 1987 on 218 firms. By having empirical data as the basis for the function, the constants are taking factors such as usage, cost of parts and general maintenance costs into account (Svensson, 1987). The problem, however, with creating a formula for maintenance cost, is the uncertainty of said maintenance, when and if it will occur as calculated (Rotz, 1987). Pettersson and Davidsson (2009) aimed to examine the maintenance cost in Swedish grain production. When comparing their work with the thesis calculated results, adjusted for inflation, the results have marginal differences even though these formulas carry the elements of both age and uncertainty.

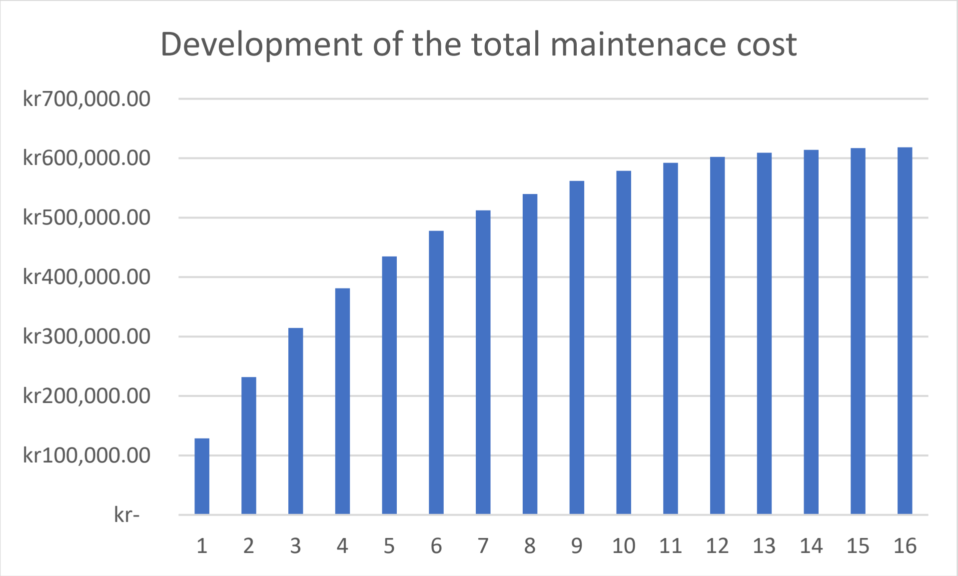


Figure 21. The development of the total maintenance cost.

5.1.5 Timeliness cost

The calculations conducted on timeliness cost show a gradual increase in the first year to later increase exponentially (Figure 22), this happens as the formula relies on an exponential equation on machinery breakdowns by Weersink (1984). The timeliness cost experiences the greatest growth between the two systems where it has an annual cost of 17 875kr in the new system and 322 112kr in the old, a growth of 1802%. The formula estimates the probability of a breakdown occurring, and how much the breakdown would cost per hectare. It then calculates how many hectares that would not be worked during the breakdown, as this is based on the field capacity of the machines, it gives the greatest effect on machines with high capacity. The greatest effect can be observed on the harrow where the timeliness cost is twice that of the maintenance cost, this phenomenon is also prevalent with the seeder and sprayer.

The formula in the thesis relies on empirical data collected by Bohm (1994) on the duration of breakdowns on agricultural machines with an average of 5.7 days. The duration of breakdowns found by Bohm (1994) can however be challenged as Andersson et al. (2017) found the duration to average 1,3 days. This was, however, not taken into consideration as this number was collected from 26 farmers, while the material produced by Bohm (1994) relies on 2500 different data points.

