FOREST ENGINEERING
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INSTITUT CANADIEN
DE RECHERCHES
EN GÉNIE FORESTIER

# TWO REPLACEMENT MODELS FOR B.C. COASTAL LOGGING EQUIPMENT

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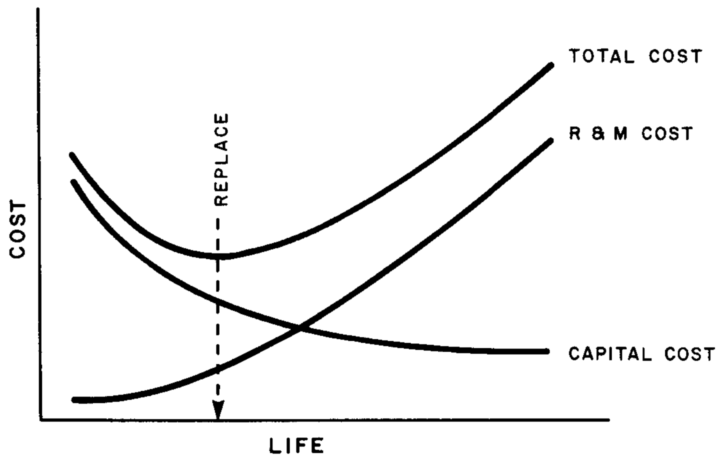
April 1986




Technical Report

TR - 68

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# PREFACE

MacMillan Bloedel Ltd. cooperated in this study by supplying costs and production data on their logging equipment. The people at their Northwest Bay, Chemainus, and Kelsey Bay logging divisions assisted with the collection of data, interpretation of results, and explanation of variances.

The following manufacturers, distributors, and auctioneers of logging equipment provided estimates of machine market values:

CAE Equipment Co. Ltd.
Chapman Industries Ltd.
Columbia Trailer Co. Ltd.
Cypress Equipment Co. Ltd.
Finning Tractor and Equipment Co. Ltd.
Gordon Machinery Co. Ltd.
Inland Kenworth Sales Ltd.
Ritchie Bros. Auctioneers Ltd.
S. Madill Ltd.
Trican Machinery Ltd.
Wajax Industries Ltd.

Appreciation is extended to G. Glen Young, Faculty of Forestry, University of British Columbia, for his guidance in the theory of equipment replacement, and to reviewers Jeremy Rickards, Chairman--Department of Forest Engineering, University of New Brunswick and Ernie Heidersdorf, Group Supervisor of FERIC. Appreciation is also extended to Paul Tse and Jane McDonald for collecting data and conducting preliminary analyses.

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SUMMARY

The first objective of this project was to compare the historical equipment replacement policies of coastal British Columbia forest companies to the results from economic replacement models and, if replacement age differed, to demonstrate cost savings from timely replacement based on economic theory.

The second and more important objective of this project was to develop an equipment replacement model on a microcomputer for use at the divisional level in the forest industry. The model would indicate the optimum economic replacement age for a variety of equipment.

Three coastal divisions of MacMillan Bloedel Ltd. (MB) participated with the Forest Engineering Research Institute of Canada (FERIC) by supplying utilization and historical repair and maintenance data from 1966 to 1983 on 141 pieces of logging equipment.

Two economic replacement models were used to analyze the data. The simpler model simulated before-tax and nondiscounted cash flow, while the second model was more complex and simulated after-tax, discounted cash flow.

In comparison with MB corporate replacement guidelines, the results from the two models suggested shorter replacement cycles for most equipment fleets. The discrepancies result from varying annual usage rates, maintenance standards, terrain, logging conditions, and logging systems.

If equipment is retained beyond its economic lifetime, an additional cost is incurred. For example, at MB's Kelsey Bay division an additional cost of approximately $8800 per year per grapple yarder is incurred by following the corporate replacement guidelines instead of those determined by economic replacement theory.

The two models are solved simultaneously by the computer program. To be readily accepted and implemented by industry, the replacement model should be easy to understand. Since both models gave similar replacement ages, the simpler model is recommended.

The importance of scheduled replacement varies with machine type. Those with rapidly increasing repair and maintenance cost histories are much more sensitive to timely replacement and should be replaced on time, while those with less rapid repair and maintenance cost increases can be retained without as great a cost penalty.

Economic replacement theory is a valuable tool for managers. However, it cannot and should not overrule the normal equipment replacement review process carried out by maintenance and production personnel. Production plans, productivity increases, standardization, logging systems, major overhauls, and changing technology are just as important in determining what machines to replace and when to replace them. Economic replacement theory is a guide, not a rule, and is only one part of the overall replacement analysis.

The two economic replacement models can be used in conjunction with current equipment assessment and replacement analysis practices. While corporate guidelines are valuable for forecasting longer-term capital expenditures, the variation between logging divisions make them ineffective for planning the replacement of individual machines.

The basic data required for the models include annual costs of equipment repair and maintenance and at least one annual level of utilization (hours, kilometres, tonnes, cubic metres, etc.) for each piece of equipment. The lack of accurate data precludes inclusion of downtime costs and costs attributable to both obsolescence and productivity increases from newer machine design into the replacement models. At the time of analyzing replacement age, current machine purchase price and salvage values are required. The computer equipment needed includes an IBM Personal Computer (or equivalent) with 256 K RAM, a dot-matrix printer, and Lotus 123 software.

