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THE UNIVERSITY OF ALBERTA

Fixed Cost Compensation in Farmland Expropriation

by

Peter A. Woloshyn

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science
IN
Agricultural Economics
Department of Rural Economy

EDMONTON, ALBERTA

Fall, 1990

ISBN 0-315-65051-6

THE UNIVERSITY OF ALBERTA

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DEGREE FOR WHICH THESIS WAS PRESENTED Master of Science

YEAR THIS DEGREE GRANTED Fall, 1990

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Fixed Cost Compensation in Farmland Expropriation submitted by Peter A. Woloshyn in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Economics.

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Dedication

To Colleen, Mom, and Dad

Abstract

The acquisition of farmland by Alberta Transportation is necessary for highway, overpass, and other related construction projects throughout the province of Alberta. In 1979 the Land Compensation Board ruled that "fixed costs" should be compensated in addition to fair market value for the land. There were no set guidelines for such compensation cases and *ad hoc* measures were subsequently used for determining the money value of fixed costs to be paid.

This analysis is based upon the theory of production and welfare economics. The study is designed to determine the appropriate compensation for landowners/farmers who have had a portion of their land taken by expropriation and have endured a loss *in addition* to the market value of land. Non land fixed costs constitute these additional costs to the landowner. Capital investment analysis is used in this study to derive the net present value of the change in fixed costs and machinery repair costs as a result of a partial taking. It is this change in the cost structure which determines the appropriate level of compensation (in addition to market value of land) to the landowner.

Compensation levels varied as a result of the size of the taking, the size of the farm, the general geographical location of the farm, and the cultural practices common to the area. Under scenarios where farm machinery could be re-sized after the partial taking compensation would be lower. However, with takings between 1 and 20 acres (the most common) very few re-sizing options were available due to the "lumpiness" of farm equipment. Fixed cost compensation amounts ranged from $190 per acre in the light soil regions of southeastern Alberta to over $400 per acre in the heavy soils in the Peace River region.

Acknowledgements

The completion of this masters program resulting in the publishing of this document was made possible through the support and encouragement of many people. Most significantly my wife Colleen, and our children Andrew and Blair who encouraged me to perservere through the necessary hours away from them in order to complete such an important undertaking. While I was away from home often my sister Jeanette was over to keep Colleen company and help with the children, I will always appreciate your help Jeanette. I also wish to acknowledge the importance my parents placed on education and the lifelong support they have offered in helping me attain this goal.

A very special thankyou must go to my thesis committee, in particular Vic and Len, for their experience, guidance and patience. I will always remember those brainstorming sessions we had on fifth floor.

A university environment is conducive to an interesting, thought provoking and often a frustrating learning experience. It was ultimately Alberta Agriculture that allowed me to once again experience such an environment. I extend my sincerest appreciation to Carlyle Ross for his support from Alberta Agriculture.

Another most rewarding aspect of my masters program was meeting new people and making new friends. Thankyou to all the Rural Economy support staff, your help is appreciated. I thank all those people who shared in both the difficult and the enjoyable times.

Finally, my acknowledgements would not be complete without mention of two special people who really made a difference and who continue to be good friends, LeeAnne and Wayne.

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I. Introduction

A. Background

The acquisition of farmland by Alberta Transportation is necessary for highway, overpass, and other related construction projects throughout the province of Alberta. In 1979 the Land Compensation Board (LCB) ruled that "fixed costs"[1] should be compensated in addition to fair market value for the land (Berry *et al*, V. The Queen, March 8, 1979). There were no set guidelines for such compensation cases and *ad hoc* measures were subsequently used for determining the money value of fixed costs to be paid.

This study is an extension of a project completed by Bauer and Phillips (1988) for Alberta Transportation. The purpose of the Bauer and Phillips study was to:

> *...provide an analysis of the issue of compensation for partial land removal from bona fide farming operations.*

The analysis was based upon the theory of production and welfare economics and was carried out within the context of theory; no empirical analysis was employed. However, it provides an important conceptual overview of the problem and the theory which can be used to apply the physical data. In the Bauer and Phillips study, the question of whether or not fixed costs are embodied in fair market value of farmland was also addressed. The findings suggested that the amount of compensation for partial takings of land that is required to make the affected party as well off as they would be without the action occurring is equal to or greater than the market land value but is *not in general* equal to the amount commensurate with current policy.

---

[1] Fixed costs are described in detail later in the study

B. Objectives

This study is designed to determine the appropriate compensation for landowners/farmers who have had a portion of their land taken by expropriation and have endured a loss *in addition* to the market value of land. Non land fixed costs constitute these additional costs to the landowner. The objective of this study is to calculate the total costs of owning non-land fixed assets, and in particular machinery. These fixed costs are estimated for the farming operation both before and after the partial taking. The difference between these before and after costs is the appropriate compensation payment in addition to the market value of land.

Presently, Alberta Transportation pays fixed cost compensation. No previous studies have empirically examined what these payments should be and how other costs on the farm are changed as a result of the partial taking. Capital investment analysis is used in this study to derive the net present value of the change in fixed costs and machinery repair costs as a result of a partial taking. It is this change in the cost structure which determines the appropriate level of compensation (in addition to market value of land) to the landowner.

Fixed cost compensation for partial takings of land will vary with the size of compensation depending on the size of the taking, the size of the farm, the general geographical location of the farm, and the cultural practices common to the area. The derivation of the appropriate compensation payment in light of these factors just mentioned is the central objective of this study.

II. Conceptual Overview

A. Land Value and the Compensation Issue

It is recognized that the market value of land is a reflection of future earnings from that land in its highest and best use. Specifically a purchaser is willing to pay up to the present value of the future net revenue stream from the land.[2] The seller requires a price for the land which is above his/her anticipated revenues less costs (fixed and variable costs)[3,4] associated with keeping the land in order to sell. The market price for land in a competitive market is a measure of such a value.

Compensation using fair market value should leave the landowner just as well off after the taking as before the taking. The widely accepted income approach used by appraisers can be used to illustrate this point. These calculations are based on the present value of the future net revenue stream from the land as explained above. The following equation shows how such a calculation can is made.

$$LV = \sum_{t=1}^{T} \{((p_t \cdot y_t - vc_t - rc_t) - FC_t \cdot (1+r)^{-t}\} + SV_T(1+r)^{-T} \qquad (II.1)$$

Where: LV is the value of one unit of land (acre)
$p_t \cdot y_t$ is the gross revenue (price x yield) for one unit of land in year t
vc_t are the variable costs per acre associated with growing some crop (fertilizer, chemicals etc.) in year t
rc_t are the repair costs per acre associated with the machinery component of the farming operation
FC_t is the cost of owning the machinery per acre in year t on a per unit basis
SV_T is the terminal sale value of one acre of land at the end of the planning horizon, year T
r is the discount rate.

---

[2] Net revenue is equal to gross sales from product attributable to the land less fixed and variable costs.

[3] This section borrows heavily from the Bauer and Phillips paper. See Bauer, L. and Phillips, W., *An Economic Analysis of Compensation For Partial Takings of Farmland*, Staff Paper No. 88-06, University of Alberta, Department of Rural Economy.

[4] Fixed costs are comprised of the ownership costs (i.e., depreciation and opportunity cost) of investment in machinery, buildings and livestock, and other depreciable items. Variable costs include annual costs for feed, seed, fertilizer, fuel, labour and other non-depreciable items.

This series can be reduced by using an annuity function and results in:

$$LV=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right]+[SV_T(1+r)^{-T}] \qquad (II.2)$$

If we now assume that both prices and costs are constant through time we are implying that no anticipated technical, structural or other time related trends exist that will affect either the revenue or the cost side. This simplifying assumption allows us to make some assumptions about the salvage value as well. The constancy through time assumption results in the salvage value being identical at T, 2T or nT[5] and equal to the initial market value. Therefore, the salvage value for the first planning horizon can be estimated by:

$$SV_T=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right]+[SV_{2T}(1+r)^{-T}] \qquad (II.3)$$

The salvage value *k*T periods away can be expressed as:

$$SV_{kT}=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right]+[SV_{(k+1)T}(1+r)^{-T}] \qquad (II.4)$$

Therefore the salvage value at any point in the future is equal to the salvage value in the original time period. Further reduction of the land value formula is possible.

$$LV=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right]+[LV(1+r)^{-T}] \qquad (II.5)$$

$$LV-LV(1+r)^{-T}]=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right] \qquad (II.6)$$

$$LV[1-(1+r)^{-T}]=[p\cdot y-vc-rc-FC]\cdot\left[\frac{1-(1+r)^{-T}}{r}\right] \qquad (II.7)$$

$$LV=\frac{[p\cdot y-vc-rc-FC]}{r} \qquad (II.8)$$

---

[5] T, 2T, nT are successive planning horizons.

The estimated land value is the net annual anticipated revenue divided by the discount rate.

The income approach shown above, accounts for all costs and returns associated with the derivation of the market value of any given unit of farmland. Furthermore, it should be noted that fixed costs were deducted from gross revenues in the estimation. Market value apparently fully compensates the landowner. If the size of the taking is large, say 160 acres, fixed costs would not require adjustment since the landowner could purchase another quarter section on the open market. After this purchase his/her fixed asset base would once again be optimized and he/she would be as well off after the taking as before the taking. Regularly traded parcels of land for agricultural purposes are quarter sections (160 acres). Table II.1 shows that the vast majority of land sales in rural Alberta are between 155 and 165 acres.

Table II.1: Average Size of Rural Real Estate Transactions 1989

Size Acres	Frequency Acres	 Cases	Percent	Cumulative Percent
0-5	126	47	0.0	0.0
6-10	409	49	0.0	0.0
11-15	373	32	0.0	0.1
16-20	470	27	0.0	0.1
21-25	487	22	0.0	0.2
26-30	617	22	0.1	0.2
31-35	551	17	0.0	0.3
36-40	1,865	48	0.2	0.4
41-45	1,009	24	0.1	0.5
46-50	761	16	0.1	0.6
51-55	1,095	21	0.1	0.7
56-60	1,455	25	0.1	0.8
61-65	1,806	29	0.2	1.0
66-70	2,107	31	0.2	1.2
71-75	3,000	41	0.3	1.4
76-80	29,543	373	2.6	4.0
81-100	9,914	113	0.9	4.9
101-120	14,145	125	1.2	6.1
121-140	26,665	201	2.3	8.5
141-150	49,028	334	4.3	12.8
151-155	68,367	447	6.0	18.8
156-165	639,360	4,015	56.1	74.9
166+	286,492	867	25.1	100.0

SOURCE: SPSS-X was used to derive the above breakdowns from the Municipal Affairs data base.[6]

A partial taking for the purposes of highway construction (or some other use for that matter) will cause a re-allocation of the resource inputs and perhaps a change in the overall efficiency of the operation. Inputs such as fertilizer, chemicals and labour are divisible and can be purchased in virtually any amount. Some of the inputs used in crop production may not be divisible to the order necessary to allow full adjustment after a partial taking of farmland. Fixed costs, for instance, are derived from some capital asset purchases necessary for the farming operation. These purchases

---

[6] All land transfers are given titles through the land titles offices in Calgary and Edmonton. The Department of Municipal Affairs catalogues each transfer which occurs in rural municipalities. A rural master tape is available which excludes cities, towns, and villages leaving primarily agricultural land.

tend to be "*lumpy*" in nature. For example a tractor or combine are only available in a limited number of sizes. Depending on the change in land base it may not be possible to purchase the appropriate size of asset.

The Bauer and Phillips study results showed that small parcels which cannot be replaced easily in the market place warrant compensation for fixed costs in addition to the market value of the land taken. However, fixed cost compensation (proportional to the ratio of land taken relative to total area) may not reflect the *fair* compensation rate since other economic adjustments will dampen the net revenue change. These dampening factors include:

i). The ability to re-size equipment so that fixed costs are at a new optimum for the smaller land base after the partial taking.

ii). Changes in the ownership costs of machinery as a result of the partial taking (which includes repair, downtime and net capital outlay costs).

iii). The optimum replacement strategy for farm machinery. In cases where re-sizing is possible, the replacement age will determine the length of time compensation is required.

The adjustments that may be possible to the machinery assets and other adjustments which occur to repair and downtime costs are at issue in this study. The size of the taking, the initial size of the farm and the location of the farm will also affect the magnitude of these adjustments to the machinery complement.

B. Organization of the Study

The remainder of the study is organized into three major sections; section III Economic Analysis, section IV Operational Models and section V Results.

In Section III the theoretical framework is presented and discussed. Within section III there are three main topic areas, ownership costs, the discount rate and capital investment analysis. As discussed earlier, the adjustment to ownership costs is a key factor in the non-land compensation issue. Techniques for predicting ownership costs (capital, repairs, and downtime) are analyzed in section III. Also included in this section is an explanation of rationale behind the choice of the discount rate. A Capital Asset Pricing Model (CAPM) was considered in this study to assist in determining the risk factor of machinery ownership. Finally in section III an outline of capital investment analysis is given. Capital investment analysis will be used to derive present values and optimal replacement cycles.

Section IV contains the framework for the operational models including details on the structure and methods used within the computer models. These models are used to determine machine sizing, ownership costs, replacement cycles and compensation payments. The machine sizing model is an engineering based model designed to size farm machinery for various farm sizes and cultural practices. The asset replacement model is used to derive annual ownership costs and optimum replacement strategies for the machines chosen and sized with the sizing model. From these results compensation payments are derived, and explanation of these calculations are in section IV.3.

The final section of the study deals with results. Tables are constructed which can be used to determine compensation payments based on farm size and location. A summary and conclusion, including recommendations for further research, are also provided in this section.

III. Economic Analysis

This section outlines the various techniques which will be used to estimate ownership costs of farm machinery. There are three major components of ownership costs, capital costs and repair and downtime costs. The American Society of Agricultural Engineers have estimated ownership cost functions since 1970. These have been updated somewhat and the strengths and weakness of these functions will be discussed below. Following the ownership cost section is a description of the methodology used to determine the discount rate. The discount rate has paramount importance to the level of fixed cost compensation payments. A capital asset pricing model was tested to determine the appropriate risk adjustment to the discount rate, this method proved unsuccessful for this study. An alternative approach will be outlined. Finally this section describes the capital investment approach used to determine annual present values of ownership costs and optimal replacement cycles.

A. Ownership Costs

Machinery investment typically represents the second largest investment on a grain farm (second to land). Surveys of grain farms across Alberta show that machinery investment varies from $118/acre to $360/acre.[7] The ownership costs associated with machinery are clearly significant. The relative amount or size of machinery held affects profitability. In calculating ownership costs the time value of money as well as opportunity costs must be incorporated into the calculation to fully capture the total costs of farm asset ownership.

1. Capital Costs of Owning Equipment

Bauer and Phillips (1988) describe fixed costs as comprised of...

---

[7] Crop Case Study results from 1988 (Production Economics Branch, Alberta Agriculture) show current market value of farm machinery.

> *...the ownership costs (ie., depreciation and opportunity cost) of investment in machinery, buildings and livestock, and other depreciable items. Variable costs include annual costs for feed, seed, fertilizer, fuel, and other non-depreciable items.*

Depreciation is the loss of value of capital assets as a result of age (obsolescence), and normal wear and tear. The investment of capital in machinery forgoes the opportunity for other investments. These capital costs of owning machinery will be calculated. The primary focus of this study is a typical grain farm enterprise and therefore fixed costs were calculated for machinery only.

Remaining values of farm machinery will be calculated using depreciation formulas developed by the American Society of Agricultural Engineers (ASAE).[8] A capital investment approach is used to account for the time value of money and foregone investment alternatives. Sections III.A.2 and III.C describe the analytical framework for these two issues respectively.

2. Salvage Values

The estimation of salvage values is a difficult task. Machinery values vary greatly depending on make, age, hours of use, past use, and historical maintenance. The American Society of Agricultural Engineers (ASAE) has developed a series of equations which predict remaining values for farm machinery.[9] These regression equations are based on data from the U.S. Midwest from the early 1970's. They take the basic form:

$$Salvage\ \ Value_n = D_1 \times (D_2)^n \times C \qquad (III.1)$$

Where; $1 - D_1$ is first year depreciation
$(1 - D_2)$ is the annual rate of depreciation; and
n is the n^{th} year.

---

[8] There are various definitions for the "market value" of a piece of farm machinery. The more commonly used terms are market value, current value, remaining value and salvage value. For the purposes of this study the term used will be *salvage value*.