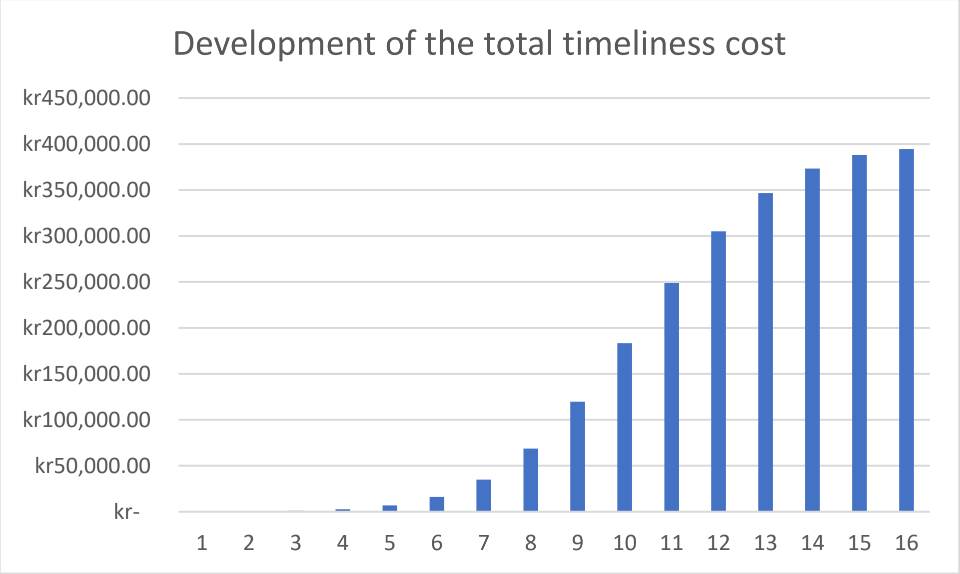


Figure 22. The development of the total timeliness cost.

5.2 Economic and operational viability

The calculations presented in chapter 4 revealed that used agricultural machinery is economically viable, shown in Figure 23. The graph displays the total annual machinery cost, where the older machinery has a lower annual cost than the new. It is therefore reasonable to assume that, for a cost-effective equipment strategy, all machines should ideally be as old as possible or at least be bought at 8 years of age if kept for another 8 years. This however is only partly true, as presented in chapter 4, three machines have a higher cost in the old system, the seeder, harrow and sprayer. This occurs as the maintenance and timeliness cost greatly increases as the machines age, for the sprayer, these two cost aspects stand for 88% of the annual cost at year 16.

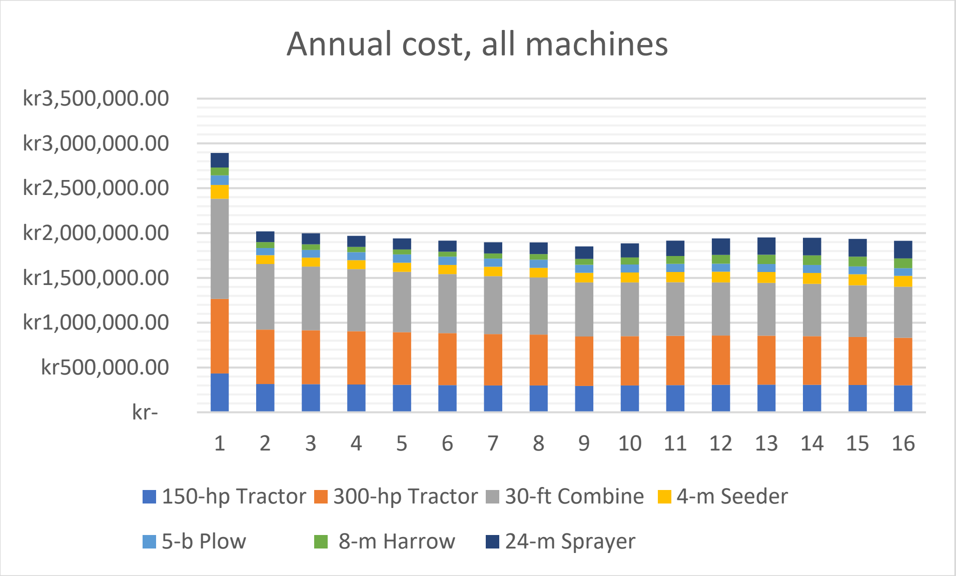


Figure 23. The development of the total annual cost.

It is apparent that fully committing to either the new or old system is not the most cost minimizing approach, but rather a combination of selected age intervals where the various machines' annual cost is minimized. With the prerequisite of utilizing the machines for 8 years the optimal ages is presented in Table 13. This gives the lowest possible annualized cost, 113 000kr lower than the old system and roughly 276 000kr lower than the new.