The computer software developed in this project, a user's manual, and a training seminar are available to FERIC member companies. Some experience with personal computers is an asset. The program may be best implemented in a mechanical shop with an existing computer or in a divisional accounting department.

SOMMAIRE

Le premier objectif de ce projet fut de comparer les politiques historiques de remplacement d'équipement des compagnies forestières de la Colombie-Britannique aux résultats de modèles de remplacement économique et de démontrer, si les âges de remplacement diffèrent, les économies de coûts obtenues grâce de modèles aux remplacements en temps opportun basées sur une théorie économique.

Le deuxième et plus important objectif de ce projet fut de développer un modèle de remplacement d'équipement sur un micro-ordinateur utilisable au niveau des divisions au sein de l'industrie forestière. Le modèle indiquerait l'âge optimum de remplacement économique pour une variété d'équipement.

Trois divisions côtières de MacMillan Bloedel Ltd. (MB) ont participées avec l'Institut Canadien de Recherches en Génie Forestier (FERIC) à l'étude en fournissant des données sur l'utilisation et sur l'historique des réparations et de l'entretien de 1966 à 1983 sur 141 pièces d'équipement forestier.

Deux modèles de remplacement économique furent utilisés pour analyser les données. Le modèle le plus simple simulait le flux financier non-actualisé avant impôt, tandis que le second modèle était plus complexe et simulait le flux financier actualisé après impôt.

En comparaison avec les lignes directrices de remplacement de la corporation MB, les résultats des deux modèles suggèrent des cycles de remplacement plus courts pour la plupart des flottes d'équipement. La divergence s'expliquait par la variation du taux d'utilisation annuel, les normes d'entretien, le terrain, les conditions d'exploitation, et par les systèmes d'exploitation.

Si l'équipement est maintenu au-delà de la durée de vie économique, un coût additionnel est encourru. Par exemple, à la division de MB Kelsey Bay, un coût additionnel d'environ $8800 par année par débusqueuse téléphérique à grappins est encourru en suivant les lignes directrices de remplacement de la corporation plutôt que celles déterminées par la théorie de remplacement économique.

Les deux modèles sont résolus simultanément par le programme d'ordinateur. Pour être accepté et utilisé par l'industrie, le modèle de remplacement devrait être facile à comprendre. Puisque les deux modèles ont donné des âges de remplacement semblables, le modèle le plus simple est recommandé.

L'importance des horaires de remplacement varie avec le type de machine. Les machines ayant un historique de coût de réparation et d'entretien à croissance rapide sont plus sensibles aux temps de remplacement et devraient être remplacées au temps opportun, tandis que celles ayant une croissance de coût de réparation et d'entretien moins rapide peuvent être maintenues sans trop amander les coûts.

La théorie de remplacement économique est un outil précieux pour les dirigants forestiers. Cependant, elle ne peut ni ne devrait supplanter le procédé de revision normal de l'équipement effectué par le personnel d'entretien et de production. Les plans de production, l'accroissement de productivité, la normalisation, les systèmes d'exploitation, les revisions majeures et le changement de technologie sont tout aussi importants en vue de déterminer quelles machines seront remplacées et quand elles le seront. La théorie de remplacement économique est un guide, non une règle, et représente seulement une partie de l'analyse complète de remplacement.

Les deux modèles de remplacement économique peuvent être utilisés de conivence avec l'évaluation courant d'équipement et les pratiques d'analyse de remplacement. D'une part, les lignes directrices de la corporation sont valable pour prévoir les dépenses de capital a long terme, d'autre part, la variation entre les divisions forestières les rendent inefficaces en vue de planifier le remplacement de machines individuelles.

Les données de base requises pour les modèles comprènent les coûts annuels de réparation et d'entretien de l'équipement et au moins un niveau annuel d'utilisation (heures, kilomètres, tonnes, mètres cube, etc.) pour chaque pièce d'équipement. Le manque de données précises exclut la possibilité d'inclure les coûts attribuables aux temps morts, à l'obsolescence et à l'acroissement de productivité à partir de machines neuves conçues à même les modèles de remplacement. Lorsque l'analyse de l'âge de remplacement est effectuée, les prix d'achat et les valeurs de revente en vigueur des machines sont requis. L'équipement informatique nécessaire comprend un ordinateur IBM PC (ou l'équivalent) avec 256K RAM, une imprimante à points, et un logiciel Lotus 123.

Le logiciel développé lors de ce projet ainsi qu'un manuel d'utilisation et une session de formation sont disponibles pour les compagnies membre de FERIC. De l'expérience sur les ordinateurs de type personnel s'avère un atout. La meilleure utilisation du programme serait dans un atelier de mécanique déja muni d'un ordinateur ou dans un département comptable d'une division forestière.

## INTRODUCTION

The first objective of this project was to determine whether historical equipment replacement policies used by coastal British Columbia forest products companies for logging equipment were the same as those based on economic replacement theory. If the replacement times differed, then the potential savings from timely logging equipment replacement could be demonstrated.

The second and more important objective of this project was to develop an equipment replacement model on a microcomputer for use at the divisional level in the forest industry. The model would indicate the optimum economic replacement age for a variety of equipment.