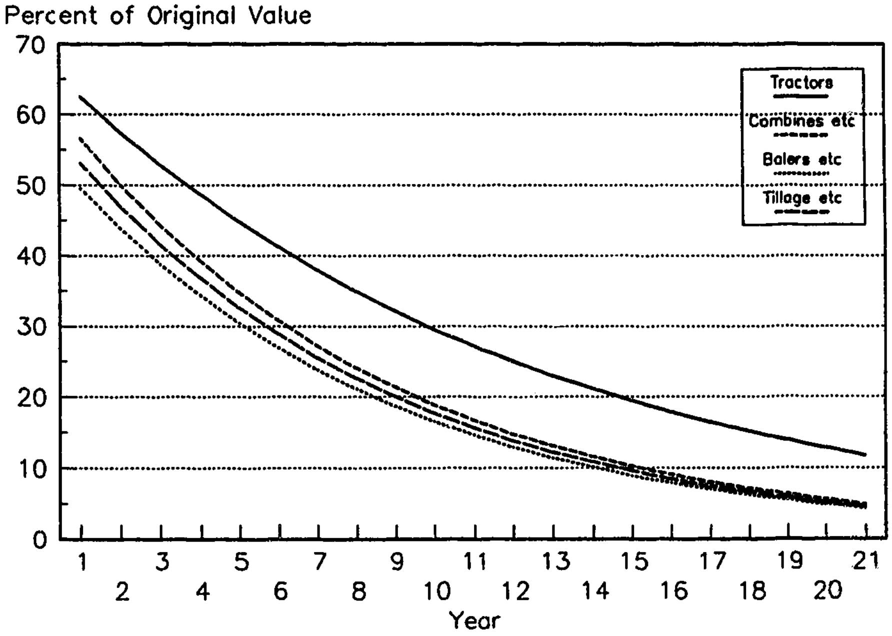
[9] ASAE Standards, 1989. Standards, Engineering Practices and Data developed and adopted by the American Society of Agricultural Engineers.

Four equations were estimated for a wide range of farm equipment. The equations are:

Tractors	$Salvage\ Value_n = .68 \times (0.920)^n \times C$
All combines, Self Propelled Windrowers	$Salvage\ Value_n = .64 \times (0.885)^n \times C$
Balers, forage harvesters, blowers, SP sprayers	$Salvage\ Value_n = .56 \times (0.885)^n \times C$
All other field machines (tillage etc.)	$Salvage\ Value_n = .60 \times (0.885)^n \times C$

The equations heavily discount the first year of ownership. Sales data[10] and survey work done at Alberta Agriculture[11] confirm this relationship.

Figure III.1: Depreciation Schedules For Farm Machinery[12]



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[10] See Marshall's Farm Guide to Used Farm Machinery, various years.

[11] Crop Case Study, Alberta Agriculture, Production Economics Branch, various years.

[12] Graphical data based on American Society of Agricultural Engineers, ASAE, Transactions.

Notice that the shape of the curves (rate of depreciation) are similar for all types of machines. The main difference is the degree of depreciation in the first year and, in the case of tractors, the salvage value.

3. Repair Costs

Estimates for repair costs are also based on ASAE calculations. In the mid 1970's data on tractors and implements were collected in the Mid-West U.S.. Most research and extension work still relies heavily on the functional forms estimated by the ASAE, though several adjustments have been made to the formulas since their inception, (Hunt, 1977; ASAE, 1979). Adjustments were made as a result of shortcomings in the original functional forms for tractors. The original equations for tractors derived by ASAE, set R_1 at 0.12 and R_2 at 1.5. This would represent repair costs which would increase smoothly at a decreasing rate (since the exponent (R_2) is less than 2.0). Such a function would likely underestimate the major cost items such as overhauls which typically occur late in the life of the machine, (Bradford and Reid, 1982). Hunt (1977) recognized this problem and presented two other formulas ,although, neither covered machine use beyond 4000 hours. The ASAE took note and made changes in their own equations which were published in their *Standards* beginning in 1979.[13] The repair cost factor R_1 remained unchanged whereas R_2 was changed to 2.033. Table III.1 shows repair cost factors for major farm equipment.

Equation (III.2) shows the general form of the repair cost equations:

$$TAR_n\% = (R_1)\left[\frac{H_n}{1000}\right]^{R_2} \qquad (III.2)$$

---

[13] See the ASAE Standards, published annually by the American Society of Agricultural Engineers.

Where; $TAR_n\%$ is the total accumulated repair costs as a percentage of the machines original cost
R_1 is Repair Factor 1
R_2 is Repair Factor 2; and
H_n is the accumulated hours of use.

This function expressed in dollars rather than a percentage of purchase price is:

$$R_n = (R_1)\left[\frac{H_n}{1000}\right]^{R_2} \cdot C \qquad (III.3)$$

Where; R_n is the total accumulated repair costs up to year n
C is the initial capital outlay.

These repair cost factors R_1 and R_2 are regression coefficients estimated using the data collected in the U.S. Midwest.[14] Unfortunately technical data on how these estimates were derived are not documented by the ASAE.

Table III.1: Repair Cost Factors for Farm Equipment

Description	R_1	R_2	Wear Out Life (hrs)
Tractors 2wd	0.012	2.033	10,000
Tractors 4wd	0.010	2.033	10,000
Combines (SP)	0.120	2.100	2,000
Combines (P.T.O.)	0.180	2.300	2,000
Swathers (SP)	0.120	1.800	2,500
Swathers (P.T.O.)	0.120	1.800	2,500
Seed Drills	0.540	2.100	1,200
Discs	0.180	1.700	2,000
Cultivators	0.300	1.400	2,000
Plows	0.430	1.800	2,000
Rodweeders	0.160	1.300	2,000
Harrows	0.160	1.300	2,000

SOURCE: American Society of Agricultural Engineers, *Standards.*

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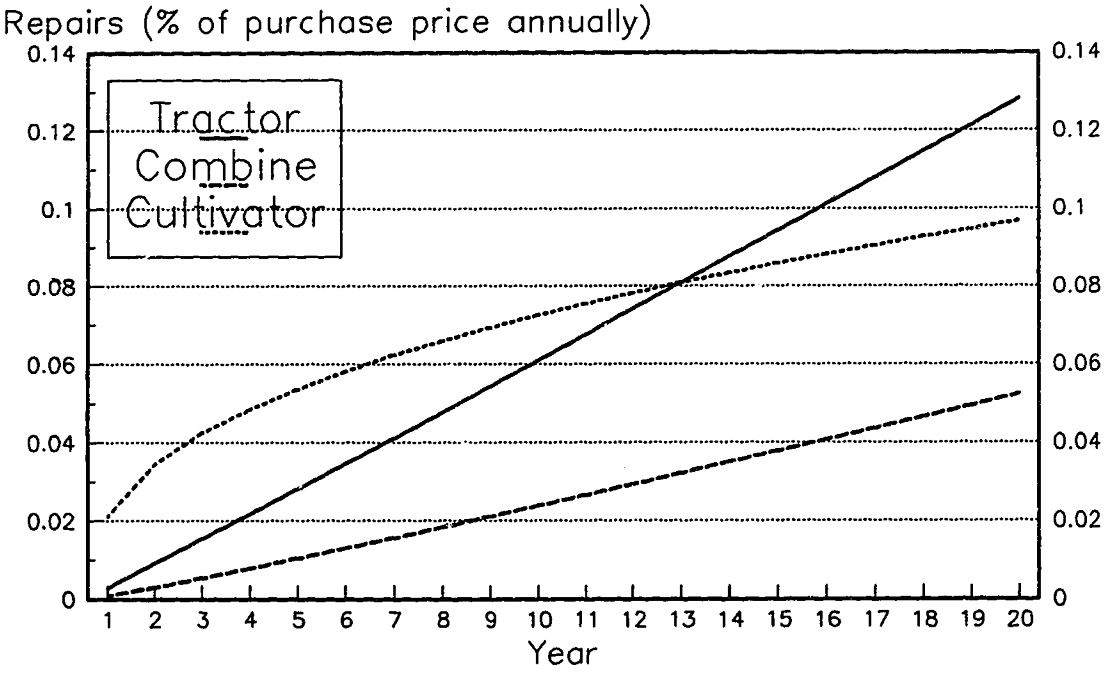
[14] The results were originally published in the Transactions of the American Society of Agricultural Engineers.

Other than the adjustments mentioned above the repair cost formulas have remained unchanged.[15] Despite their shortcomings (eg: data are somewhat outdated and apply to the U.S. mid-west), these equations are used in much research including this project. Figure III.2 shows the annual repair costs as a percentage of original purchase cost for two wheel drive tractors, self propelled combines, and cultivators. Figure III.3 shows the cumulative repair costs of the same equipment, again expressed as a percentage of original purchase cost.[16]

Figure III.2: Annual Repair Costs[17]



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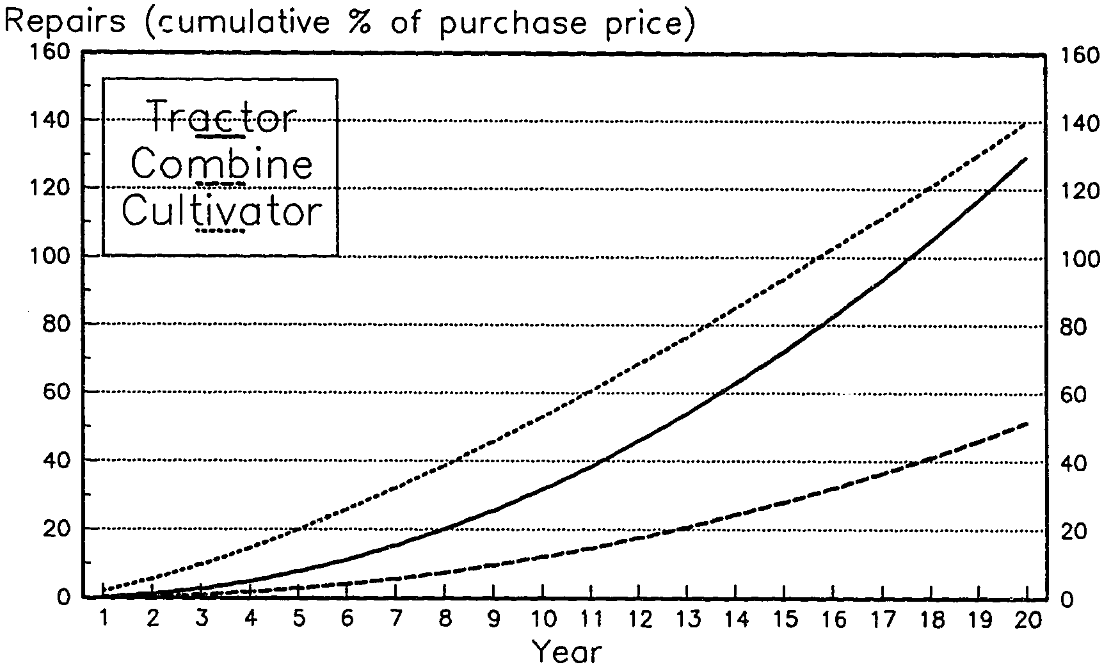
15 The author, in conjunction with Alberta Agriculture, is presently collecting farm level data to address the issue of repair costs. Data will be collected from crop case study participants throughout the province of Alberta.

16 Annual use of the machines were assumed at 500 hours per year for tractors, 150 hours per year for combines and 200 hours per year for cultivators for the purposes of illustration.

17 These graphs are based on the American Society of Agricultural Engineers data as presented in Table III.1.

Figure III.3: Cumulative Repair Costs



4. Downtime Costs

a). Traditional Approach

Some evidence exists which suggests that farmers have sized equipment larger than can be justified from an engineering point of view (Brown and Schoney, 1985). This trend towards bigger and newer equipment has been linked to the cost of downtime (Parsons *et al*, 1981). Downtime or timeliness costs are part of, or a result of, repair costs. Preventative repair and maintenance can, to a certain degree, offset the cost of not having ***optimum timing*** of field operations. Nevertheless, downtime remains an unavoidable cost associated with owning farm machinery. Various methods are used in determining the extent of such downtime and the economic penalties which result.

Hunt (1977) and ASAE (1989) have estimated yield loss and grade reductions resulting from machinery breakdowns. Brown and Schoney (1985) also used this approach in their machinery sizing program for grain farms in Saskatchewan. The method has merit, however it is region and crop specific. Large yield grade variations are apparent as a result of weather alone. Separating the effects of weather and machinery downtime is very difficult. The following equation represents the method developed by Hunt and accepted in the ASAE standards.

$$T_i = \frac{cA}{Swe} \cdot \frac{KYVC_a}{Uh(sc)(nt)} \qquad (III.4)$$

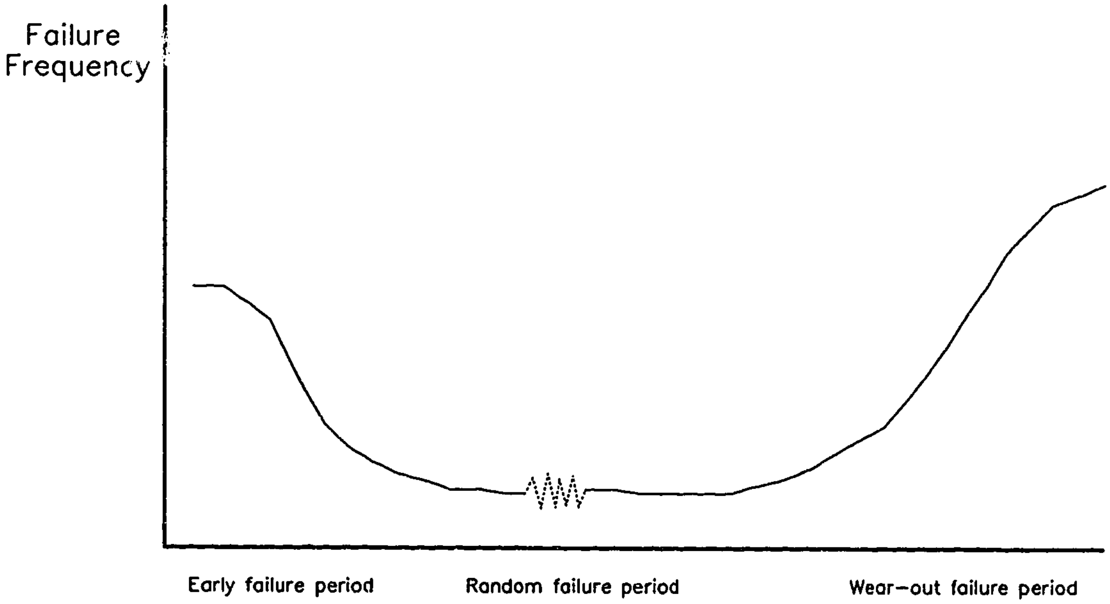
Where;
T_i is the timeliness cost of implement i ($)
c is a the constant 8.25 to convert to acres/hour
A is the area covered (acres)
S is speed of operation (mph)
w is width of implement (feet)
e is the field efficiency of the implement (%)
K is the timeliness loss factor (yield/day of delay)
Y is potential crop yield (bu/acre)
V is the value of the crop ($/bu)
C_a is crop area (acres)
U is the fractional utilization of time (integer)
h is total hours available per day
sc is a scheduling factor (2 or 4)
nt number of times C_a should be divided because of dispersed optimum times (Eg: different varieties or different crops mature at various times). Usually set at 1.

There are several factors in the equation which are difficult to estimate, in particular the timeliness loss factor (K). Other variables in the equation are region specific or typically have a high variance (ie: crop yield and price). Also, much of the data required for this equation are only available for Saskatchewan and the U.S. mid-west. For these reasons it was decided to depart from this traditional approach and use machinery downtime estimates. A flat rate charge can be applied to the estimated downtime which alleviates most of the problems found in the above timeliness estimate.

b). The "Bathtub Curve" Approach

Engineers have depicted failure rates for machinery with a "*bathtub curve*" (Hardesty and Carman, 1988). Figure III.2 Shows the general shape of such a curve.[18]

Figure III.4: Relative Failure Rates During A Machine's Life



Adapted from Hardesty and Carman, 1988

Failures which occur in the early stages of machine life are typically manufacturing defects or machine flaws and though they may be covered under warranty, downtime costs may still exist. The random breakdown period covers most of the operating life but during the wear-out failure stage there is an increase in breakdowns due to parts *degradation* from age. An exponential distribution is used to characterize the failure rates during the random and wear-out periods (Hardesty and Carman, 1988). The exact shape of the curve depicted in figure III.4 will vary depending on the complexity of the machine, engineering design, field testing, and quality control during assem-

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[18] For more details see *Reliability Mathematics* by Bertram L. Amstadter, McGraw-Hill, 1973.

bly. The main problem with this system is that it does not reflect the cost of failure only the frequency. The amount of time lost, the cost of repairs and the cost to the crop are all undetermined in the "bathtub" approach.

c). Study Approach to Downtime Costs

Downtime can be predicted for any particular machine, although the variance is usually large. Most work which has been done to date is centered around the power equipment on the farm, usually the tractor and combine since these machines are complex in design and break down more frequently than non-powered machinery.

The Hardesty and Carman (1988) study was used as the basis for downtime costs for this study. The study, funded by the Giannini Foundation (University of California), focused on 2 very large farming operations in the San Joaquin Valley. Access to detailed records were gained for common types of farm machinery on California row crop farms, including tractors and grain combines. Other row crop machinery were also studied, however, these are not put to use in this study. Data on pre-season maintenance and seasonal repairs and downtime costs were kept for several large fleets of machinery over the period 1971 to 1982. The ASAE repair cost schedules, which are available for a wide range of equipment and are based on a large sample size, were considered to most accurately reflect repair costs for the purposes of this study. Downtime costs, however, have been neglected as noted in the above sections. Therefore the Hardesty and Carman study was used for estimating downtime.