Table 13. Summary of the old, new and optimal systems annuities

Machine	**Annuity year 1-8**	**Annuity year 9-16**	**Annuity year, optimal**	**Optimal years**
150-hp Tractor	352 013,06 kr	330 956,71 kr	329 051,42 kr	Year 5-12
300-hp Tractor	674 967,23 kr	594 323,94 kr	594 323,94 kr	Year 9-16
30-ft Combine	801 278,31 kr	643 644,70 kr	643 644,70 kr	Year 9-16
4-m Seeder	118 356,58 kr	127 818,72 kr	111 953,42 kr	Year 2-9
5-b Plow	99 783,76 kr	97 351,58 kr	97 351,58 kr	Year 9-16
8-m Harrow	68 861,48 kr	103 766,73 kr	65 942,57 kr	Year 2-9
24-m Sprayer	141 140,67 kr	195 790,58 kr	137 804,41 kr	Year 2-9
Total	**2 256 401,10 kr**	**2 093 652,96 kr**	**1 980 072,04 kr**	

By utilizing the machines in their optimal ages, the lowest annualized cost is achieved, this may however not always be the goal. In some instances, there may be value to not have the inconvenience of needing to do constant repairs, especially as the probability of a breakdown at year 16 is 97%. The plow does for example have the optimal age interval set to the years 9-16, if the interval of year 1-8 is utilized, the annualized cost for the plow is raised by 2400kr but the average probability of a breakdown is 12%. A rise in annual cost of 2400kr is in a broader context relatively insignificant for avoiding the inconvenience of doing as many repairs. This thought can be applied to nearly all machines where there needs to be a consideration between operational and economic viability. With the example of the plow, the justification for utilizing a new plow can be simple as it may be deemed more operationally viable. This can, however, quickly add up to significant amounts. If the combine is utilized on year 5-12 instead of 9-16, as it is deemed more operationally viable, the probability of a breakdown lowers from 76% to 45%, while raising the annual cost by roughly 40 000kr. The consideration between operationally and economically viable may therefore vary in each instance, as the value placed on avoiding inconvenience may differ.

Newer machines may be considered more operationally viable, this however comes at the expense of committing significant capital in machinery investments. The cost of committing capital is presented as interest cost, this however does not fully account for the implication of the act of purchasing the machine. The act of investing significant funds into machinery may not be justifiable for firms with liquidity constraints (Shutske, n.d.). This implication alone may deter the consideration for newer machines as economically and operationally viable, especially on machines that require a significant investment, such as the combine or tractor. There is however a justification for acquiring new machines when the annual cost for the early years is lower than the old and where the farm has sufficient liquidity required to invest. These machines being the seeder, harrow and sprayer, the plow could also be placed in this category as the raise in cost is fairly insignificant.

6 Discussion and conclusions

Chapter 6 addresses the given result and compares it to existing literature and discuss their relation to a practical setting. The chapter does also elaborate on the thesis strengths and limitations, and the need for further research on the subject along with the conclusions reached.

6.1 Discussion

The calculations have demonstrated that older agricultural machinery proves economically viable and can in this instance lower the total machinery cost by 15%. This is at least true for tractors and combines while older implements have a greater cost than new, largely because of maintenance and timeliness cost. The thesis can therefore conclude that newer implements carry the benefit of being both economically and operationally beneficial, and older tractors and combines, while they may not be operationally beneficial, have a clear economic viability.

The thesis concluded that both newer and older equipment have economic viability, notably that newer implements, and older tractors and combines, give in combination the lowest annual cost. This conclusion can be made as the calculations were conducted on each machine individually, which enables a cost-effective equipment strategy to emerge. The calculations did, however, rely on some assumptions in order to come to this conclusion. These assumptions will therefore be discussed in the following chapter.

Firstly, the calculations conducted on notably depreciation and maintenance cost relies on the work by Svensson (1988) and Svensson (1987) respectively. Svensson (1987; 1988) collected empirical data to derive variables through regression analysis, which in turn is used while calculating depreciation and maintenance cost. As these variables were derived nearly 40 years ago, the relevancy could be questioned. To verify the thesis outcome, the results were triangulated against other literature (Ellis *et al.*, 2021; Pettersson & Davidsson 2009), which showed a small margin of difference, rendering Svenssons work still viable. The same problem arises with the equation for breakdown probability in relation to machinery age by Weersink (1984). Weersinks formula was derived 40 years ago and were applicable to combines in Montana, USA. It is debatable if the probability curve retains the same expression today, given the development of machines since 1984. Due to the lack of similar work, the thesis must assume that the work by Weersink (1984) remains viable.