Many approaches have been used to determine economic equipment replacement ages. These include minimizing total ownership and repair costs (Brenan 1964, Edge and Irvine 1981, Wellwood and Sinclair 1971), maximizing revenues or profits (Douglas 1970), and setting repair expenditure limits (Drinkwater and Hastings 1967). Two models which minimize overall costs of owning, repairing, and maintaining equipment were chosen for this project. The first model was simpler but theoretically less accurate; the second was more complex but more accurate in terms of economic theory.

In this report, the two replacement models were used to analyze four different classes of machines at three separate logging divisions. The three logging divisions have a variety of operating conditions and maintenance standards, and so variations in replacement times were expected. Also, the replacement times based on economic replacement theory were compared with MacMillan Bloedel Ltd. (MB) corporate policies for equipment replacement. Potential cost savings were shown.

A computer analysis which solves both models simultaneously was developed for use on microcomputers. The software, user's manual, and a training seminar are available to FERIC member companies.

The dilemma for equipment managers is whether to continue repairing the machine and accept higher repair costs and downtime, or to replace the machine and accept higher ownership costs. The Forest Engineering Research Institute of Canada (FERIC) cooperated with MB to provide an analytical tool to determine optimum equipment replacement age.

## STUDY METHOD

Two equipment replacement models were chosen. Repair and maintenance data were collected from three of MB's coastal divisions and ownership cost data were obtained from equipement distributors and auctioneers. A series of computer programs and spreadsheets were designed. The collected data were entered into the computer database and individual machines were grouped into fleets. Economic replacement ages were then generated for each fleet.

## DESCRIPTION OF THE REPLACEMENT MODELS

### A. Equipment Replacement Theory

Equipment replacement theory is basic to management science. It has been widely used in the Armed Services and in other industries. Many articles have been published about different replacement models which vary in accuracy and complexity. The first model used in this project is similar to one implemented at Canadian Forest Products Ltd. in 1972 (Wellwood and Sinclair 1971). It is a before-tax, nondiscounted cash-flow model which determines the machine age that yields the lowest combined cost of owning, repairing, and maintaining the equipment. While not as theoretically correct as other models, it is easily understood. This model simulates before-tax, nondiscounted cash flow rather than discounted, after-tax cash flow and therefore does not accurately reflect the effect of equipment replacement on the company financial statement. However, it provides an indication of optimum equipment age and gives the relative cost penalties of equipment replacement before or after the optimum age.

For this model, hereafter called the simple model, the cumulative combined cost of repair, maintenance, and ownership of an individual machine to year y is determined by:

$$C_y = R_y + O_y$$

Where
- $y$ = machine age (years)
- $C_y$ = cumulative combined cost of repairing, maintaining, and owning the machine to year y
- $R_y$ = cumulative cost of repairing and maintaining the machine to year y
- $O_y$ = cumulative cost of machine ownership to year y and includes loss in market value (depreciation), lost opportunity cost, and insurance cost

The simple model calculates Cy for each year of machine life (y = 1 to 20). The optimum replacement age is determined when the average combined cumulative cost per unit of use (Cy/Uy) is minimum (Figure A and Appendix I).

Where
- $u$ = fleet annual average usage rate (e.g., h/yr, km/yr, etc.)
- $U_y$ = cumulative usage to year y (i.e., $U_y = y * u$ yielding h, km, etc.)

(asterisks indicate multiplication when used in formulae)

The fleet average annual usage rate is determined from historical fleet data and is a better measure of utilization than age alone.

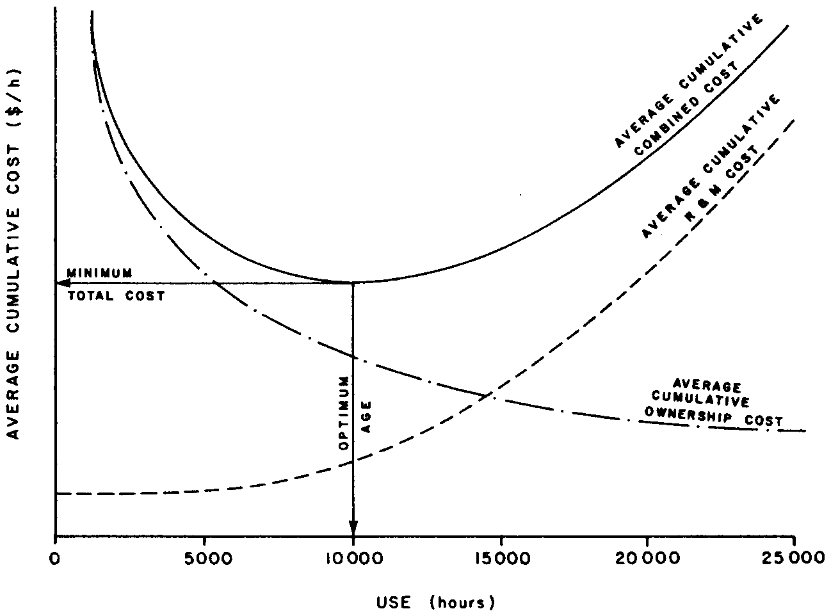


FIGURE A. Rate of Change of Average Cumulative Combined Cost Versus Time.

The second economic replacement model is more complex and hereafter is called the complex model. It is based on a model described by C.G. Edge in "A Practical Approach to the Appraisal of Capital Expenditures, 1981". The model determines after-tax cash flows and accounts for the time value (discounting) of money. It is considered to reflect more accurately the effect of equipment replacement on corporate cash flow.