The farming operations (from which the data are collected) use extensive preventative maintenance programs. Tomatoes represented a large proportion of the crop grown on these farms. Downtime is particularly expensive since tomatoes are perishable and processors either discount late deliveries heavily or reject them altogether. For this reason pre-season maintenance programs were very well defined and carried out meticulously. With this in mind, we would expect that downtime estimates derived from these farms may be considered as a lower bound.

Hardesty and Carman incorporated the exponential function for downtime as suggested in the theoretical literature (Amstadter, 1973). The equation used is:

$$\frac{DTH_{mn}}{AMH_{mn}} = ae^{(bCMHL_{(mn-1)}+\epsilon_{mn})} \qquad (III.5)$$

Where; mn is an observation for machine m in year n
DTH_{mn} is the annual hours of downtime for machine m in year n
AMH_{mn} is the annual machine (m) hours in year n
$CMHL$ is the cumulative machine hours lagged one year
a is an equation parameter
b also an equation parameter.

With this specification the hours of downtime per hour of use changes at a constant rate *b* with cumulative machine hours (Hardesty and Carman, 1988). In natural log form the downtime equation becomes:

$$\ln\left(\frac{DTH_{mn}}{AMH_{mn}}\right) = a^{*} + bCMHL_{(mn-1)} + \epsilon_{mn} \qquad (III.6)$$

Where; a^{*} is the natural log of a

Results from the estimation are presented in the following table III.2.

Table III.2: Estimated Downtime Relationships by Machine Type[1,2].

Machine	Constant	CMHL	R^2	F-Stat
Tractor	-3.9967 (-37.20)	.0001872 (9.11)	.79	33.86
Combine	-4.3058 (-23.92)	.0005401 (8.11)	.67	65.77

Source: Hardesty and Carman, 1988.

[1] t-statistics are in parentheses.

[2] The estimated coefficients are significantly different from zero at the one percent level.

The percentage of variation of the downtime rate explained by machine use (hours) varied from 0.67 to 0.79, which is acceptable given the relatively small sample sizes (Hardesty *et al*). The annual amount of downtime increases as cumulative machine hours increase, as expected. These functional forms were used to estimate downtime hours in this study. A flat rate charge per hour was charged for every hour of downtime. Custom rates were used as a proxy for opportunity costs of downtime.[19]

B. The Discount Rate

Procedures for choosing a discount rate are often controversial. In this study the appropriate discount rate needs to capture the risk of correctly predicting salvage values and repair costs at various stages of machine life. Initial effort was given using a capital asset pricing model (CAPM). This model defined the relationship between changing machinery values and repair costs (over time) vis a vis the rest of the market. This relationship is estimated as a "*beta*" coefficient and is used to adjust a real discount rate for risk associated with the project. A "*beta*" coefficient was estimated for new machinery values and repair costs relative to a well diversified portfolio, represented by the Toronto Stock Exchange (TSE 300), (Jacob *et al*, 1984).

1. Capital Asset Pricing Model (CAPM)

The CAPM model has been used extensively to analyze portfolio risk. Specifically, it helps define risk of a single security in terms of its contribution to the riskiness of the entire portfolio as opposed to its risk in isolation (Brigham and Gapenski, 1985). To measure the correlation between a single security (or project) against that of a well diversified portfolio, a *beta* coefficient is calculated. Coles (1989) states that:

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[19] See Farm Machinery Costs as a Guide to Custom Rates, Alberta Agriculture, Farm Business Management Branch.

> ***A riskless investment which does not contribute any additional risk to a portfolio will have no risk premium and a beta of zero while an investment which contributes the same amount of risk to a market portfolio as the portfolio already exhibits will have a beta of one and a risk premium equal to that of the market portfolio.***

The CAPM is a useful tool to estimate beta coefficients[20], and is used to estimate the relative risk of machinery values and repair costs over time compared to the TSE 300 index. The general functional form in estimating the project risk is:

$$r_p = r_f + \beta(r_m - r_f) \qquad (III.7)$$

Where:
r_p is the project risk (return)
r_f is the risk free rate of return
r_m is the rate of return in the market
β is the beta value.

2. TSE 300 and Machinery Indices

Listings of the TSE 300, treasury bill rates, power machinery, non-power machinery and farm machinery repair indices are found in Appendix A. All three machinery indices were regressed on R_m-R_f (TSE 300 - Treasury bill) to estimate the beta. The power and non-power machinery indices were available for the years 1961 through 1988 while the repair index was only available from 1972 through 1988. The TSE was available for all years. Results are shown in Table III.3.

Table III.3: Beta Coefficients for Farm Machinery

	Power Machinery	Non-Power Machinery	Repairs
Constant	-0.02764	-0.02803	-0.02170
Beta	0.01867	-0.00301	-0.00396
t-statistics[21]	0.6021	-0.1244	-0.2000
R Squared	0.00546	0.00023	0.00060

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[20] For more detailed discussions on CAPM and beta coefficient estimations see Brealy *et al* (1986), Brigham *et al* (1985), and Jacob *et al* (1984).

[21] The null hypothesis is $\beta = 0$. No beta coefficients were significant at a 20 percent level of confidence, therefore, the null hypothesis could not be rejected for any of the regressions. It follows that

None of the estimated beta coefficients were significant. The use of a CAPM model to determine an appropriate discount rate was therefore not possible. The machinery price indices had very little relationship with historical market returns. This suggests that better measures of machinery investment risk[22] are necessary. Future research in optimal replacement decisions will require a discount rate which accurately depicts farm machinery investment risk.

An alternate, less desirable, approach was taken to determine an appropriate discount rate. Long term real rates of return on the TSE 300 and treasury bills were used to derive the discount rate. Brealy (et al, 1986) show that the average real rate of return on the TSE 300 was approximately 9 percent. The average real rate of return on treasury bills were estimated at .5 percent.[23] A conservative discount rate of 10 percent was chosen for this study. Future research in machinery investment risk would benefit this work. A discount rate which is based on the risk which is internal to the model, machinery investment risk, obviously would have advantages over the method used in this study.

3. Further Adjustments to the Discount Rate

In this study a real after-tax risk adjusted rate is desired to accurately reflect tax and risk considerations. All cash flows are in 1988 dollars, and inflation is assumed to affect all cash flows equally and therefore, no inflation adjustments to cash flows were necessary.

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the R Squared values are also extremely low.

[22] Risk from changing machinery values (new and used) plus risk of repairs and the costs associated with repairs constitute total machinery investment risk.

[23] They based their findings on Canadian corporate bond data (1949-1981), treasury bills (1926-1981) and the TSE 300 (1956-1981).

The discount rate was adjusted to account for tax and capital cost allowance. Tax benefits from repair costs and CCA[24] write-offs can have significant impact on cash flows and thus the replacement decision. Adjustments to the capital cash flows to an after tax basis (incorporating tax savings from CCA) is incorporated by equation (III.8).

$$CCA \quad tax \quad savings = 1 - \frac{dt}{d+r} \qquad (III.8)$$

Where: d is the CCA rate
t is the marginal tax rate
r is the after-tax, risk adjusted discount rate.

These tax and capital cost adjustments are incorporated into the asset replacement model presented in the following sections.

C. Capital Investment Analysis

1. Overview of Approach

Total ownership costs of machinery are required in order to determine the additional non-land fixed costs incurred by the landowner as a result of expropriation. Traditional cost accounting for depreciation and interest opportunity costs have not taken into account the time value of money. These methods underestimate ownership costs since future salvage values are not discounted to present value terms. Determination of the optimal time to replace must be based on full ownership costs (repairs and depreciation) which are discounted. A capital investment approach is employed to estimate ownership costs.

Furthermore the decision of replacement is not only based on the present machine's ownership costs but also on costs associated with the new asset. A common technique to deal with asset replacement is the use of an identical challenger

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[24] CCA is capital cost allowance and is the amount of depreciation allowed under Federal tax laws.

replacement model (Bradford and Reid, 1982). The capital investment tools applied to an identical challenger replacement scheme should provide useful insight to optimal replacement cycles and costs of farm machinery.

The identical challenger replacement model assumes the asset owner will replace the asset at the end of each replacement cycle with an identical asset. This approach in one form or another has been a generally accepted procedure for choosing asset replacement patterns. Unfortunately, the identical challenger method does not account for various changes in technology nor does it account for general changes in farm structure such as;

i). Increasing farm sizes over time.

ii). General movement of the labour force away from farms and therefore increasing the use of capital.

iii). Changing Labour/leisure trade-offs.

These changes can have important impacts on the capital structure of farms. However, dealing with these socio-economic implications is outside the scope of this paper though it would provide a useful basis for future research. For the purposes of calculating fixed cost compensation payments the assumptions of the identical challenger methodology were not considered overly restrictive.

Others have dealt with the asset replacement problem with much the same methodology as is used in this study. A depreciating capital asset should only be kept for another production period if the ownership costs are less than the average cost of a new replacement machine. Perrin (1972) summarizes the cost minimization problem as:

> *A machine should be kept another period if the marginal costs of retaining it . . . are less than the 'average' periodic costs of a replacement machine.*

Bradford and Reid (1982) showed that the *optimal replacement age for a machine to be successively replaced by an infinite series of identical challengers can be determined in the discrete case by finding the age (S) which minimizes the absolute value of the expression:*

$$PV(S)=[1-(1+r)^{-S}]^{-1}\left[-M(O)-\sum_{t=1}^{S}(1+r)^{-t}R(t)+(1+r)^{-S}M(S)\right] \tag{III.9}$$

Where: $PV(S)$ **is the present value for each value of S**

$[1-(1+r)^{-S}]^{-1}$ **is the present value of a $1 perpetual annuity received (paid) at the beginning of each and every S years**

$M(O)$ **is the new cost of the machine, assumed to be constant for the identical challenger problem**

$M(S)$ **is the remaining value of each machine when replaced, also assumed to be constant**

$R(t)$ **are the costs attributable to the machine during each time period *t*, including repairs, opportunity costs of breakdown time and tax savings due to depreciation**

r **the after-tax discount rate.**

The capital investment problem for a planning horizon of "*S*" years is characterized by the variables; $M(O)$ the value of the machine at t=0, $\sum_{t=1}^{S}(1+r)^{-t}R(t)$, the discounted revenues and/or costs expected during the machines life; and $(1+r)^{-S}M(S)$, the salvage value of the machine discounted to t=0. The annuity factor which converts the capital investment into a perpetuity so that the replacement issue can be solved is $[1-(1+r)^{-S}]^{-1}$ (Bradford and Reid, 1982). It is basically this approach which is taken to solve the replacement problem for the fixed cost compensation issue.

Total ownership costs of each machine are discounted over *s* years and expressed as an annual equivalent cash flow where *s* varies from 1 to ∞. In order to find the optimal replacement age the minimum present value of all cycles generated from s to ∞ is determined. This process was defined above and is defined in the context of this study within the next two sections.

2. Capital Investment Analysis and Capital Costs

The change in machinery values over time are calculated using ASAE formulas as described in earlier sections. In this section capital investment analysis will be used to incorporate the time value of money and therefore account for all costs, both loss in asset value and opportunity costs. Annual cash flows in real terms generated using the ASAE standards are discounted to present value terms as follows:

$$NCO_{cycle1} = \left[-C + \frac{SV_T}{(1+r)^T} \right] \qquad (III.10)$$

Where: NCO_{cycle1} is the present value of depreciation and opportunity costs
$-C$ is the capital outlay in period 0
SV_T is the salvage value at year T
T is the number of years the machine is kept
r is the discount rate.

Under the identical challenger assumption the current machine is replaced with an identical machine. Therefore upon replacement of the worn out machine the present value of the second machine will be:

$$NCO_{cycle2} = \frac{1}{(1+r)^{2T}} \left[-C + \frac{SV_{2T}}{(1+r)^{2T}} \right. \qquad (III.11)$$

Where: NCO_{cycle2} is the present value of repairs for machine 2
SV_{2T} is the salvage value of a machine at the end [illegible] time
"T"is the length of time the machine is kept.

Assuming multiple replacements of the asset under conside[illegible] expand the present value of any one asset to the present value of "k' [illegible] cycles. Expansion of equation (III.11) to the general case of "k" replac[illegible]es is:

$$NCO_{k\text{-}cycles} = \left[-C + \frac{SV_T}{(1+r)^T}\right] + \frac{1}{(1+r)^T}[\cdot] + \frac{1}{(1+r)^{2T}}[\cdot] + \ldots + \frac{1}{(1+r)^{(k-1)T}}[\cdot] \qquad (III.12)$$

Where: k is assumed to approach infinity and

$[\cdot]$ represents $\left[-C + \frac{SV_T}{(1+r)^T}\right]$.

By factoring out $[\cdot]$ the above equation simplifies to:

$$NCO_{k\text{-}cycles} = \left[-C + \frac{SV_T}{(1+r)^T}\right]\left[1 + \frac{1}{(1+r)^T} + \ldots + \frac{1}{(1+r)^{T(k-1)}}\right] \qquad (III.13)$$

and if we take the limit of this equation as $k \to \infty$ the result is:

$$NCO_{k\text{-}cycles} = \left[-C + \frac{SV_T}{(1+r)^T}\right]\left[\frac{(1+r)^T}{(1+r)^T - 1}\right] \qquad (III.14)$$

Where; $\left[-C + \frac{SV_T}{(1+r)^T}\right]$ is the net present value of the initial cash outlay less the future salvage value of the machine kept for "T" years

$\left[\frac{(1+r)^T}{(1+r)^T-1}\right]$ represents the net present value of all future replacements of an asset kept each time a period of "T" years.

So far the present value of all future machine replacement decisions have been represented in terms of a "total" present value. In order to define the average annual equivalent (AAE) cash outlay for equipment ownership costs we multiply the discounting part of equation (III.14) by the discount rate "r".

$$AAE_{NCO} = \left[-C + \frac{SV_T}{(1+r)^T}\right]\left[r\frac{(1+r)^T}{(1+r)^T - 1}\right] \qquad (III.15)$$

This reduces as follows:

$$AAE_{NCO} = \left[-C + \frac{SV_T}{(1+r)^T}\right]\frac{(1+r)^T}{(1+r)^T}\left[\frac{r}{1 - \frac{1}{(1+r)^T}}\right] \qquad (III.16)$$

$$AAE_{NCO} = \left[-C + \frac{SV_T}{(1+r)^T}\right]\left[\frac{r}{1 - \frac{1}{(1+r)^T}}\right] \qquad (III.17)$$

Equation (III.17) represents the average annual ownership costs in present value terms of a given asset. The final step required is to adjust the discount rate for tax and capital cost allowance (CCA). In section III.B.3 it was shown that the cash flows could be adjusted to account for tax and CCA with the following equation:

$$1-\frac{dt}{d+r} \qquad (III.18)$$

Where: d is the CCA rate
t is the marginal tax rate
r is the after-tax, risk adjusted discount rate.[25]

The after tax adjusted equation for the present value of depreciation and ownership costs is then:

$$AAE_{NCO}=\left[-C+\frac{SV_T}{(1+r)^T}\right]\left[1-\frac{dt}{d+r}\right]\left[\frac{r}{1-\frac{1}{(1+r)^T}}\right] \qquad (III.19)$$

3. Capital Investment Analysis and Repair/Downtime Costs

An approach similar to that taken in the ownership cost section is taken to discounting repair costs. Annual cash flows in real terms for repair costs were generated using the ASAE repair cost equations (explained in earlier sections). Cash flows for annual downtime costs were also generated using the methodology outlined in section III.A.4. These cash flows are converted to present value as follows:

$$PV \quad RDT_{cyclel} = \left[\frac{RDT_1}{(1+r)^1}+\frac{RDT_2}{(1+r)^2}+\ldots+\frac{RDT_n}{(1+r)^n}\right] \qquad (III.20)$$

Where: $PV \quad RDT$ is the present value of repair and downtime costs from years 1 to n
RDT_n are the repair and downtime costs in year n
r is the discount rate.

This one cycle repair cost present value can be simplified to:

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[25] See section on "*The Discount Rate*" for a more detailed discussion on the derivation of the discount rate.

$$PV \quad RDT_{cycle1} = \sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n} \qquad (III.21)$$

Since the repair costs change each year within each cycle "*k*" a summation of the present value of repair costs for each of the years $n = 1 \rightarrow T$ is required. The present value of taking the number of cycles to infinity is then derived using the same process as outlined in the previous section on ownership costs.

Expanding equation (III.21) to "*k*" cycles leaves:

$$PV \quad RDT_{kcycles} = \left[\sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n}\right] + \frac{1}{(1+r)}\left[\sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n}\right] + \ldots + \frac{1}{(1+r)^{(k-1)T}}\left[\sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n}\right] \qquad (III.22)$$

Where: $k = 1 \rightarrow \infty$

Simplifying as in section III.C.2 we have:

$$AAE_{RDT} = \left[\sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n}\right]\left[\frac{(1+r)^T}{(1+r)^T - 1}\right] r \qquad (III.23)$$

And by factoring further simplification leads to:

$$AAE_{RDT} = \left[\sum_{n=1}^{T} \frac{RDT_n}{(1+r)^n}\right]\left[\frac{r}{1 - \frac{1}{(1+r)^T}}\right] \qquad (III.24)$$

Equation (III.24) represents the annual equivalent cash flow of repair and downtime costs for an asset kept "*T*" years and replaced with an identical asset at each interval "*T*".