Secondly, the timeliness equation used in the calculations is based on work by Axenbom *et al.* (1988), which also presented the timeliness factors for seeding and harvesting. By combining the work of Axenbom *et al.* (1988) and Weersink (1984), an equation for timeliness cost in relation to breakdown probability could be created. Although the equation is viable on the individual machines, it can be debated if the calculations have a grounded relation to a practical setting. As the timeliness cost is calculated on the individual machine, there is no regard for the practical timeline if a breakdown occurs. This means that if the plow experiences a breakdown, it postpones the work of the harrow and seeder, creating timeliness cost for the following implements, as they will be operated at a sub-optimal time due to delays. It would therefore be more realistic to consider timeliness cost as part of the whole operation where one delay ultimately leads to delays across the whole timeline. The problem with computing this is the amount of input that would be needed to create significant results as there are too many uncertain variables at play. The probability of a breakdown, how long the breakdown lasts and the accuracy of the timeliness factor to name a few. It should also be noted that there are often alternative ways to complete the fieldwork in the event of a breakdown, such as using a different tractor or implement. As this type of calculation would imply too much uncertainty, it would therefore be reasonable to assume that calculating the machine's individual timeliness cost is feasible.

It can also be debated how the calculation for the tractor's timeliness cost should be conducted as they are critical to all field operations. If the tractors experience a breakdown, the timeliness cost will vary depending on which implement that is used during the breakdown as they vary in capacity. This can't be computed as the probability given by Weersinks (1984) calculations remains static throughout the whole year. This means that it is impossible to predict during which field operation the tractor will experience a breakdown. The thesis addressed this by applying the average capacity for all relevant machines to have a feasible approach towards this uncertainty.

Thirdly, the thesis is based on some presumed variables in order to achieve quantifiable results. The replacement cost for the various machines, along with fuel consumption, fuel price and field capacity are derived from Maskinkalkylsgruppen (2023). The grain price is obtained from Jordbruksverket (2023) and the interest rate from Agriwise (2009) and Maskinkalkylsgruppen (2023). These variables are unlikely to remain static, which may lead to the invalidation of the results given. A higher grain price would for instance increase the timeliness cost, which may render different results than found in the thesis. It is more feasible to assume a need to recalculate the machinery costs when these presumed variables change, or when different variables are chosen.

6.2 Conclusions

The aim of this thesis was to identify the economic viability of used agriculture machinery as part of a cost-effective equipment strategy. The objective was to contribute a comprehensive strategy for managing operational costs.

The thesis has proven the economic viability of used agricultural machinery and their suitability as an integral part of a cost-effective equipment strategy. The results indicated that the economically optimized strategy contains a combination of new and old machinery, notably new implements and old tractors and combines. It can also be noted that the first year of a machine is significantly more costly due to a high depreciation cost, this can be seen in the optimized system where no machine is to be purchased at year one. As the financial costs of new tractors and combines are substantially high, it’s proven more cost-effective to utilize older tractors and combines. Implements have proven the contrary, as newer implements’ financial costs are substantially lower in comparison with the maintenance and timeliness cost of older machinery, making newer implements more economically and operationally viable.

6.3 Further research

The thesis has conducted an investigation on the economic viability of used agricultural equipment, but as used equipment is underrepresented in the current literature, further research should be conducted on related topics.

Further research could expand on the operational viability of used equipment, for example in terms of fuel efficiency, technological development, and overall performance. Newer machines can benefit from advancements in technology that improve operational efficiency, which may be absent from older machines. It would therefore be relevant to explore the economic consequences of the eventual absence of such technology in older equipment.

In addition, studying how operational contexts would impact the economic viability of older versus newer machinery, such as farm size, crop type, and climate. For example, older machinery might be more cost-effective for small-scale operations, while newer, more efficient machinery may be better suited for larger farms.

In summary, used agricultural equipment is underrepresented in the current literature, meaning all relevant topics should be considered for further research.

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