This model makes the same assumptions as the simple model that at some point in machine age, the cumulative combined cost per unit of usage, $C_y/U_y$, reaches a minimum which indicates the optimum economic replacement age. However, a different approach is used to combine costs and determine when they are minimized. Specifically, repair, maintenance, and ownership costs are calculated annually and are not cumulative. The annual costs are treated for tax considerations (capital cost allowance and income tax deduction for expenses), then discounted to year one. The discounted repair, maintenance, and ownership costs are combined and then cumulated year by year. A capital recovery factor (CRF) is applied to each year's total to yield a uniform annual equivalent (UAE) cost of repair and maintenance. This cost is expressed per unit of usage (i.e., $/h, $/km, $/tonne, etc.). The machine age yielding the minimum UAE combined cost per unit of use is the optimum economic replacement age. The UAE combined cost of repairing, maintaining, and owning a machine for each year, y, is given by:

$$UAE_y = CRF_y * [ R_y + O_y ]$$

Where $y$ = machine age (years)

$UAE_y$ = uniform annual equivalent combined cost for year y

$CRF_y$ = capital recovery factor. A factor applied to a present value sum of money to yield the uniform annual equivalent (UAE) for a specific number of years in the future at a given rate of interest. This factor is calculated for each year of the analysis and applied to the annual present value after-tax, of repair, maintenance, and ownership costs for a machine.

$R_y$ = present value after-tax, of the repair and maintenance cost to year y

$O_y$ = present value after-tax, of ownership cost to year y. Ownership costs include loss in market value (depreciation) and insurance costs.

The ratio $UAE_y$ / $U_y$ gives the UAE cost per unit of use. The optimum equipment replacement time is determined when this value is minimized. For more information about the complex model, see Appendix I.

B. Computer Program

A computer program was developed to solve both models simultaneously. The database and primary data processing modules for the repair and maintenance costs, ownership costs, and machine utilization data were written in BASIC. The regression analysis was written in FORTRAN and a LOTUS 1,2,3 spreadsheet was used for final compilation and graphing. As well, the spreadsheet calculated the internal rate of return (IROR) and net present value (NPV) of the replacement alternatives. This combination of languages and programs was chosen to utilize available software and offer increased versatility, flexibility, and portability.

The ownership cost assumptions in the models, including equipment purchase and salvage prices, insurance rate, corporate tax rate, capital cost allowance, and the capital cost of money, can be easily changed to allow an interactive analysis of replacement age. This facilitates sensitivity tests of replacement time under differing economic scenarios.

The program was developed on an IBM PC computer, but can be installed on any MS-DOS based computer supporting Microsoft Advanced BASIC, FORTRAN, and LOTUS 1,2,3. A minimum 256 K bytes RAM memory, two disk drives, and a dot-matrix printer are also required. A detailed user's manual accompanies the software.

C. Repair and Maintenance Costs

Historical repair and maintenance records were collected for 141 pieces of logging equipment from three MB logging divisions (Chemainus, Kelsey Bay, and Northwest Bay) on Vancouver Island. The data reflected the annual parts and labour costs incurred to repair and maintain each piece of equipment. Labour costs included the hourly wage rate plus fringe benefits, but excluded bunkhouse and shop vehicle expenses and shop overhead costs. As well, annual machine utilization was collected in terms of operating hours or shifts. If information was available, production data ($m^3$, km, or pieces) were also collected for each machine. At least one measure of machine utilization is required for the models.

The models assume hourly repair and maintenance costs increase with usage. Breakdowns occur more often and each breakdown is more costly. A cost pattern, such as that shown in Figure B, develops.

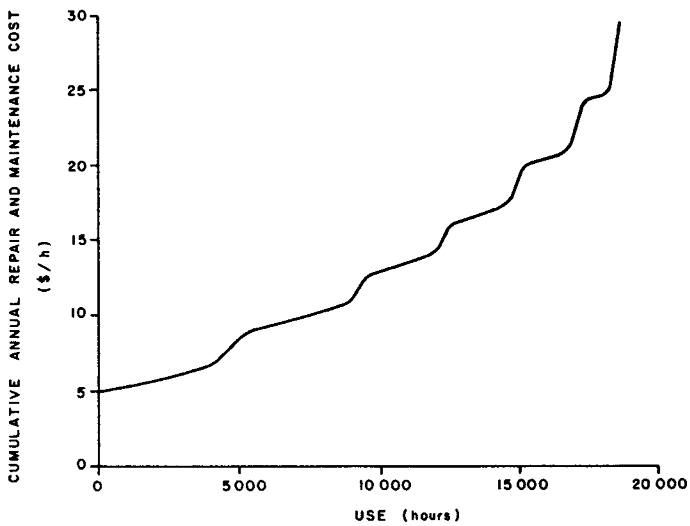


FIGURE B. Average Cumulative R & M Costs per Hour. Kenworth 849 Series Logging Truck (Kelsey Bay Division). Average Use = 1338 h/yr.

The user must decide which costs constitute repair and maintenance items. The same costs must then be included throughout the machine history to maintain consistency of data and to illustrate reliable trends of repair and maintenance costs with time.

In this study, costs not associated with normal repair and maintenance were omitted (e.g., parts and labour costs to repair accident or fire damage and to make major machine modifications). In addition, data were omitted when a machine's prime function was changed. For instance, older road building excavators were converted to mobile grapple yarding crane backspars. In this case, only the data associated with the road construction career were used to determine economic lifetimes for grade excavators.