Tax adjustments can also be made to the repair cost cash flows using a tax adjusted discount rate. The result is:

$$AAE_{RDT} = \left[\sum_{n=1}^{T} RDT_n \frac{(1-t)}{(1+r)^n}\right]\left[\frac{r}{1 - \frac{1}{(1+r)^T}}\right] \qquad (III.25)$$

The key formulas specifically used in the asset replacement model are III.20 and III.25. These are used to calculate annual repair costs (in present value terms) and average annual repair costs for the entire range of plausible replacement cycles.

Summing the average annual repair/downtime costs with the average annual capital outlay for each possible replacement cycle will determine *the* optimum replacement cycle for each machine.

Section IV outlines the operational models which size the farm equipment and determine the optimal replacement pattern for each machine.

IV. Operational Models

A. Machine Sizing Model

1. Overview

Machine sizing has been an important farm level decision since machinery has become an integral part of farm capital stock. There are many factors which influence machinery purchasing decisions including status, efficiency (technology), financial status of the farm, required field use, timeliness and ability or desirability to bear risk. All the factors listed (including status) have economic consequences for each individual farmer.

Perhaps the two most important factors to consider when sizing equipment are:

i. The total acreage to be covered and the amount of time available to do the work.

ii. The risk of downtime and the relative costs associated with the occurrence of downtime.

A farmer typically sizes his/her machinery complement so that the costs of downtime are equated with the cost of purchasing the next largest size of equipment. This assumes indifference between paying the downtime costs or having larger equipment. As described earlier downtime was valued at equivalent custom rate charges. Though downtime could not be implicitly integrated with the sizing equations the costs of downtime were calculated for the replacement model. Since the costs of downtime were not incorporated directly in the sizing equations the size of equipment chosen will represent the upper bound in terms of size. A least cost complement derived using timeliness costs will necessarily be smaller in size than the complements chosen using this studies approach.[26] As a result the compensation

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[26] For a more detailed explanation on this matter see section 3.A.4.a and Brown and Schoney, 1985.

payments outlined in later sections will also represent upper bounds. The larger the machine chosen the larger the compensation payment for a given farm size. These are important considerations for future policy and research in fixed cost compensation.

The following sections describe the sizing model in more detail.

2. Data Input and Flow of the Sizing Model

In the sizing model initial machinery complements are chosen and cultural practices of the farm are defined. Most of the common types of machinery are supported by the model. Corresponding drafts, speeds, field efficiencies and tractive efficiencies are listed for all machinery which enter the sizing program. Cultural practices for the areas being studied (Peace River, Edmonton-Red Deer, Airdrie and Oyen) are also input at this stage. The types of equipment and the typical number of field operations made by each piece of equipment are entered. Appendix C shows the number of field operations by machine for each region under study. Similar data are required for non-sized equipment for use in the asset replacement model.[27]

Once the machinery is sized the number of hours each machine operates for a given farm size is calculated. This is done for both machinery which is sized and machinery which is not sized.[28] These estimates are required for the "Asset Replacement" model to derive repair and downtime costs. These variable costs along with the fixed ownership costs will determine the total ownership costs and optimal replacement cycles.

The farm size is then incrementally decreased 20 times by 1 acre to represent

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[27] Handling of non-sized equipment for compensation payments is described in more detail in the "*Asset Replacement Model*" section later in the paper.

[28] Equipment which is not used in the seeding window is still eligible for compensation. Also, the annual use is important to the replacement issue and therefore, the compensation issue.

the most probable expropriation situations. Once again, a series of average annual hourly uses is generated for each machine. These are generated while holding the machine complement fixed and calculating the number of hours spent on all farm operations. Secondly, the equipment is re-sized for every increment in farm size to determine if a feasible smaller piece of equipment could be substituted on the smaller land base.[29]

The following flow chart represents the workings of the sizing model.

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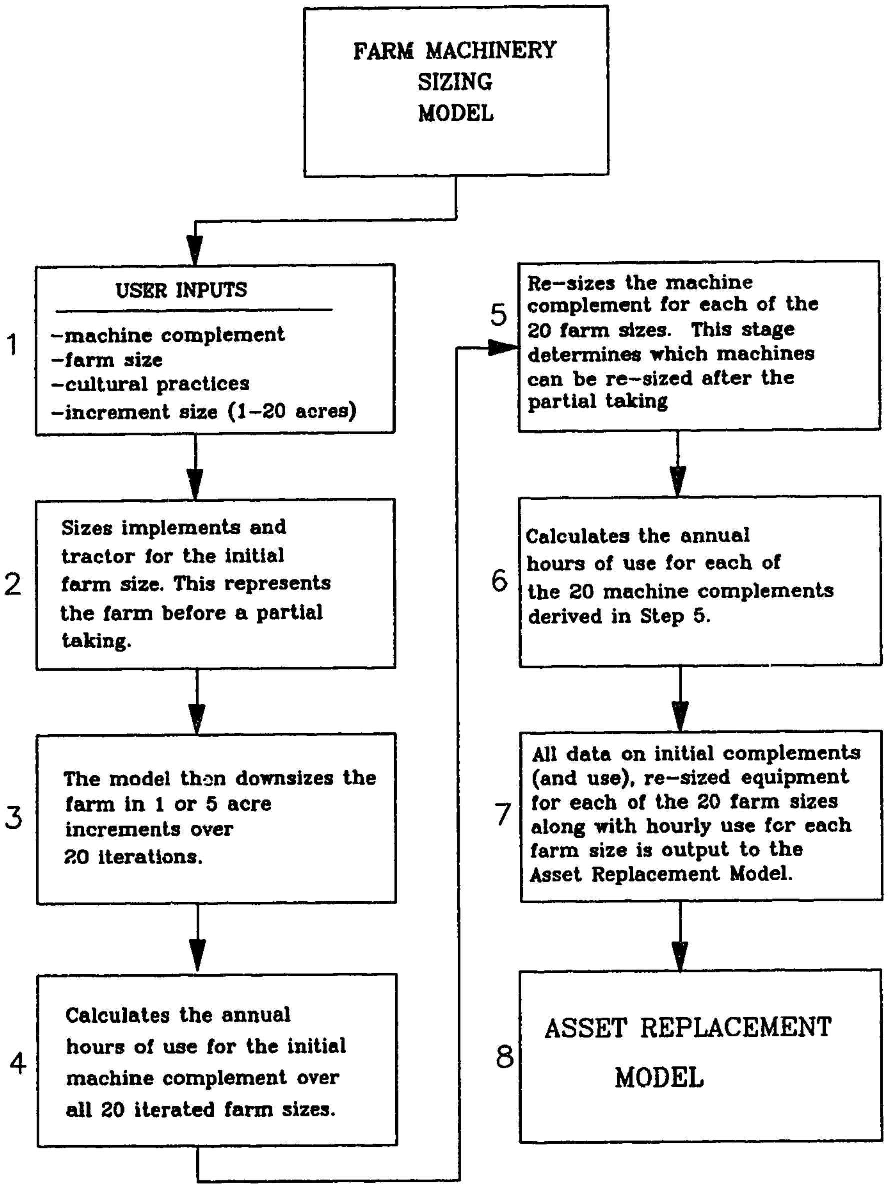
[29] It would be expected that small incremental changes of say one acre would have minimal impact on machine complement sizes. This held true, though for slightly larger partial takings there are cases where machinery could be re-sized, see the results section for more details.

Figure IV.1: Flowchart Of The Machine Sizing Model



3. Seeding Window and Workday Probabilities

The time available for seeding is generally the constraining factor for machine sizing. Late seeding due to under-capacity of machines and/or excessive downtime can reduce net revenue through reduced yields and/or grades. This is a result of a shortened growing season and pushing the harvest schedule later than would otherwise occur.

Rutledge and Russell[30] generated a series of work day probabilities for tillage operations in Alberta. These probabilities are based on weather parameters such as rainfall, temperature, and wind which affect the moisture content of the soil and in turn influence the operation of tillage and seeding machinery (Rutledge and Russell, 1971).

Based on the relationship between available hours and farm machinery sizes Rutledge and Russell state that:

> *Since the size of machinery system required to complete a given task is inversely proportional to the amount of time available, it is necessary to have an estimate of available time before the least cost machinery system can be determined.*

Their model incorporated field tractability (based on type and moisture of soil), evaporation and evapotranspiration estimates, and machine draft requirements. To derive "*field tractability*" and other related estimates accurate weather data was required. Daily or monthly observations of temperature, precipitation, wind speed, hours of sunshine and dew-points were necessary and were available only through the Edmonton, Calgary, Lethbridge, Medicine Hat, and Fairview weather stations. These stations however, cover the province quite well.

These workday probabilities were used to determine the available time for seeding in the Fairview, Edmonton, Calgary and Lethbridge areas. An average workday of 10 hours was assumed and a seven day work week. Table IV.1 shows the breakdown of working hours available for seeding for the four study areas.

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[30] Rutledge, P.L. and Russell, D.G., *Work Day Probabilities for Tillage Operations in Alberta*, Agricultural Engineering Research Bulletin, University of Alberta, 1971.

Table IV.1: Available Hours for Seeding by Study Area

Description	Peace River	Edmonton	Airdrie	Oyen
Prob. of workday	.77	.73	.67	.74
Work Day (hrs)	10	10	10	10
Work Week	7	7	7	7
Start Date	May 01	May 01	April 27	April 23
Finish Date	June 7	June 15	June 5	May 31
Total Days	38.00	46.00	40.00	39.00
Available Days	29.12	33.44	26.70	28.88
Available Hours	291	334	267	289

Source: Derived from Rutledge and Russell (1971) and Best Field Records from Alberta Agriculture (Production Economics Branch).

The following sections describe how the available working hours are used to determine implement and tractor sizes.

4. Implement Power Requirements

The analytical framework for sizing farm machinery is based on work done by Anderson.[31] Once the available hours for seeding are derived the power requirements for each implement are calculated. The power requirement is a function of the draft of the implement, reserve capacity of the tractor, tractive efficiency and field efficiency. The power requirement is derived using the following equation:

$$P_{i(KW/ha/hr)} = \frac{2.8935 \times KN}{(1 - rc)u \times E} \qquad (IV.1)$$

Where: $P_{i(KW/ha/hr)}$ is the power requirement of implement i
KN is the implement draft (KN/m)
rc is the reserve capacity of tractor
u is the tractive efficiency and approximates
.88 on concrete
.78 on stubble
.65 on tilled soil
.55 on soft soil
E field efficiency.

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[31] Anderson, A.W., Determining Optimal Machine Capacity For Cropping Systems, Agriculture and Forestry Bulletin, March 1985.

These measurements are only taken for implements which are required during the seeding window for seedbed preparation and seeding. Other implements and operations (such as summerfallowing) are not under time constraints and therefore do not enter the sizing equations.[32]

5. Tractor and Implement Sizing

In order to find tractor size the total complement power requirements are summed, converted to kilowatt-hours (KW-HRS) and divided by the total hours available for seeding as calculated in section IV.A.3. A description of the equations for calculating tractor and implement sizes follow.

The power requirement of each implement *i* as defined in section IV.A.4 are first converted to kilowatt hours (KW-HRSs) by:

$$P_{i(KW/ha/hr)} = \frac{2.935 \times KN}{(1-rc)u \times E} \qquad (IV.2a\&2b)$$

$$KW-HRSs_i = P_{i(KW/ha/hr)} \times ha_{totalcovered(i)}$$

Where: $KW \cdot hrs_i$ is the conversion to kilowatt hours for each implement i

$P_{i(KW/ha/hr)}$ is the power requirement of implement i in Kilowatts per hectare per hour

$ha_{totalcovered(i)}$ is the total area implement i is required to cover.

Total tractor power requirements are calculated by summing the individual power requirements of each implement ($from \quad i=1 \quad to \quad I$).

$$T_{power(KW)} = \frac{\sum_{i=1}^{I}(KW-hrs_i)}{Total \quad Working \quad Hrs \quad Available} \qquad (IV.3)$$

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[32] For example combines and swathers are not included in the sizing model.

Where: $\sum_{i=1}^{I}(KW-HRSs_i)$ is the sum of power requirements for all implements

$Total\ \ Working\ \ hrs\ \ Available$ is the total working hours available for seeding.

The required work rate for each implement is then established by dividing the total power requirement ($T_{power(KW)}$) by the power requirement of each implement (in kilowatts per hectare per hour) as follows:

$$Implement_{i(ha/hr)} = \frac{T_{power(KW)}}{KW/ha/hr_i} \qquad (IV.4)$$

Where: $Implement_{i(ha/hr)}$ is the work rate of implement i in hectares per hour

$T_{power(KW)}$ is the tractor power in kilowatts.

The final step is to calculate the width of each implement. Equation (IV.5) converts the work rate to width. This step determines the necessary machine width to complete the assigned tasks (field work) within the allotted time.

$$Implement_{i(width)} = \frac{10 \times Implement_{i(ha/hr)}}{(speed_i \times efficiency_i)} \qquad (IV.5)$$

Where: $Implement_{i(width)}$ is the width in meters of implement i

10 is a conversion factor to meters

$Speed_i$ is the field speed of implement i

$Efficiency_i$ is the field efficiency of implement i.[33]

Table IV.2 shows the field efficiencies, drafts, speeds, and tractive efficiencies for the equipment available in the sizing model.

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[33] Field efficiency takes into account lost time as a result of turning, working of headlands, overlap and in the case of seed drills re-filling.

Table IV.2: Field Coefficients for Machine Sizing Model (Edmonton)*

Description	Field Eff.(%)	Draft (KN/m)	Speed (Km/hr)	Tractive Eff.(%)
Combine SP	75	n/a	4.9	n/a
Combine P.T.O.	75	n/a	4.9	n/a
SP Swather	80	n/a	9.0	n/a
P.T.O. Swather	75	n/a	9.0	n/a
Hoe Drill	75	3.0	8.0	.63
Double Press Drill	75	3.0	8.0	.63
Hoe Drill W/Trans	75	3.0	8.0	.63
Air Seeder W/F.Cult	75	4.0	6.4	.63
Air Seeder W/Chisel	75	4.0	6.4	.63
Offset Disc Single	80	4.0	7.2	.63
Offset Disc Double	80	4.0	7.2	.63
Tandem Disc Rigid	80	4.0	7.2	.63
Tandem Disc Folding	80	4.0	7.2	.63
Field Cult	80	4.0	8.0	.63
HD Field Cult	80	4.0	8.0	.63
Cult W/Anhyd	80	4.0	8.0	.63
Moldboard Plow	80	5.0	7.0	.78
Rodweeder W/Multi	80	4.0	8.0	.63
Harrows No Autofold	80	2.0	8.0	.63
Harrows W/ Autofold	80	2.0	8.0	.63
Field Sprayer	80	n/a	10.7	n/a

SOURCE:ASAE Standards and ASAE Transactions (various years).
*Appendix B shows coefficients for all soil types.

B. Asset Replacement Model

1. Overview

The purpose of the asset replacement model is to determine the optimal replacement period of some given farm machine and the average annual ownership costs associated with that asset and replacement period. Many factors are involved in the asset replacement decision. The re-sale value, expected future repair costs, availability of new technology and labour constraints are some of the most obvious. This model is an identical challenger replacement model and therefore rules out any improvements in machine design over time as a motivating factor for replacement. This is a weakness of such models, however, the primary focus of this research is to determine fair compensation payments for fixed costs. While the modelling of asset replacement behavior is important, minor changes in replacement cycles should not bias the compensation payments greatly. The primary influences in this replacement model are changing repair and downtime costs over time along with annual depreciation/opportunity costs of holding that asset. It is the interaction of these factors over the assets life expectancy which determine the optimum replacement cycle.

It should be noted that only new machines are used in the analysis. This study determines optimal replacement cycles for farm machinery assuming all equipment is purchased new. Should replacement of a machine happen before it wears out there must also be a market for used machinery (it is this market which the salvage value formulas are predicting). An analysis on the economics of purchasing used versus new machinery was beyond the scope of this work.

The following sections describe the workings of the asset replacement model. As in the sizing model, Lotus 1-2-3 is used to facilitate the process.

2. Data Input and Lookup Tables

Data from the sizing model is used as input to the replacement model. Recall that, in the sizing model, all required machinery was chosen and details on the farm structure and cultural practices were defined. The replacement model brings the following data from the sizing model for further analysis:

i). inventory of machinery
ii). initial size of complement for given farm size
iii). annual hourly use of all equipment for initial farm size
iv). annual hourly use for all equipment for all farm sizes (farm size decreased in increments of 1-5 acres)

v). equipment sizes after re-sizing for all farm sizes

vi). annual hourly use for all equipment after re-sizing[34]

In section III (Economic Analysis), the methodology for calculating repairs and salvage values were defined. In the case of repair cost estimation there are equations which use regression coefficients to derive hourly costs. These coefficients vary for each type or group of farm machinery. A lookup table is used so that repair coefficients are matched automatically with the farm machinery brought in from the sizing model. These are then used in the necessary repair cost calculations which are explained later in this chapter. Coefficients for salvage value estimation are handled in the same manner as the repair cost coefficients, through the lookup table.

Other data brought into the lookup table include; annual hourly use of each machine in the base case scenario[35], the hourly use of each machine in the scenario under examination, and the machine size being used.[36]

Also included in the lookup table are the financial data used by the model. These data include the discount rate (see section III.B), downtime opportunity cost per hour (see section III.A.4), labour cost per hour and the machine risk coefficient (the latter two will be discussed in more detail later in this chapter). The factors mentioned above can be changed easily and allow for sensitivity analysis.

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[34] Note that some equipment is assumed to be fixed at the outset (ie: combines), and annual hourly use will therefore change as farm size change. If equipment is available at a size which is optimum for the new smaller farm, annual use will remain relatively unchanged since the seeding window allows the same hours for seeding after the taking as were available before the taking. Jobs which are done outside the seeding window (ie: summerfallowing) will result in a different total hours of use if the size of equipment has changed.

[35] The base case scenario is the initial farm machinery complement used in the farming operation before the partial taking.

[36] The machine size and annual hourly use for all scenarios are brought into the lookup table in a "loop" and used for determining ownership costs and replacement cycles as described later in this chapter.

Following sections explain the subsequent steps in the model which are taken to determine annual ownership costs, optimal replacement cycles and compensation payments.

3. Determining Initial Purchase Prices

It was assumed that all machinery is purchased new for the purposes of this study. A market for used equipment exists, however, it was beyond the scope of this study to evaluate the economic alternatives of used versus new versus leased equipment. Clearly there must be a portion of equipment on farms which was purchased new, however, only new equipment was evaluated.

The Production Economics Branch of Alberta Agriculture have done several dealer surveys of new machinery values with their most recent being 1985. The study "*Farm Machinery Costs*" typically used manufacturers suggested list prices. In the early 1980's however, it was believed that these prices were likely higher than actually received by the dealers. Therefore, the 1985 study collected average actual sales data rather than suggested list prices. Where not enough sales existed suggested list prices were used. The data was collected by machine type and size. Prices were indexed to 1989 using the farm input price index.

For the purposes of this study and the programming aspect of the models it was preferable to have purchase prices in the form of an equation rather than strictly a data set since the sizing model generated sizes in integer increments. Ordinary Least Squares (OLS) regression estimates were applied to the data set of new machinery values. The data for all machinery fit well with linear regression. Figures IV.2 and IV.3 show a sample of the results for 2 and 4 wheel drive tractors, press drills and cultivators. Shown in the figures are the actual data points, best fit lines and the OLS coefficients. The coefficients of determination (R^2) values were all extremely high, usually above 95 per cent. An R^2 of 95 percent implies that 95 percent of the variation in the dependant variable (price of the machine) is explained by the independent variable (size of machine). The t-stats for all coefficients were significant at the 1% percent confidence level.

Figure IV.2: Regression Results For Tractor Pricing

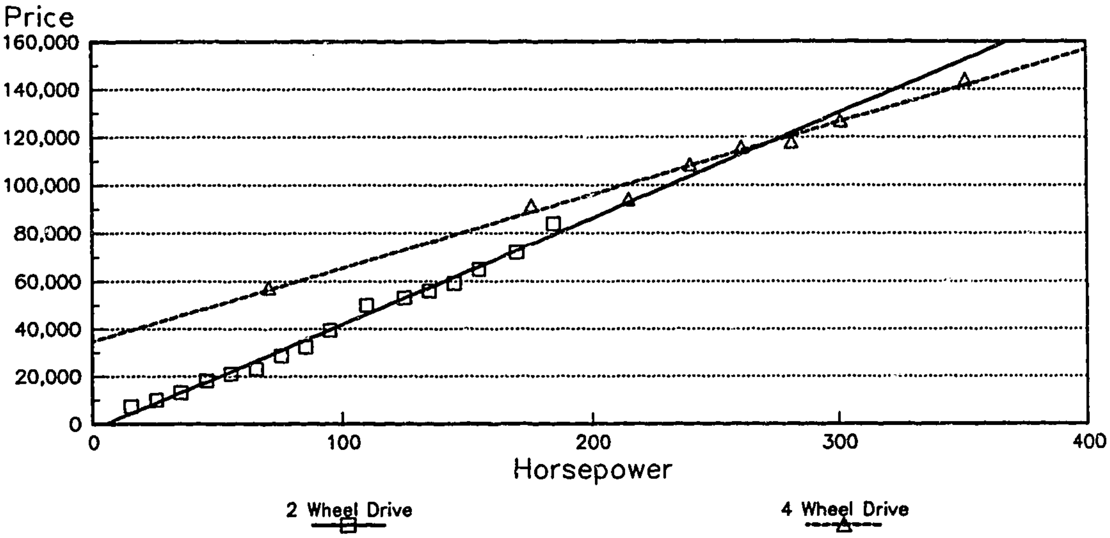

Figure IV.3: Regression Results For Drills & Cultivators

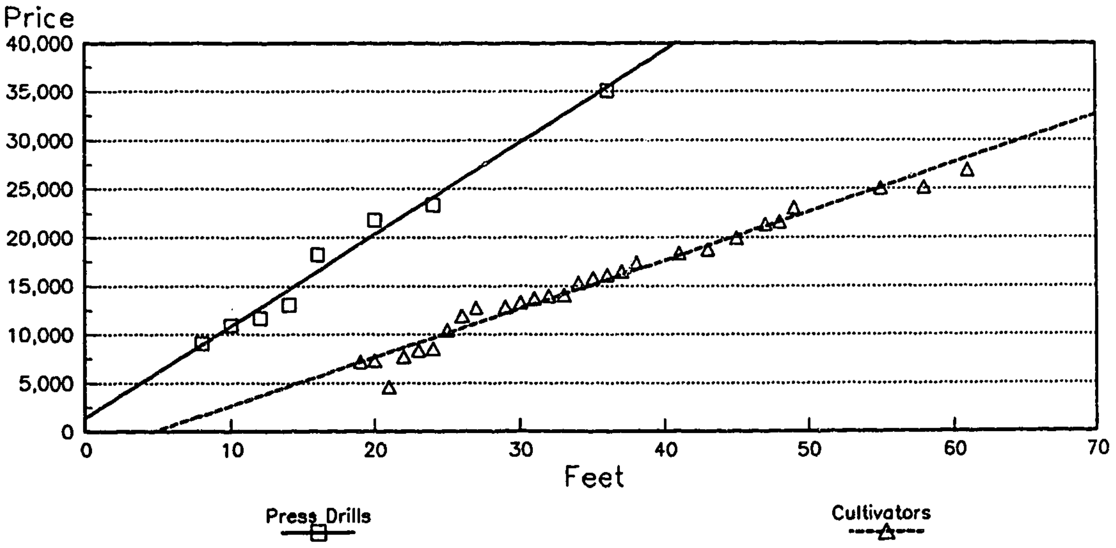

Table IV.3 contains the results from the regressions run for the equipment incorporated in this study.

Table IV.3: Regression Estimates for Machinery Prices[1]

Description	Constant	Slope	t-stat	R^2
Tractor 2WD	-2324.62	440.55	38.20	.9905
Tractor 4WD	34894.70	304.15	21.39	.9871
Combine SP	-21079.80	6778.30	12.86	.9822
Combine P.T.O.	-4628.00	3540.25	4.27	.9480
SP Swather	11762.21	177.05	6.74	.9380
P.T.O. Swather	1789.10	240.60	6.93	.9600
Hoe Drill	754.57	916.95	39.45	.9962
Double Press Drill	1352.76	945.88	18.28	.9824
Hoe Drill W/Trans	95.79	1327.05	151.18	.9998
Air Seeder W/F.Cult	22988.75	502.77	10.22	.9721
Air Seeder W/Chisel[2]	23853.09	626.07	3.20	.7733
Offset Disc Single	-2691.81	947.75	10.96	.9525
Offset Disc Double	3085.06	516.50	20.77	.9840
Tandem Disc Rigid	844.60	372.93	11.33	.9554
Tandem Disc Folding	1032.01	626.03	7.85	.9249
Field Cult	-1847.43	487.87	40.31	.9843
HD Field Cult	-1396.20	520.46	23.79	.9792
Rodweeder W/Multi	-2379.16	369.97	21.16	.9868
Harrows No Autofold	-2003.62	131.49	9.33	.9561
Harrows W/ Autofold	2099.84	76.12	19.26	.9867

[1] Note: All t-statistics significant at the 1% confidence level.

[2] t-statistic significant at the 5% confidence level.

4. Present Value of Repair and Downtime Costs

In this stage the present value of annual repair and downtime costs are calculated. They are calculated for each year up to a maximum of 21 years or the machine's wear-out life, whichever occurs first. For each year repair and downtime costs are estimated and calculated in present value terms. An example follows for illustrative purposes. A tractor in year 2 of the analysis has the following data as would appear in the lookup tables.

Table IV.4: Repair and Annual Use Data for 2WD Tractor

Machine	Size (h.p.)	Price ($)	Annual Use (hrs)	Wearout Life (hrs)	R_1	R_2
Tractor 2WD	120.1	50,588	498	10,000	0.012	2.00

The repair formula has the form:

$$TAR_n = (R_1)\left[\frac{AH \cdot n}{1000}\right]^{R_2} \cdot PP \qquad (IV.6)$$

Where; TAR_n is the Total Accumulated Repair costs at year n
R_1 is the repair coefficient 1[37]
R_2 is the repair coefficient 2
AH is the annual use in hours
n is the year
PP is the purchase price.

Therefore, in our example the repair costs in year two would be:

$$TAR_2 = \left[(0.012)\left[\frac{498 \cdot 2}{1000}\right]^{2.00} - (0.012)\left[\frac{498 \cdot 1}{1000}\right]^{2.00}\right] \cdot \$49{,}900 \qquad (IV.7)$$

$$TAR_2 = \$445.31$$

The repair costs for year 2 are then put into present value terms by standard discounting techniques. The present value of a sum of money received in the future is derived by:

$$PV_0 = \frac{FV_n}{(1+r)^n} \qquad (IV.8)$$

Where; PV_0 is the present value of a lump sum of money to be received in year n
FV_n is the non-discounted lump sum of money received in year n.

In the example then, the present value of the second year repair costs are:

$$PV_0 \ of \ (TAR_2) = \frac{(\$445.31)}{(1+.08)^2} = \$381.78 \qquad (IV.9)$$

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[37] See section III.A.3 for details on their source and derivation.

The estimated costs of downtime also need to be calculated for each year in the 21 year analysis. Recall that the function for estimating downtime hours is:

$$DT_{mn} = \left[a \cdot AMH_{mn} \cdot e^{(b \cdot CMHL_{mn-1})}\right] \cdot DTOC \qquad (IV.10)$$

Where; mn is an observation for machine m in year n

DT_{mn} is the cost of downtime for machine m in year n

AMH_{mn} is the annual machine (m) hours in year n

$CMHL_{mn-1}$ is the cumulative machine hours lagged one year

$DTOC$ is the downtime opportunity cost per hour.

Once again for the tractor example the cost of downtime in year 2 would be:

$$DT_2 = [0.0184 \cdot 498 \cdot e^{(0.0001872 \cdot (498(2-1)))}] \cdot \$0.20/hr \times 121.1\,H.P. \qquad (IV.11)$$

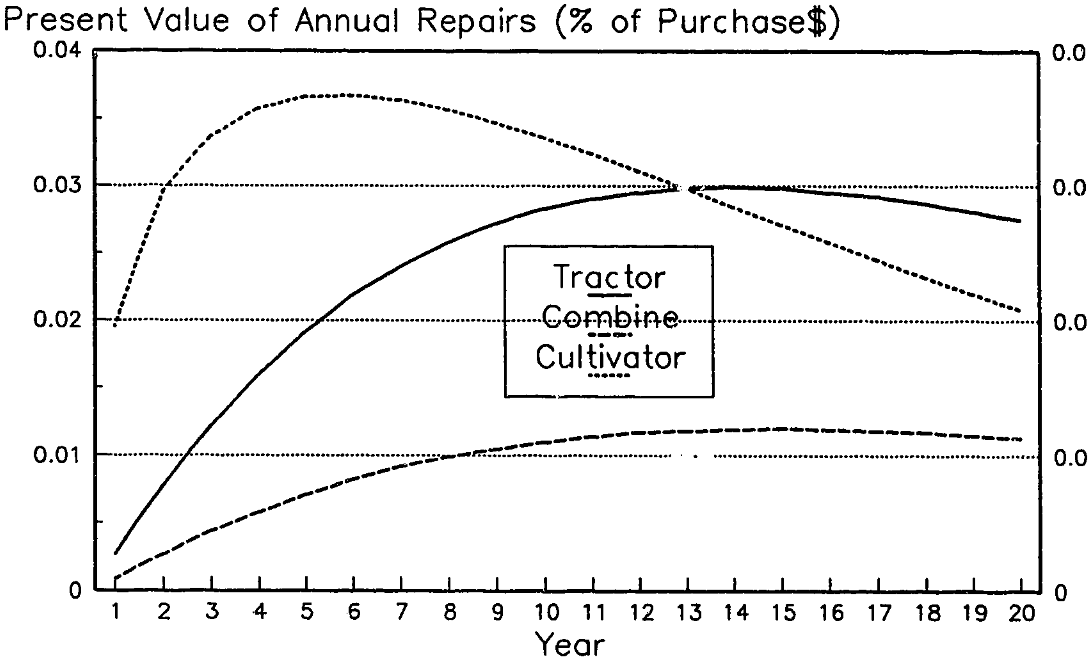
$$DT_2 = \$243.62$$

In present value terms the downtime costs for the tractor in year 2 are:

$$PV_0 \quad of \quad (DT_2) = \frac{(243.62)}{(1+.08)^2} = \$208.86 \qquad (IV.12)$$

This process is carried out for years 1 to 21 or until the machine reaches its wear-out life (whichever occurs first). These results are incorporated with the depreciation costs to determine the optimal replacement cycle. Figure IV.4 shows the **present value** of annual repair costs expressed as a percentage of original purchase cost. Discounting has a significant impact on the form of the repair cost schedule. The non-discounted (nominal) annual repair cost schedule retains a positive slope throughout the machines useful life (recall figure III.2 in section III.3). This is quite different from the discounted annual repair costs shown in figure IV.4.

Figure IV.4: Present Value of Annual Repair Costs



5. Present Value of Capital Costs

The present value of depreciation and opportunity costs are calculated in much the same manner as the repair and downtime costs in section 4. As was the case with repair costs the costs of ownership (depreciation and opportunity costs) are calculated for each of 21 years or until the machine wears out, whichever occurs first. The cost in each year represents the total present value of ownership costs if the machine is kept from new (year=0) to the year being evaluated (year-n). For instance year 2 in this section of the model would represent the present value of ownership costs from year 0 to year 2.[38]

An example using the 2WD tractor (also used in the example with repair and

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[38] This differs slightly from the previous section on repairs and downtime costs. In that section the costs associated with each individual year were calculated. The sum of individual years yields the same results as this section on ownership costs.

downtime costs) will more clearly show how the calculations are made. The lookup table values used in the calculation of ownership costs for the tractor are shown in Table IV.5.

Table IV.5: Depreciation and Annual Use Data for 2WD Tractor

Machine	Size (h.p.)	Price ($)	Annual Use (hrs)	Wearout Life (hrs)	D_1	D_2
Tractor 2WD	120.1	50,588	498	10,000	0.68	0.92

These values are used to estimate depreciation and opportunity costs. Recall that the equation to calculate depreciation costs take the form:

$$NCO_n = \left[-C + \frac{SV_n}{(1+r)^n} \right] \qquad (IV.13)$$

Where: C is the initial capital outlay
SV_n is the salvage value in year n
r is the discount rate.

Also recall that the salvage value is calculated using the form:

$$SV_n = [D_1 \times (D_2)^n \times C] \qquad (IV.14)$$

Where: D_1 adjusts for the first year depreciation
$1 - D_2$ is the annual rate of depreciation.

These equations are used in the calculation of total accumulated ownership costs from year 0 to year n. Once again as an example the 2WD tractor is used. We assume year two of the analysis and use the appropriate data from table IV.5. To simplify we can also combine the previous to equations to obtain:

$$NCO_n = \left[-C + \frac{(D_1 \times (D_2)^n \times C)}{(1+r)^n} \right] \qquad (IV.15)$$

In the example the actual present value of ownership costs incurred through year two would be:

$$NCO_n = \left[-49,900 + \frac{(.68 \times (.92)^2 \times 49,900)}{(1+.08)^2} \right] \left[1 - \frac{.2 \times .3}{.3+.08} \right] \quad (IV.16)$$

$$NCO_n = \$21,286$$

This calculation for the present value of ownership costs is performed for each of the 21 years in the asset replacement model. Data in the lookup table (table IV.5.) which have not yet been used includes annual hours of use and wearout life of the machine. The following section outlines the purpose these factors have in the calculation of ownership costs.