Furthermore, operating cost items such as tires, lubricants, wire rope, and fuel were not included in repair and maintenance cost data. It was assumed that these items did not increase significantly with machine age. Also, insufficient data were available to assign the cost of consumable items to individual machines.

The reliability of the economic lifetime analysis depends largely on the quality of the historical data (the effort invested in keeping accurate and complete records), and the participation of operating and maintenance personnel. During the study, several return visits to the divisions were necessary to confirm trends in the data, to establish future cost trends, and to have data variances explained. With the guidance of divisional maintenance personnel, machines of similar type and use were assembled into fleets for analysis.

Table 1 shows the data collected for an off-highway log truck. The basic data include annual parts and labour costs for repairing and maintaining the individual machine and at least one measure of its utilization or production (hours, kilometres, pieces, etc.).

TABLE 1. Example of Machine History Data. (Actual Historical Data)

Machine No.: TRUCK 007
Description: Kenworth 849 Logging Truck
Fleet type: Off-highway hauling
Year purchased: 1968

| Annual Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Labour † ($) | Parts ($) | <---- Usage †† ---- Hours | Km | Pieces | Loads | $m^3$ | Tonne-km ----> |
| 1968 | 1 630 | 695 | 1 464 | 5 289 | 12 025 | 423 | 9 988 | No Data |
| 1969 | 2 547 | 183 | 1 965 | 6 943 | 17 172 | 549 | 12 982 | |
| 1970 | 2 603 | 576 | 1 558 | 6 326 | 15 831 | 527 | 14 383 | |
| 1971 | 5 579 | 2 644 | 1 510 | 6 495 | 18 294 | 609 | 16 932 | |
| 1972 | 5 955 | 1 205 | 1 374 | 6 843 | 15 621 | 520 | 14 388 | |
| 1973 | 8 000 | 14 714 | 1 329 | 6 900 | 13 548 | 451 | 11 303 | |
| 1974 | 6 689 | 8 172 | 1 346 | 5 127 | 13 398 | 446 | 11 711 | |
| 1975 | 8 416 | 40 094 | 908 | 3 691 | 9 643 | 321 | 8 859 | |
| 1976 | 10 771 | 1 172 | 1 434 | 6 330 | 13 848 | 461 | 12 731 | |
| 1977 | 11 710 | 5 636 | 1 376 | 7 398 | 12 737 | 424 | 11 735 | |
| 1978 | 14 173 | 22 344 | 1 356 | 7 809 | 12 407 | 413 | 11 606 | |
| 1979 | 15 338 | 6 457 | 1 194 | 6 490 | 11 295 | 376 | 10 617 | |
| 1980 | 15 041 | 27 952 | 1 116 | 5 965 | 10 604 | 353 | 9 556 | |
| 1981 | 10 771 | 3 773 | 854 | 7 713 | 6 819 | 277 | 11 586 | |
| 1982 | 18 333 | 9 682 | 786 | 7 697 | 7 780 | 259 | 11 787 | |
| 1983 | 28 613 | 26 407 | 1 099 | 3 542 | 9 804 | 341 | 9 445 | |

† Costs as recorded in the year of expenditure.
†† A minimum of one measure of usage is required.

Calculations Using Repair, Maintenance, and Utilization Data

The repair, maintenance, and utilization data were entered into the computer database. The historical data were then read from the database for each analysis, allowing costs to be expressed in dollars for the current year.

The program removed the effects of inflation from the parts costs data by transforming all historical costs to the equivalent current dollars (1985 dollars for this report). Calculations are based on increases of the Canadian consumer price index (CPI) for the Vancouver area. For example, $100 spent on parts in 1972 (CPI = 105) is equivalent to $285 (299/105 * $100) spent on parts in 1985 dollars (CPI = 299).

Similarly, historic labour costs were transformed to current dollars by tracking changes in the I.W.A. wage rates for a certified heavy-duty mechanic. For example, $100 spent on labour in 1972 (wages = $5.665/h) is equivalent to a $332.66 ($18.845 / $5.665 * $100) labour cost in 1985 (wages = $18.845/h).

Failure to remove inflation would result in replacement times which are too early (inflationary effect) and fleet cost data of mixed dollar values.

In order to estimate the average fleet repair and maintenance cost as a function of usage, the program fits a series of regression equations to the cumulative annual repair and maintenance costs and cumulative annual usages of the fleet. Thus for any usage level, repair and maintenance costs can be estimated. To generate nonlinear equations, the usage levels were squared and cubed in the program. A stepwise multiple regression[1] was used to generate three equations. One of the three was chosen based on fit to historic data, statistical significance, and realistic forecast of future repair and maintenance costs. The computer model also has provision for adjusting the per-unit-usage repair and maintenance costs calculated from the regression equation to better fit the estimated cumulative costs to actual costs. This is particularly useful in the early years of an analysis and in forecasting.

The user is cautioned that extrapolating repair and maintenance costs from the regression equations beyond the range of actual historical fleet data will give replacement ages that are less reliable. The equations tend to fit well in the range of actual data but are often incongruous beyond historical data. See Appendix II for the regression equations chosen to estimate cumulative repair and maintenance costs for the study fleets.

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[1] "Multiple Regression Program for Conditioned and Unconditioned Regression Analysis" Courtesy of Dr. A. Kozak, Faculty of Forestry, University of B.C., Vancouver, B.C., 1979.