6. Depreciation Rate Recalculation

Previous sections have outlined the methodology for calculating salvage values which are based on the ASAE formulas. The functional form is derived from sales data of farm machinery. The parameters used were sale price and age of machine. No efforts were made to correlate the accumulated hours use with the resale value of the machine. This is a significant drawback of the ASAE approach to estimating salvage values, however, better estimates are not currently available. Therefore, the ASAE approach was adopted.[39]

Note that table IV.5 listed not only the coefficients used for calculating depreciation (D_1 and D_2), but also annual hours of use and machine wearout life. This information is used in conditional statements to determine if a machine reaches its physical wearout life before the end of the models 21 year analysis. Upon physical wearout of a machine it is assumed that the salvage value is ten percent of the initial capital outlay. Since the estimation for depreciation is based on machine age only, it is possible that machines wear out either before or after they reach the ten percent

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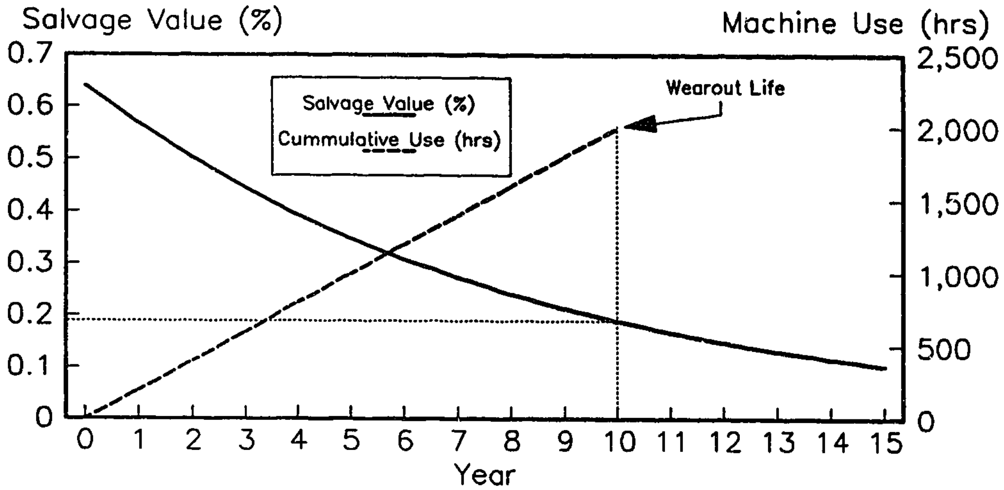
[39] Earlier it was mentioned that Alberta Agriculture and the University of Alberta are currently studying this issue in order that better estimation techniques are available for salvage values.

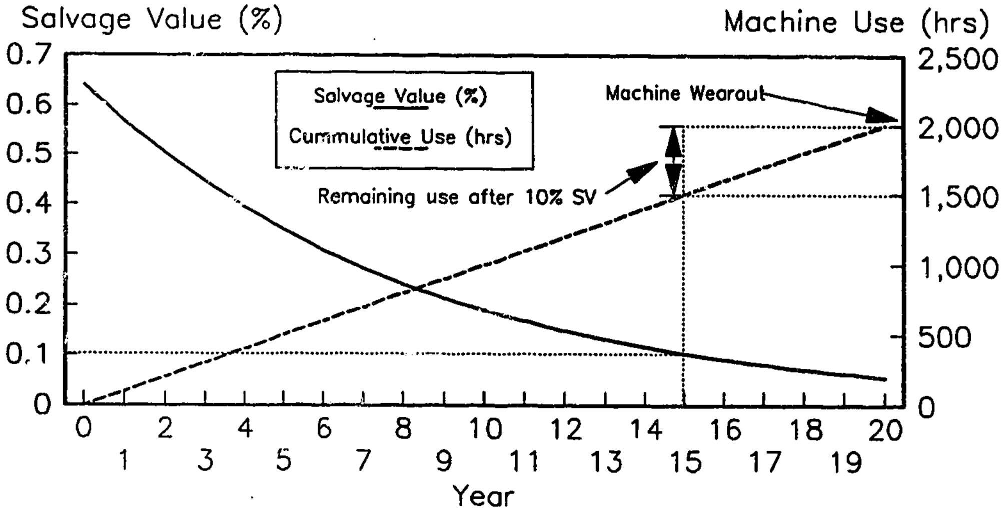
salvage value figure. In these cases an adjustment must be made to the annual rate of depreciation ($1-D_2$) such that the machine reaches a salvage value of ten percent of initial capital outlay upon wearing out. Figure IV.5 and IV.6 show a hypothetical case where a machine reaches its wearout life before and then after its salvage value reaches ten percent.

Figure IV.5: Wearout Life and Salvage Value
Machine Wears Out Before SV=10%



Based on Depreciation Factors For Combines
D1=.64 D2=.885

Figure IV.6: Wearout Life and Salvage Value
Machine Wears Out After SV=10%



Based on Depreciation Factors For Combines
D1=.64 D2=.885

In the event that a machine wears out either before or after its salvage value reaches ten percent the salvage value equations are re-worked and solved for a new D_2 which will depreciate the machine at the appropriate annual rate. In these cases the machine will depreciate to ten percent of its original cost at the point in which it wears out. The functional form of the equations remains unchanged, however, the depreciation rate is either accelerated or decelerated. Following are the steps taken to determine the appropriate depreciation rate.

The salvage value equation can also be expressed in terms of a percentage of capital outlay as:

$$SV(\%)_n = D_1 \times (D_2)^n \qquad (IV.17)$$

Where: $SV(\%)_n$ is the salvage value as a percentage of the original purchase price.

We assume the salvage value at the end of the machines physical life to be ten percent. Therefore, equation (IV.17) is represented as:

$$SV(\%)_n = D_1 \times (D_2)^n = 0.10 \qquad (IV.18)$$

Since D_1 remains unchanged we have an equation with only one unknown, D_2. Solving for D_2:

$$n\,log(D_2) = \log\left(\frac{0.10}{D_1}\right) \qquad (IV.19)$$

$$\log(D_2) = \frac{\log\left(\frac{0.10}{D_1}\right)}{n} \qquad (IV.20)$$

$$D_2 = \frac{\exp\left(\log\left(\frac{0.10}{D_1}\right)\right)}{n} \qquad (IV.21)$$

V

$$D_2 = \frac{10^{\log\left(\frac{0.10}{D_1}\right)}}{n} \qquad (IV.22)$$

Where: D_1 and n are known variables
n is the year in which the machine wears out.

The asset replacement model uses a conditional statement in each year to determine if the machine has reached its physical wearout life or depreciated to less than ten percent of its purchase cost. If either of these conditions are met the factor D_2 is re-calculated so that the machine will have reached ten percent of its original value in the same year in which it wears out.

7. Optimal Replacement Strategy

In previous sections the present value of annual repair and downtime costs and capital costs were determined. These present value annual ownership costs are used in the calculations for optimum replacement cycles. This section outlines the capital investment analysis which was incorporated in the asset replacement model to accomplish this task.

Recall from section III.3 that the annual average capital costs were determined by:

$$AAE_{\substack{capital \\ AfterTax}} = \left[-C + \frac{SV_T}{(1+r)^T} \right] \left[1 - \frac{dt}{d+r} \right] \left[\frac{r}{1 - \frac{1}{(1+r)^T}} \right] \qquad (IV.23)$$

Also recall that the annual average repair and downtime costs were estimated using the following:

$$AAE_{\substack{repairs \\ AfterTax}} = \left[\sum_{n=1}^{T} RDT_n \frac{(1-t)}{(1+r)^n} \right] \left[\frac{r}{1 - \frac{1}{(1+r)^T}} \right] \qquad (IV.24)$$

For each implement (i) in the machinery complement the above capital and repair costs are calculated. The total average annual ownership costs (Equation IV.25) for each implement are calculated for each of the 21 years in the model.

$$AAE_{ownership} = \left\{ \left[-C + \frac{SV_T}{(1+r)^T} \right] \left[1 - \frac{dt}{d+r} \right] + \left[\sum_{n=1}^{T} RDT_n \frac{(1-t)}{(1+r)^n} \right] \right\} \left\{ \frac{r}{1 - \frac{1}{(1+r)^T}} \right\} \qquad (IV.25)$$

These average annual ownership costs are the present value of all future costs based on replacing the machine every "*T*" years to infinity.[40] These costs are calculated for each of the 21 years available in the model. Replacement cycles (represented as "*T*") can be no longer than 21 years. This seems reasonable given the life span of most agricultural machinery. The minimum value in the 21 year string of present values represents the optimum age to replace. This is the point at which average annual costs of ownership have reached a minimum. Conversely if a machine were replaced every year (T=1) the expected average annual costs are extremely high. This follows from earlier discussions on salvage values and repair costs. Farm machinery is depreciated quite heavily after the first year of ownership while repair[41] costs are quite low. If the machine is replaced every year the burden of first year depreciation would be spread only over the one year. Clearly it makes sense to hold the machine while the annual costs are decreasing.

Figure IV.7 shows typical optimal replacement curves for a combine and tractor. The average annual ownership costs decline quickly in the first few years, reach a minimum then begin to increase. As the annual capital costs are declining over time the cost of repairs are increasing. After the point at which average annual costs reach a minimum, the cost of repairs begin to increase at a faster rate than the capital costs are decreasing and therefore total annual costs begin to rise. Before the minimum the opposite was true.

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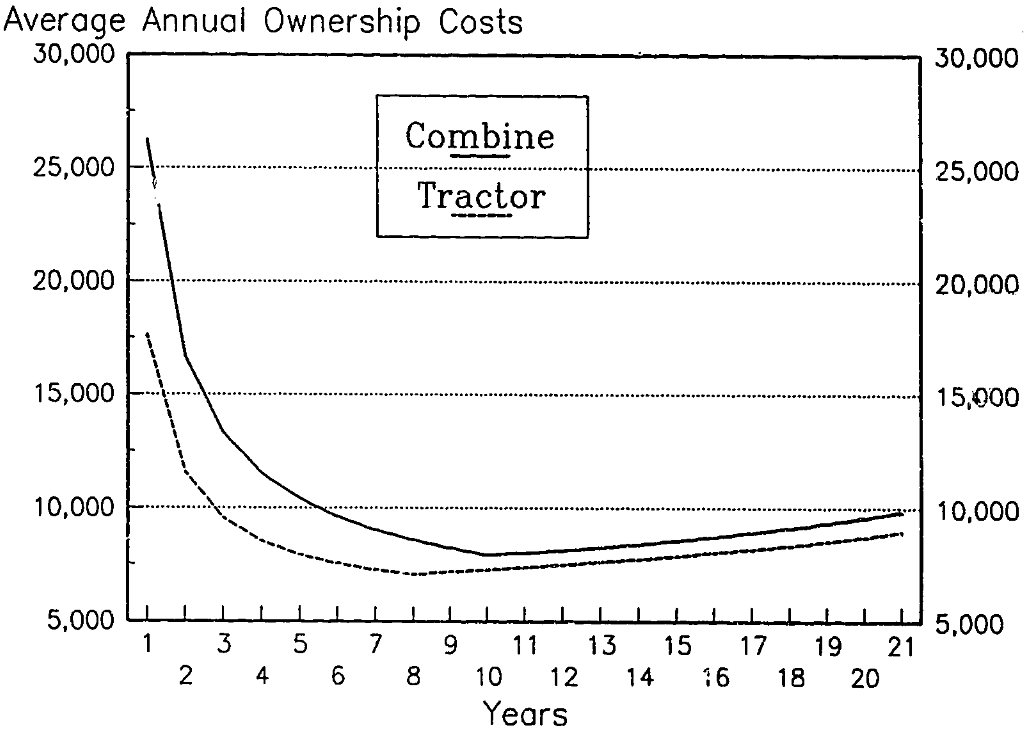
[40] The process for annualizing the total present value of all future replacement cycles was shown in section III.3.

[41] Repair costs include both repairs and cost of downtime.

Figure IV.7: Optimal Replacement of a Combine and Tractor



a). Tolerance Coefficient

In some cases, especially where machines typically have low lifetime repair costs, the optimal replacement curve decreases at a decreasing rate but never actually reaches a minimum. Often low maintenance tillage equipment falls into this situation.

The optimal replacement curve "flattens" out and usually there is a minimal difference in actual costs from one year to the next. For instance, in some cases the difference between two years in total ownership costs have been as small as $150 to $500. Various factors which have not been incorporated into the asset replacement model would likely force the annual costs to a minimum at some point less than 21 years. Some of these factors include technical improvements in machinery, risk of further breakdown, and ease of use. It is likely that incorporation of technical changes in machinery would have more than offset small differences in annual ownership costs experienced with some of the machinery analyzed.

A tolerance coefficient was used to overcome this problem. The method used was to measure the difference in ownership costs between years on a percentage basis. If this percentage difference between two consecutive years was less than the tolerance coefficient, the annual ownership costs were assumed to have reached a minimum. This tolerance level is 4 percent and was chosen arbitrarily. Choosing a replacement cycle with the 4 percent rule resulted in replacement strategies for tillage equipment similar to those experienced on Alberta farms.[42]

C. Fixed Cost Compensation

This section deals with the determination of compensation payments for fixed costs. The equipment has been sized for various farm sizes both before and after partial takings and annual ownership costs have been derived. These data are used to develop the compensation payments necessary for various sizes of partial takings.

The basic premise of the compensation payment is to calculate the difference between the total annual ownership costs before and after the taking. Compensation payments will vary depending on whether some or all of the machinery can be resized. Cases where re-sizing was possible are discussed followed by the method used for calculating compensation payments when re-sizing was not possible.

1. Compensation When Machines are Re-Sized

In previous compensation payments no consideration was given to the possibility of re-sizing equipment. Where the size of the taking is large enough say 80 to 160 acres no further compensation is necessary since the landowner can purchase an

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[42] The crop case study (Alberta Agriculture) was used as a guide to help determine an appropriate tolerance level.

equivalent amount of land on the open market. His/her asset base has remained unchanged under such a scenario. Where the taking is smaller and no equivalent blocks of land are available on the market the issue of fixed cost compensation arises. However, if some or all of the equipment can be re-sized the landowner would once again be economically efficient with the bundle of capital assets and compensation should be based only on the length of the old machine's replacement cycle. The asset replacement model calculates the compensation payment for equipment which can be re-sized using the principals just described.

The replacement cycle of the initial machinery complement may well be altered as a result of the partial taking. Since the structure of capital and repair costs has changed with the smaller land base these changes in costs are also calculated. The net change in the cost structure for non-land fixed costs are measured and used for the compensation payment. The loss then is the difference in annual ownership costs (before and after the taking) calculated for the duration of one replacement cycle of each machine. Ownership costs have been calculated as annualized net present values and therefore represent an annuity. In order to calculate the compensation payment the present value of an annuity will be calculated. This annuity is the difference between the annualized net present value of the fixed costs before and after the partial taking. The present value of an annuity can be expressed as:[43]

$$PV_{annuity} = PMT\left(\frac{(1-(1+r)^{-n})}{r}\right) \qquad (IV.26)$$

Where: $PV_{annuity}$ is the present value of an annuity
PMT is the annual annuity or payment
$PMT\left(\frac{1}{1+r}\right)^{n}$ recall that this is the single period present value formula used earlier in the capital investment analysis
n is the year.

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[43] See Brigham and Gapenski, "*Intermediate Financial Management*", 1985, for more details.

The fixed cost compensation is then derived using the annuity factor defined above multiplied by the difference in annual ownership costs as a result of the partial taking.

$$FCC_{re-sized_m} = \Delta AOC_m \cdot PMT\frac{(1-(1+r)^{-T_m})}{r}) \qquad (IV.27)$$

The compensation for the farm is then the summation of the compensation for all machines which were re-sized to the new smaller farm size as a result of the partial taking.

$$FCC_{re-sized} = \sum_{m=1}^{M}\left[\Delta AOC_m \cdot PMT\frac{(1-(1+r)^{-T_m})}{r}\right] \qquad (IV.28)$$

Where: $\sum_{m=1}^{M}$ is the summation of all machines from m=1 to M.