From the regression equation, the computer model calculated annual repair and maintenance costs and converted the figures to a dollars-per-unit-usage ($/h, $/km, $/t, etc.) basis for each year of the analysis. Multiples of the fleet average annual utilization rate (hours) were used to determine the cumulative repair and maintenance cost for each analysis year. Figure C illustrates a fleet repair and maintenance cost curve, the three regression equations, and the regression equation chosen to represent the fleet R & M cost curve of the Kenworth 849 logging truck fleet.

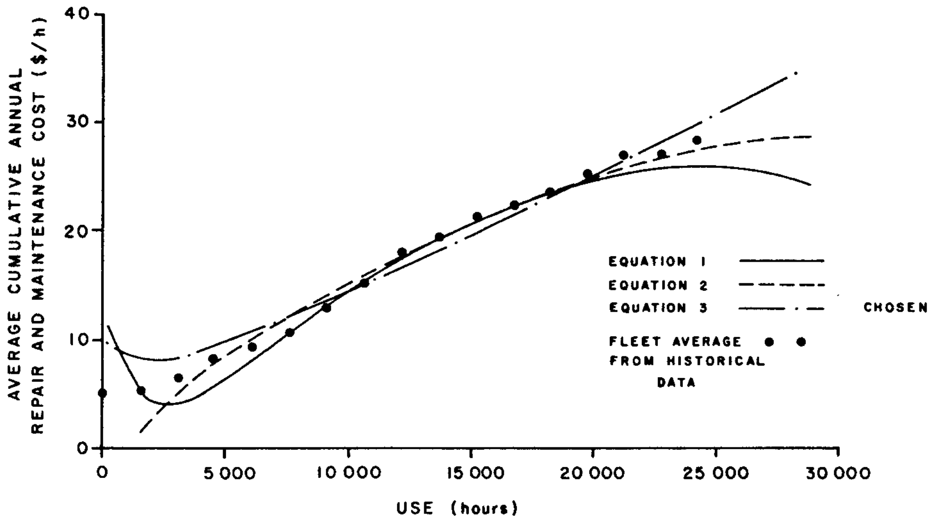


FIGURE C. R & M Regression Equation Selection.

For the simple model, no manipulation of the repair and maintenance costs by the program were required. However, for the complex model, the annual repair and maintenance costs must be reduced to an after-tax, present-value basis, then converted to uniform annual equivalent (UAE) amounts. The method is described in Appendix I.

## D. Ownership Costs

Eleven equipment companies were interviewed to obtain their estimates of ownership cost parameters. The parameters included data on current machine prices, estimated percentage loss in market value after the first year, estimated constant market value (salvage value), and machine age when the resale value reached a constant. In most cases, the estimates of costs were very similar between companies. After sensitivity testing for effect on replacement time, the following estimates were used (Table 2).

TABLE 2. Ownership Costs.

| FLEET | INITIAL PURCHASE PRICE | CONSTANT MARKET VALUE † | YEARS UNTIL CONSTANT MARKET VALUE REACHED | DECLINE IN MARKET VALUE IN FIRST YEAR |
|---|---|---|---|---|
| Yarder | | | | |
| 27-m highlead (tank carrier) | $317 800 | $110 000 | 7 | 33% |
| 27-m highlead (rubber-tired carrier) | 374 500 | 130 000 | 7 | 33% |
| Grapple (Madill 044) | 717 000 | 165 000 | 8 | 30% |
| Grapple (American 7220) | 633 000 | 165 000 | 8 | 26% |
| Cable Log Loader (American Loaders) | | | | |
| Rubber-tired carrier (5675) | $570 000 | $160 000 | 9 | 25% |
| Crawler carrier (7220) | 561 750 | 146 000 | 8 | 26% |
| Rubber-tired carrier (7220) | 695 500 | 180 830 | 9 | 26% |
| Logging truck tractor | | | | |
| Large off-highway size | $375 000 | $ 63 750 | 8 | 40% |
| Highway size | 96 300 | 20 200 | 6 | 21% |
| Crawler tractor | | | | |
| Caterpillar D8 size | $449 000 | $ 90 000 | 8 | 20% |
| International TD 25C size | 374 500 | 75 000 | 5 | 60% |

† Constant Market Value: the minimum, steady resale value of a machine after a number of years.

The variable ownership cost parameters used for all report results were:

| | | |
|---|---|---|
| insurance cost | = | 1% of average machine value |
| corporate tax rate | = | 50% |
| capital cost allowance | = | 30% declining balance |
| complex model, real cost of capital | = | 4% |
| simple model, cost of capital | = | 14% (investment threshold or hurdle rate) |

Appendix I describes the calculation of annual and per-unit-usage capital costs. In general, it is assumed that annual ownership costs **decrease** with machine age. This is because the major factor, the rate of loss in resale value per year (depreciation), is rapid at first then decreases until at some age it reaches zero and there is no further loss in resale value. The pattern of average capital cost per hour from the complex model for the Kenworth 849 logging truck shown in Figure D is given in Figure E. Ownership costs, expressed in current dollars (1985), reflect the loss of resale value and the cost of insurance in both replacement models and, in the simpler model only, the lost opportunity cost.

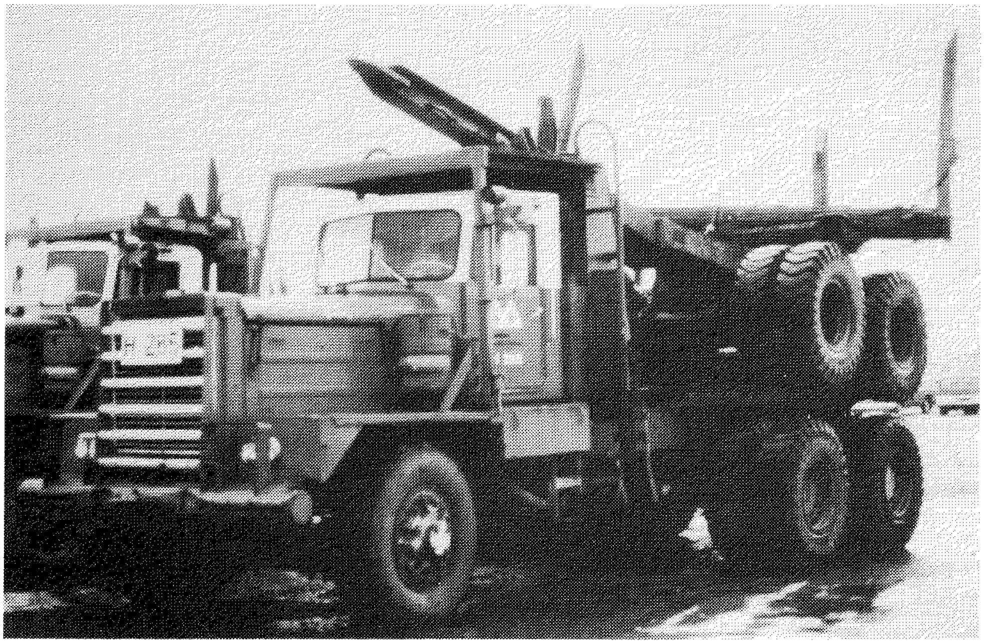

FIGURE D. Kenworth 849 Series Logging Truck.

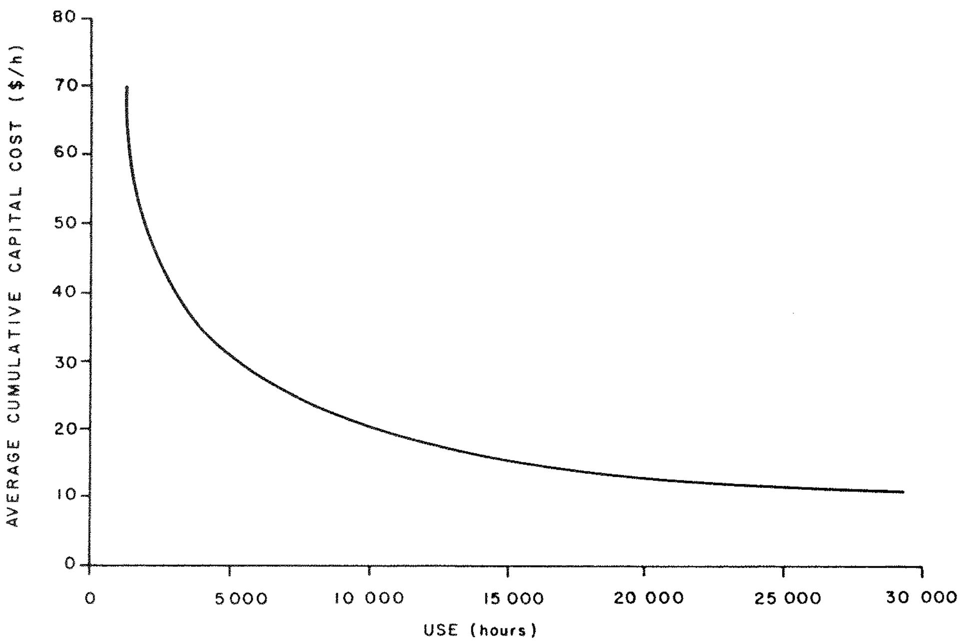


FIGURE E. Average Cumulative Ownership Cost per Hour. Kenworth 849 Series Logging Trucks (Kelsey Bay Division). Average Use = 1338 h/yr.

Calculations Using Capital Cost Data

For the simple model, the capital cost for each year is the sum of loss in resale value, insurance costs, and lost opportunity costs cumulated to that year. The cumulative cost is then expressed per unit of usage (i.e., \$/h, \$/km, \$/t, etc.) by dividing by the cumulative usage.

For the complex model, loss in resale value and insurance costs are calculated annually. These costs are not cumulated. The annual loss in resale value and insurance expenses are reduced to a present-value, after-tax basis and converted to uniform annual equivalent amounts. The UAE values are expressed, per unit usage, by dividing by the annual machine utilization rate (see Appendix I).

## E. Other Costs

Sensitivity tests of the two replacement models to inclusion of operating costs which do not vary significantly with the age of the machine (e.g., tires, fuel, wire rope, etc.) showed increased combined costs, but no change in the replacement time. Repair and maintenance costs in this project only reflected the costs of repairing and maintaining the machines and did not include operating supplies. To generate accurate R & M cost equations, users of the model should compile their data in a similar way.