2. Compensation When Machines Cannot be Re-Sized

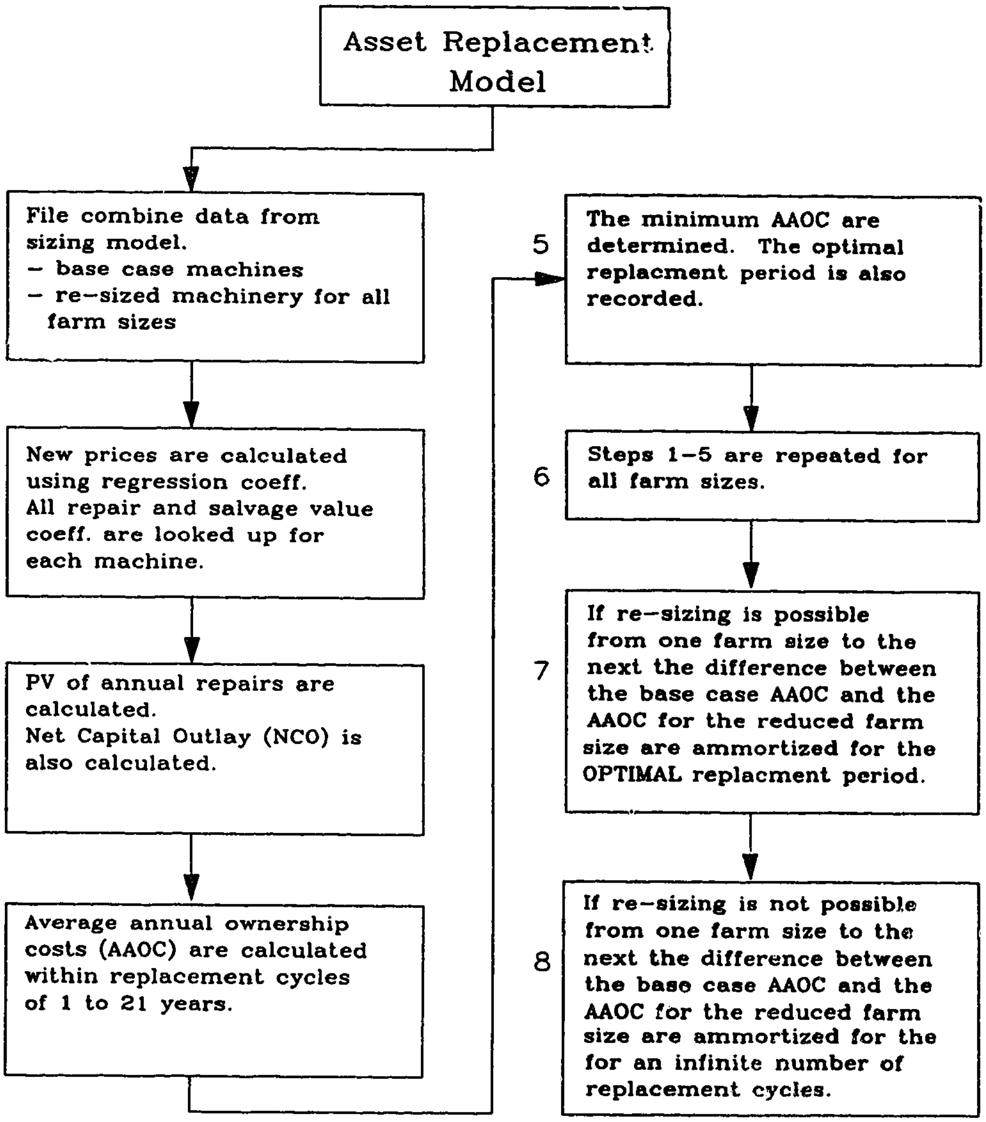
Farm size, the size of the taking and the type of machine will influence whether a machine can be re-sized. In cases where a machine cannot be re-sized the landowner will have incurred a permanent loss in efficiency. Since he/she will not be as well off after the taking as before, compensation is necessary. These compensation payments are based on the appraisers approach to estimating land value. The loss has been incurred permanently and thus can be expressed in present value terms by:

$$FCC_{nore-sizing_m} = \frac{\Delta AOC_m}{r} \qquad (IV.29)$$

Where: $FCC_{nore-sizing_m}$ is the fixed cost compensation for machine m which cannot be re-sized
ΔAOC_m is the change in annual ownership costs (AOC) for machine m.

Figure IV.8 is a basic flowchart of the Asset Replacement Model.

Figure IV.8: Flowchart Of The Asset Replacement Model



V. Results

The purpose of this study was to determine the effects partial takings of farmland have on non-land fixed costs. Results shown in this section outline specifically what these additional costs are. Tables have been organized by region and farm size. Within each table are the appropriate compensation payments for various sizes of partial takings and four typical farm sizes (640, 960, 1280, and 1600 acres). Determination of an appropriate compensation payment is done by looking up the farm size and the size of the partial taking within the correct region. The corresponding value is the compensation payment on a per acre basis[44] which is required to leave the landowner as well off after the taking as he/she was before the taking.[45] Tables V.1 to V.4 show the compensation payments for the Edmonton, Peace River, Airdrie, and Oyen.

A. Compensation Payments by Farm Size and Region

The results from running the sizing and asset replacement model are in tables V.1 to V.4. Three farm sizes were run for each region. A total of 20[46] iterations on each of the farms were used to estimate compensation payments for various sizes of partial takings. Payments appear to be linearly related to the size of takings which ranged from 1 to 19 acres. Earlier simulations (not included here) using 5 acre increments showed significant changes where the partial taking was quite large, say 50 to 75 acres. The optimal replacement period does not vary with takings less than 50 acres. As a result the compensation payments on a per acre basis are fairly uniform.

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[44] The compensation payments are represented by dollars per acre taken. In other words if the partial taking was 5 acres with a compensation payment of $200 per acre, the total payment to the landowner is $1000.

[45] These compensation payments are for fixed costs, the market value of land is assumed to have already been compensated for.

[46] The first iteration is the base case scenario (ie: no change in farm size) a further 19 iterations were run to compare to the base case.

Payments differ between regions since machinery use, cultural practices, machine drafts, and available working hours all vary significantly around the province. These relationships have important consequences for the final compensation payment.

Table V.1: Compensation Payments (Edmonton Region)

	Initial Farm Size		
Size of Taking	640 Acres	960 Acres	1280 Acres
	Compensation Payments ($/acre)		
1	385.52	316.06	284.94
2	385.59	316.11	284.98
3	385.65	316.15	285.02
4	385.72	316.20	285.06
5	385.78	316.25	285.10
6	380.40	311.42	280.55
7	380.46	311.46	280.58
8	380.53	311.51	280.62
9	365.63	311.56	280.66
10	367.19	311.60	280.70
11	368.48	311.65	280.74
12	345.43	287.79	256.99
13	346.35	272.98	257.02
14	347.15	274.09	257.06
15	347.85	275.05	257.10
16	348.48	275.90	257.13
17	349.03	276.65	242.38
18	324.73	277.33	243.24
19	326.49	277.94	244.01

Table V.2: Compensation Payments (Peace River Region)

	Initial Farm Size		
Size of Taking	640 Acres	960 Acres	1280 Acres
	Compensation Payments ($/acre)		
1	411.98	336.44	302.12
2	412.04	336.48	302.15
3	412.09	336.52	302.18
4	412.14	336.56	302.22
5	412.20	336.60	302.25
6	412.25	336.64	302.28
7	407.31	332.26	298.18
8	397.84	332.30	298.21
9	398.95	332.34	298.24
10	399.85	332.38	298.27
11	400.59	321.31	298.31
12	401.23	268.54	298.34
13	379.29	251.25	276.24
14	373.88	255.50	276.27
15	374.69	259.19	265.09
16	367.54	254.04	257.17
17	368.18	256.90	257.82
18	368.74	259.44	258.40
19	369.26	261.72	258.92

Table V.3: Compensation Payments (Airdrie Region)

	Initial Farm Size		
Size of Taking	960 Acres	1280 Acres	1600 Acres
	Compensation Payments ($/acre)		
1	261.38	240.49	220.69
2	261.41	240.52	220.71
3	261.44	240.54	220.73
4	261.47	240.57	220.75
5	261.50	240.59	220.77
6	261.53	240.62	220.79
7	174.79	240.64	220.81
8	185.66	240.67	220.84
9	190.60	237.45	217.78
10	197.38	237.47	217.80
11	202.93	237.50	217.82
12	207.56	237.52	217.84
13	211.49	237.55	217.86
14	214.85	237.57	217.89
15	212.32	237.59	217.91
16	215.22	237.62	217.93
17	217.79	237.64	217.95
18	202.92	220.65	201.03
19	204.96	220.67	201.05

Table V.4: Compensation Payments (Oyen Region)

Size of Taking	Initial Farm Size 960 Acres	 1280 Acres	 1600 Acres
	Compensation Payments ($/acre)		
1	237.21	216.38	194.42
2	237.23	216.39	194.43
3	237.25	216.41	194.44
4	237.26	216.42	194.46
5	237.28	216.44	194.47
6	237.30	216.45	194.48
7	237.32	216.47	194.50
8	237.34	216.48	194.51
9	237.35	216.50	194.52
10	237.37	216.51	194.53
11	234.37	213.79	191.98
12	234.39	213.81	191.99
13	234.41	213.82	192.01
14	234.43	213.84	192.02
15	234.44	213.85	192.03
16	234.46	213.86	192.04
17	234.48	213.88	192.06
18	234.50	213.89	192.07
19	234.52	213.91	192.08

Notice that the relative compensation amounts on a per acre basis increase from the lighter soils in the Oyen and Airdrie regions to the heavier soils in the Peace region. This is mainly due to the increased draft requirements on heavier soils in the more northern areas of the province which causes higher power requirements per unit width of machinery. Also, the number of field operations required during the critical seeding window will have an affect on machine sizing. An increased number of field operations will require relatively larger equipment, this is the case in Peace River and Edmonton regions as compared to southern Alberta.

Although the results show a linear trend as the size of taking increases they are sensitive to a number of factors. Already mentioned were machine draft and cultural practices, others include available time for seeding, types of machines required, repair and depreciation schedules and discount rate.

The amount of time available for seeding has a significant affect on the size of equipment required. It follows that as the amount of time available to complete a given task decreases the size of machine required increases. This translates into higher purchase prices (recall that purchase price is linearly related to size). Higher purchase prices result in higher compensation payments on a per acre basis.

Repair and depreciation schedules also have an affect on the compensation payments. The compensation payment is based on the net present value of the change in fixed costs as a result of the taking. The absolute level and change in fixed costs is directly affected by the repair and depreciation schedules. For example if the repair and depreciation schedules changed such that the minimum average annual ownership costs were shifted this would also shift the relative compensation levels.

The discount rate is clearly a dominant factor in determining compensation payments. It has impact in the capital investment analysis (section III.C) and on computation of the final compensation payment. In cases where re-sizing is not possible the change in fixed costs as a result of the partial taking are divided by the discount rate to derive the present value of all future losses. Clearly in this case a change in the discount rate has a proportional impact on the compensation payment.

VI. Summary, Conclusions and Limitations

The models developed in this study are no different than most other models which are designed to predict some real world situation. Mathematics and other physical relationships allow us to build models which can provide reasonable estimates of complex situations and alternatives. The study of many different real life situations is often not practical or even possible. Modelling provides a tool which can be used to study or predict many different alternatives in a relatively short period of time. Also, it is often required that the issue be reviewed periodically, modelling allows us that convenience. Most of the problems which arise from the use of models is a result of inappropriate application of the model itself. Models must be used within the boundaries of the input data. Assumptions were made in developing the models in this study, careful attention was given to ensure that these assumptions were reasonable and did not affect the credibility of the models.

This study employed two main models, a machine sizing model and an asset replacement model. Various types of input data were required for these models ranging from drafts of tillage equipment to a discount rate. All the assumptions and physical/economic coefficients used in the models affect the results and the quality of those results. The next few paragraphs deal with some of the limitations of the data, and limitations of the models.

The machinery sizing model was developed using widely accepted engineering practices. However, it was beyond the scope of this paper to determine optimum harvest systems and the sizing of a two tractor tillage system. These components would be useful additions to the sizing model at a future date. Only the primary tractor was evaluated for re-sizing opportunities, the secondary tractor and a harvest system were incorporated in the models, they were not however, tested for re-sizing possibilities.

Another drawback of the sizing model is that it is developed as an engineering optimum and not a least cost complement. Others have developed such approaches (Brown and Schoney, 1985), however, the critical timeliness costs which are required for these models were not available for Alberta. As better data become available on the costs of timeliness it would be a definite asset to the models presented in this study.[47] This study will have erred by overcompensating rather than undercompensating as a result of the omission of a least cost approach.

The assumption that the farm begins, and replaces with only new equipment will also generate compensation payments which reflect an upper bound. Compensation payments would likely decrease with the use of a mixed line of equipment (new and used).

The tables in the results section are, by design, general in nature. They apply to large regions and assume homogeneous farming practices throughout the region. It was felt that the possible error of such generalities were small. That is not to say that more region specific farm models should not be developed. Once the concepts and methods of this study are accepted additional farm models may be required. On-farm survey work carried out by Alberta Agriculture could prove useful for such extensions.

A. Recommendations For Future Work

The previous section outlined some limitations of the models developed for machinery sizing and replacement. This section will briefly discuss current research work and future research work which would assist in alleviating some of these limita-

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[47] The inclusion of timeliness costs essentially allows a trade-off between smaller less expensive machinery and higher losses in revenue due to untimely field operations. Losses in revenue result from lower yields and/or grades due to late seeding, late harvesting, or a combination of the two.

tions.

Downtime costs in this study were calculated using equations based on data from California (annual downtime hours) and applying Alberta farm machinery custom costs to these annual downtime hours. It would be useful to have information on the most likely method farmers use to mitigate downtime costs. For instance, during the period of time a particular machine is down a farmer may rent the required machinery, custom hire the job out, simply delay the field operation, or some combination of the above depending on the machine, time of year, workload, and time required for repairs. Information in this regard would go a long way in not only defining downtime costs more accurately but also determining the penalties to revenue as a result of such decisions. Some studies (Brown and Schoney, 1985) assume that all downtime costs are reflected in yield/grade reductions. However, this is likely an oversimplification. Further research in this area is required.

A two tractor tillage system with *both* tractors being sized to match field requirements would be an improvement to the sizing model in this study. A closer look at the possibility of re-sizing harvest equipment would be prove useful for the purposes of determining compensation payments.

The asset replacement model depends heavily on the estimation of repair, downtime and capital costs. The need for improved downtime costs has been discussed. Repair and capital cost estimation also could use improvement. The repair data are based on a Mid-West U.S. survey in the early 1970's. Clearly farming practices have changed along with machine technology over the past 20 years. Repair cost functions have also likely changed with the advent of high-tech machinery (monitoring devices, instrumentation, computerization etc.). The capital costs were derived using ASAE functions based on similar data as the repair cost functions. They also have limitations. Perhaps the biggest drawback of the depreciation formulas is that they are based only on machine age with no emphasis on machine use. It is unlikely that two machines of the same age but dissimilar hours of use would sell for the same price. To resolve these issues Alberta Agriculture[48] has begun collecting on farm data for both repair costs and current market value of farm machinery. Over 200 hundred farms are surveyed annually for the crop case study. This data over several years should prove extremely useful in defining repair and depreciation cost functions for farm machinery operated on Alberta farms.

Researchers at the University of Alberta[49] are also working on establishing improved data on salvage values (resale value) of farm machinery in Alberta. Their objective is to establish a computerized database of machinery sales in Alberta.

As the research on repair and depreciation costs are completed it is recommended that the models in this study be updated.

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[48] The Production Economics Branch of Alberta Agriculture is located in Edmonton, Alberta, and annually carries out survey work on Alberta farms

[49] The Department of Rural Economy and Faculty of Business are working on a study to determine salvage values of farm machinery in Alberta.

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APPENDIX A. Real Annualized Rates of Return[50]

Yr/Qrt	TSE300 %	T-Bill %	Power[51] Mach. %	Non-Power[52] Mach. %	Mach.[53] Repairs %	R_p-R_f[54] %	R_m-R_f[55] %
6101	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6102	36.22	3.09	0.00	1.22	n/a	-3.09	33.13
6103	9.77	2.50	4.64	2.44	n/a	2.14	7.27
6104	25.57	0.03	-2.49	-2.49	n/a	-2.53	25.54
6201	-5.28	3.09	7.73	7.40	n/a	4.64	-8.38
6202	-49.52	1.07	3.41	1.02	n/a	2.34	-50.59
6203	1.82	3.91	7.66	3.46	n/a	3.75	-2.10
6204	46.15	1.55	-2.45	-2.45	n/a	-4.00	44.60
6301	22.80	3.71	7.31	5.91	n/a	3.60	19.09
6302	11.22	0.86	0.32	-0.20	n/a	-0.54	10.36
6303	4.58	1.05	0.31	-1.31	n/a	-0.73	3.53
6304	14.18	1.14	-2.41	-2.41	n/a	-3.55	13.03
6401	26.85	2.56	13.14	8.03	n/a	10.58	24.29
6402	32.82	2.41	0.12	-0.11	n/a	-2.29	30.41
6403	27.90	2.49	1.45	-1.20	n/a	-1.04	25.41
6404	4.00	0.09	-3.53	-3.53	n/a	-3.63	3.91
6501	19.52	2.51	8.27	5.51	n/a	5.76	17.01
6502	-19.56	-2.14	-3.28	-3.68	n/a	-1.14	-17.42
6503	16.27	4.06	2.59	1.08	n/a	-1.47	12.20
6504	1.98	-0.50	-4.56	-4.56	n/a	-4.06	2.48
6601	-0.59	0.00	6.92	5.08	n/a	6.92	-0.59
6602	-11.01	1.55	4.02	-0.29	n/a	2.47	-12.55
6603	-36.12	1.55	-2.16	-2.33	n/a	-3.71	-37.67
6604	17.08	2.79	-2.22	-2.22	n/a	-5.02	14.29
6701	54.44	2.26	6.36	6.18	n/a	4.10	52.18
6702	-0.11	-2.53	-3.04	-4.50	n/a	-0.50	2.42
6703	15.34	-0.09	-4.27	-3.29	n/a	-4.18	15.43
6704	-9.14	1.91	-3.19	-3.19	n/a	-5.10	-11.05
6801	-31.04	3.10	6.28	5.95	n/a	3.18	-34.14
6802	62.87	2.43	-3.05	-2.25	n/a	-5.48	60.43
6803	28.38	1.54	-4.11	-4.11	n/a	-5.65	26.84
6804	30.90	1.44	-4.07	-4.07	n/a	-5.51	29.47

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[50] All rates of return are annualized and expressed on a quarterly basis.

[51] Statistics Canada price index for powered farm machinery in Western Canada.

[52] Statistics Canada price index for non-powered farm machinery in Western Canada.

[53] Statistics Canada price index for machinery repair costs for Canada.

[54] Rate of return from the project R_p (powered machinery index) minus the rate of return from risk free investment R_f (Treasury bills).

[55] Rate of return from the market R_m (TSE 300 index index) minus the rate of return from risk free investment R_f (Treasury bills).

Yr/Qrt	TSE300 %	T-Bill %	Power Mach. %	Non-Power Mach. %	Mach. Repairs %	R_p-R_f %	R_m-R_f %
6901	3.36	3.19	8.56	4.81	n/a	5.37	0.16
6902	-25.03	-1.52	-5.73	-6.01	n/a	-4.21	-23.51
6903	-5.98	4.44	-1.88	-2.96	n/a	-6.31	-10.42
6904	10.58	3.53	-3.89	-3.89	n/a	-7.42	7.05
7001	-4.80	4.48	3.69	5.75	n/a	-0.79	-9.27
7002	-55.21	3.33	-0.76	-1.97	n/a	-4.09	-58.54
7003	60.40	4.61	-0.97	-0.04	n/a	-5.58	55.80
7004	22.76	5.85	4.29	5.78	n/a	-1.56	16.91
7101	22.92	0.18	-0.67	-1.11	n/a	-0.84	22.75
7102	-7.64	-2.67	-3.56	-3.84	-1.76	-0.89	-4.98
7103	-10.79	-0.99	-3.60	-3.74	-2.71	-2.61	-9.80
7104	10.58	-1.27	-4.56	-4.56	-1.72	-3.29	11.85
7201	42.89	-0.33	2.62	4.52	6.12	2.95	43.21
7202	6.09	0.83	0.36	1.70	2.00	-0.47	5.27
7203	15.57	-6.27	-8.51	-7.84	-5.99	-2.24	21.84
7204	20.21	0.00	-1.49	-1.78	-0.76	-1.49	20.21
7301	-0.49	-3.03	-1.90	0.80	0.34	1.13	2.55
7302	-31.34	-5.99	-6.86	-7.42	-5.55	-0.87	-25.35
7303	28.38	-4.85	-8.45	-7.94	-5.33	-3.60	33.22
7304	-20.93	-0.27	2.37	-0.64	1.38	2.63	-20.67
7401	0.74	-4.99	4.21	6.15	5.13	9.20	5.73
7402	-55.50	-6.71	-6.12	-1.30	-2.32	0.59	-48.78
7403	-50.38	-0.36	5.58	9.56	7.93	5.94	-50.02
7404	-11.17	-4.01	18.92	8.08	4.37	22.93	-7.16
7501	87.75	-0.90	25.84	7.64	10.13	26.74	88.65
7502	19.80	-4.47	-5.67	-6.23	-4.66	-1.21	24.27
7503	-29.58	-2.64	-7.62	-4.11	0.92	-4.98	-26.94
7504	-11.40	0.15	4.68	-3.31	0.16	4.54	-11.55
7601	45.92	3.24	4.19	3.89	2.10	0.95	42.67
7602	-2.28	1.53	-5.50	-1.36	-1.82	-7.03	-3.81
7603	-10.03	3.65	-6.94	-2.52	-1.18	-10.59	-13.68
7604	-7.12	2.84	12.48	2.45	2.04	9.64	-9.97
7701	-2.35	-3.45	-2.24	0.46	-1.04	1.21	1.10
7702	-0.25	-1.31	-4.92	-4.69	-3.41	-3.61	1.06
7703	-13.53	-0.72	-2.33	-2.87	-3.32	-1.61	-12.80
7704	19.39	-2.19	3.72	2.93	0.34	5.91	21.58
7801	-2.28	-1.32	11.95	1.66	2.05	13.27	-0.96
7802	18.15	-1.98	-4.39	-7.38	-5.17	-2.42	20.12
7803	64.40	3.05	1.10	-1.01	-0.32	-1.95	61.35
7804	3.11	1.16	11.51	9.49	5.99	10.35	1.95
7901	43.69	-1.56	5.14	4.54	4.09	6.70	45.24
7902	40.06	1.76	-0.11	-5.87	-2.84	-1.87	38.29
7903	30.60	2.84	0.90	0.96	1.73	-1.94	27.75
7904	8.50	3.45	14.63	11.82	9.30	11.18	5.05

Yr/Qrt	TSE300 %	T-Bill %	Power Mach. %	Non-Power Mach. %	Mach. Repairs %	R_p-R_f %	R_m-R_f %
8001	-9.01	3.11	5.89	5.18	8.16	2.77	-12.12
8002	57.81	0.87	-6.18	-5.97	1.13	-7.06	56.94
8003	33.69	-0.43	-1.19	-5.72	-6.92	-0.76	34.12
8004	-5.69	1.90	1.05	-0.16	-0.46	-0.85	-7.59
8101	0.17	1.20	1.04	-7.33	-6.86	-0.16	-1.03
8102	-4.66	3.71	-0.26	-3.90	1.84	-3.97	-8.37
8103	-59.12	9.51	-0.68	-0.66	-0.30	-10.19	-68.63
8104	9.79	5.99	4.86	4.89	5.23	-1.13	3.80
8201	-56.82	1.24	-4.00	-1.43	-4.38	-5.23	-58.06
8202	-45.91	2.68	-5.57	-1.36	0.85	-8.25	-48.59
8203	82.55	7.72	-23.00	-15.74	-13.82	-30.73	74.83
8204	115.73	5.14	1.28	1.78	1.35	-3.86	110.59
8301	43.60	4.19	18.18	10.43	5.73	13.99	39.42
8302	60.16	3.36	-4.65	-5.34	-0.20	-8.02	56.79
8303	8.00	5.28	-6.76	-2.98	-3.32	-12.04	2.71
8304	7.94	5.44	-3.63	-2.26	-1.59	-9.07	2.50
8401	-24.78	4.22	3.76	5.97	2.65	-0.46	-29.00
8402	-23.23	7.59	-2.89	-1.57	-0.90	-10.48	-30.83
8403	34.90	9.47	-2.58	0.45	0.10	-12.05	25.42
8404	1.33	7.08	-6.55	-3.82	-1.53	-13.63	-5.75
8501	36.66	4.88	-14.50	-8.80	-7.21	-19.38	31.78
8502	13.96	4.53	0.38	0.70	0.96	-4.15	9.43
8503	-10.31	6.34	-6.66	-9.52	-5.05	-13.01	-16.65
8504	43.79	3.84	0.82	-1.56	-3.91	-3.02	39.95
8601	19.68	6.03	0.75	8.47	3.71	-5.28	13.65
8602	4.79	5.46	-5.75	-1.38	1.20	-11.20	-0.66
8603	-13.75	3.83	-5.51	-0.29	-1.94	-9.35	-17.58
8604	9.81	3.22	-3.62	-6.21	-3.73	-6.84	6.59
8701	114.14	2.73	-2.59	-3.07	-4.63	-5.32	111.41
8702	-2.68	2.44	-5.79	-19.40	-7.53	-8.23	-5.12
8703	17.07	5.49	-9.25	11.48	3.97	-14.74	11.58
8704	-55.40	4.85	-8.57	-8.35	-4.29	-13.42	-60.26
8801	18.89	3.88	-3.45	-0.60	-1.06	-7.33	15.01
8802	14.21	4.17	-2.96	-4.07	-0.38	-7.13	10.04
8803	-17.14	5.49	-4.16	-3.81	-1.68	-9.65	-22.64
8804	13.44	7.29	-1.17	4.25	3.53	-8.46	6.15

APPENDIX B. Field Coefficients Used in the Sizing Model

Table B1: Field Coefficients Sizing Model (Light Soils)[56]

Description	Field Eff.(%)	Draft (KN/m)	Speed (Km/hr)	Tractive Eff.(%)
Combine	75	n/a	5.0	n/a
Swather	80	n/a	9.0	n/a
Plow	80	4.9	7.0	70
Heavy Duty Cultivator	80	2.6	8.0	58
Field Cultivator	80	1.9	8.0	58
Rodweeder	80	1.4	8.0	58
Hoe Drill	75	1.5	8.0	58
Double Disc Drill	75	1.1	8.0	58
Air Seeders	75	3.9	6.5	58
Tandem Disc	80	3.4	7.0	58
Offset Disc	80	4.4	7.0	58
Harrows	80	0.8	8.0	58

SOURCE:- ASAE Standards and ASAE Transactions (various years),
- Prairie Agricultural Machinery Institute (PAMI, various years)
- Lorne Turner, Program Planning for a Machinery Sizing and Cost of Ownership Workshop.
- Consultations with Wayne Anderson, Associate Professor, University of Alberta, Department of Agricultural Engineering.

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[56] "Light" soils included the brown and dark brown soil zones.

Table B2: Field Coefficients Sizing Model (Medium Soils)[57]

Description	Field Eff.(%)	Draft (KN/m)	Speed (Km/hr)	Tractive Eff.(%)
Combine	75	n/a	5.0	n/a
Swather	80	n/a	9.0	n/a
Plow	80	5.5	7.0	70
Heavy Duty Cultivator	80	3.5	8.0	63
Field Cultivator	80	2.5	8.0	63
Rodweeder	80	1.8	8.0	63
Hoe Drill	75	2.0	8.0	63
Double Disc Drill	75	1.5	8.0	63
Air Seeders	75	5.3	6.5	63
Tandem Disc	80	4.5	7.0	63
Offset Disc	80	5.8	7.0	63
Harrows	80	1.0	8.0	63

SOURCE:- ASAE Standards and ASAE Transactions (various years),
- Prairie Agricultural Machinery Institute (PAMI, various years)
- Lorne Turner, Program Planning for a Machinery Sizing and Cost of Ownership Workshop.
- Consultations with Wayne Anderson, Associate Professor, University of Alberta, Department of Agricultural Engineering.

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[57] "Medium" soils are the thin black soil zones.

Table B3: Field Coefficients Sizing Model (Heavy Soils)[58]

Description	Field Eff.(%)	Draft (KN/m)	Speed (Km/hr)	Tractive Eff.(%)
Combine	75	n/a	5.0	n/a
Swather	80	n/a	9.0	n/a
Plow	80	6.4	7.0	70
Heavy Duty Cultivator	80	4.4	8.0	58
Field Cultivator	80	3.1	8.0	58
Rodweeder	80	2.3	8.0	58
Hoe Drill	75	2.5	8.0	58
Double Disc Drill	75	1.9	8.0	58
Air Seeders	75	6.6	6.5	58
Tandem Disc	80	5.6	7.0	58
Offset Disc	80	7.3	7.0	58
Harrows	80	1.3	8.0	58

SOURCE:- ASAE Standards and ASAE Transactions (various years),
- Prairie Agricultural Machinery Institute (PAMI, various years)
- Lorne Turner, Program Planning for a Machinery Sizing and Cost of Ownership Workshop.
- Consultations with Wayne Anderson, Associate Professor, University of Alberta, Department of Agricultural Engineering.

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[58] "Heavy" soils include the black and grey wooded soil zones.

APPENDIX C. Field Operations by Region

Table C1: Field Operations For Peace River[1]

MACHINERY	Seeding[2] ST	Seeding[2] SF	Other[3] ST	Other[3] SF	Fallow[4]	Seeding Total	Other[5] Total
COMBINE SP	0	0	1	1	0.0	0.0	0.8
FIELD CULT	1	1	0	0	2.0	0.8	0.4
FIELD SPRAYER	0	0	2	1	0.0	0.0	1.4
HARROWS	2	2	0	0	0.0	1.6	0.0
HD FIELD CULT	1	1	1	0	1.0	0.8	0.8
HOE DRILL	1	1	0	0	0.0	0.8	0.0
P.T.O. SWATHER	0	0	1	1	0.0	0.0	0.8
TANDEM DISC	1	1	1	1	0.0	0.8	0.8

[1] A 20% summerfallow rotation was assumed for Peace River.

[2] Represents the number of operations required during the critical seeding period on stubble (ST) and fallow (SF) seeded crops.

[3] Represents the number of operations required for proper seedbed preparation but occur outside the seeding window.

[4] Represents the number of operations carried out on summerfallow fields.

[5] The total of non-critical time operations for each machine.

Table C2: Field Operations For Edmonton Region[1]

MACHINERY	Seeding ST	Seeding SF	Other ST	Other SF	Fallow	Seed Total	Other Total
COMBINE SP	0	0	1	1	0.0	0.0	0.9
FIELD SPRAYER	0	0	2	1	0.0	0.0	1.7
HARROWS	1	1	0	0	0.0	0.9	0.0
HD FIELD CULT	2	1	1	1	2.0	1.7	1.1
HOE DRILL	1	1	0	0	0.0	0.9	0.0
P.T.O. SWATHER	0	0	1	1	0.0	0.0	0.9
TANDEM DISC	2	1	1	1	2.0	1.3	1.1

[1] A 10% summerfallow rotation was assumed for Edmonton Region.

Table C3: Field Operations For Airdrie Region[1]

MACHINERY	Seeding ST	Seeding SF	Other ST	Other SF	Fallow	Seed Total	Other Total
COMBINE SP	0	0	1	1	0.0	0.0	0.8
FIELD CULT	1	1	0	0	2.0	0.8	0.5
FIELD SPRAYER	0	0	2	1	0.5	0.0	1.4
HARROWS	2	2	0	0	0.0	1.5	0.0
HD FIELD CULT	1	1	1	1	1.0	0.8	1.0
HOE DRILL	1	1	0	0	0.0	0.8	0.0
P.T.O. SWATHER	0	0	1	1	0.0	0.0	0.8

[1] A 25% summerfallow rotation was assumed for Airdrie Region.

Table C4: Field Operations For Oyen Region

ACHINERY	Seeding ST	Seeding SF	Other ST	Other SF	Fallow	Seed Total	Other Total
MBINE SP	0	0	0	1	0.0	0.0	0.5
LD CULT	0	1	0	0	2.0	0.5	1.0
LD SPRAYER	0	0	0	1	0.5	0.0	0.8
RROWS	0	2	0	0	0.0	1.0	0.0
IELD CULT	0	2	0	0	1.0	1.0	0.5
DRILL	0	1	0	0	0.0	0.5	0.0
.O. SWATHER	0	0	0	1	0.0	0.0	0.5

[1] A 50% summerfallow rotation was assumed for Oyen Region.

APPENDIX D. Optimum Replacement Cycles[59]

TABLE D1: Optimum Replacement Cycles For Peace River Region

Machine	---- Farm size ---- 640 ACRES	960 ACRES	1280 ACRES
	---- Cycle (years) ----		
COMBINE SP	10	9	8
FIELD CULT	10	10	10
FIELD SPRAYER	11	11	10
HARROWS	11	11	11
HD FIELD CULT	8	8	8
HOE DRILL	10	10	10
P.T.O. SWATHER	11	11	10
TANDEM DISC RIGID	8	8	8
TRACTOR 2wd (80hp)	10	10	10
TRACTOR 2wd	7	7	8

TABLE D2: Optimum Replacement Cycles For Edmonton Region

Machine	---- Farm size ---- 640 ACRES	960 ACRES	1280 ACRES
	---- Cycle (years) ----		
COMBINE SP	10	8	8
FIELD SPRAYER	11	11	10
HARROWS	11	11	11
HD FIELD CULT	7	7	7
HOE DRILL	10	10	10
P.T.O. SWATHER	11	10	10
TANDEM DISC RIGID	7	7	7
TRACTOR 2wd (80hp)	10	10	10
TRACTOR 2wd	7	7	7

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[59] In all regions the size of partial taking (1-19 acres) did not influence the length of the optimum replacement cycle. In other simulations where large takings were assumed (ie: greater than 50 acres) optimum replacement cycles were shortened.

OPTIMUM REPLACEMENT CYCLES FOR FARM MACHINERY

TABLE D3: Optimum Replacement Cycles For Airdrie Region

Machine	960 ACRES	1280 ACRES	1600 ACRES
	---- Cycle (years) ----		
COMBINE SP	9	9	8
FIELD CULT	8	8	8
FIELD SPRAYER	11	10	10
HARROWS	11	11	11
HD FIELD CULT	7	7	7
HOE DRILL	9	9	9
P.T.O. SWATHER	11	10	10
TRACTOR 2wd (80hp)	10	10	10
TRACTOR 2wd	8	8	8

TABLE D4: Optimum Replacement Cycles For Oyen Region

Machine	960 ACRES	1280 ACRES	1600 ACRES
	---- Cycle (years) ----		
COMBINE SP	10	10	9
FIELD CULT	8	8	8
FIELD SPRAYER	11	11	11
HARROWS	11	11	11
HD FIELD CULT	7	7	7
HOE DRILL	10	10	10
P.T.O. SWATHER	11	11	11
TRACTOR 2wd (80hp)	10	10	10
TRACTOR 2wd	7	7	7