Loss of productivity costs (from foregone technological improvements) and downtime costs were not included in the models. Although they affect replacement time, they were omitted because of the lack of data and because of the difficulty in defining a realistic cost. Normally, the addition of downtime costs and loss of productivity costs would manifest earlier replacement of a machine.

## F. Combined Costs

In the models, the increasing R & M costs are added to the decreasing ownership costs for each year of the analysis to give an average cumulative combined cost which decreases initially, levels, and then increases. In the more complex model, the UAE values of repair and maintenance costs and capital costs are summed for each year to give the same shaped curve as the simple model. The time to replace is when the cumulative combined cost per hour or when the uniform annual equivalent is minimum.

Table 3 and Figure F show the average combined costs determined by the simple model for the fleet of Kenworth 849 logging trucks. The indicated replacement age is 16 100 hours or 12 years at an average annual utilization of 1338 hours. The minimum average combined costs would be about \$54.58/h.

TABLE 3. Simple Model--Combined Cost/Hour.
Kenworth 849 Series Logging Truck Fleet
(Kelsey Bay Division).

| CUMULATIVE OPERATING TIME HOURS | YEARS | CUMULATIVE R&M COSTS PER HOUR ($/h) | CUMULATIVE OWNERSHIP COSTS PER HOUR ($/h) | CUMULATIVE COMBINED COSTS PER HOUR ($/h) |
|---|---|---|---|---|
| 13 400 | 10 | 18.82 | 36.63 | 55.45 |
| 14 700 | 11 | 20.53 | 34.28 | 54.81 |
| **16 100 †** | **12** | **22.26** | **32.32** | **54.58** |
| 17 400 | 13 | 23.99 | 30.67 | 54.66 |
| 18 700 | 14 | 25.74 | 29.25 | 54.98 |

† **Bold** figures are values at optimum replacement time. As is usually the case with logging trucks, the combined cost per hour curve does not increase rapidly after reaching the lowest cost point. If capital funds are limited, replacement of logging trucks may be delayed without incurring rapidly escalating combined costs. Hours have been rounded to nearest 100 hours. This also applies to Table 4.

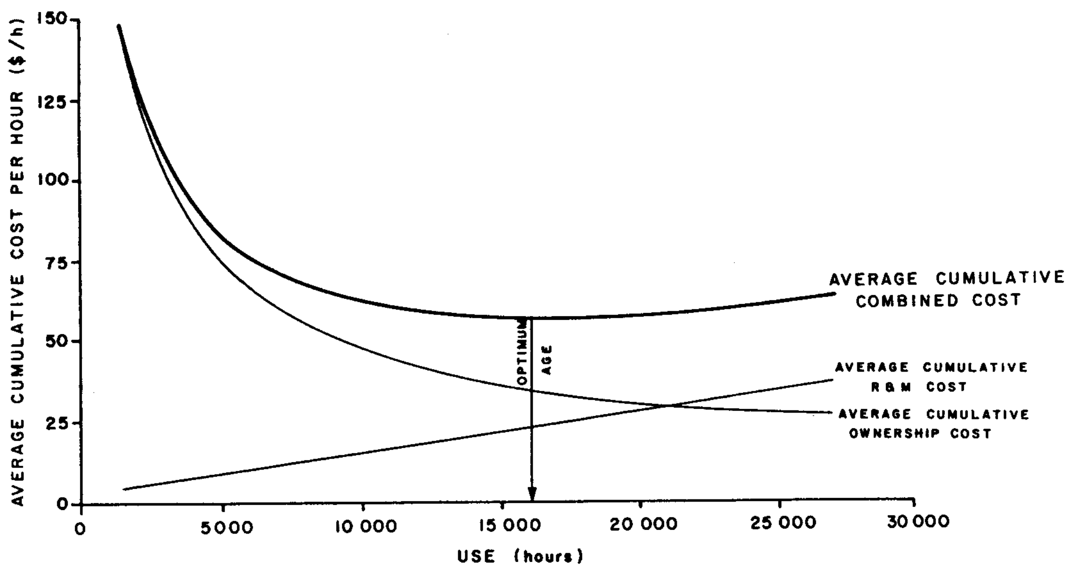


FIGURE F. Simple Model--Average Cumulative Cost per Hour.
Kenworth 849 Series Logging Truck
(Kelsey Bay Division). Average Use = 1338 h/yr.

For the same Kenworth 849 logging trucks, Table 4 and Figure G show the combined UAE costs calculated by the complex model. The indicated replacement age is 17 400 hours or 13 years at 1338 hours of use per year. The UAE combined cost would be $25.09/h.

TABLE 4. Complex Model--Equivalent Annual Cost. Kenworth 849 Series Logging Truck Fleet (Kelsey Bay Division).

| CUMULATIVE OPERATING TIME HOURS | YEARS | R&M ANNUAL EQUIVALENT COST PER HOUR ($/h) | OWNERSHIP ANNUAL EQUIVALENT COST PER HOUR ($/h) | TOTAL ANNUAL EQUIVALENT COST PER HOUR ($/h) |
|---|---|---|---|---|
| 14 700 | 11 | 9.63 | 15.66 | 25.29 |
| 16 100 | 12 | 10.36 | 14.76 | 25.12 |
| **17 400 †** | **13** | **11.08** | **14.01** | **25.09** |
| 18 700 | 14 | 11.80 | 13.36 | 25.16 |
| 20 100 | 15 | 12.51 | 12.81 | 25.32 |

† Optimum equipment replacement age.

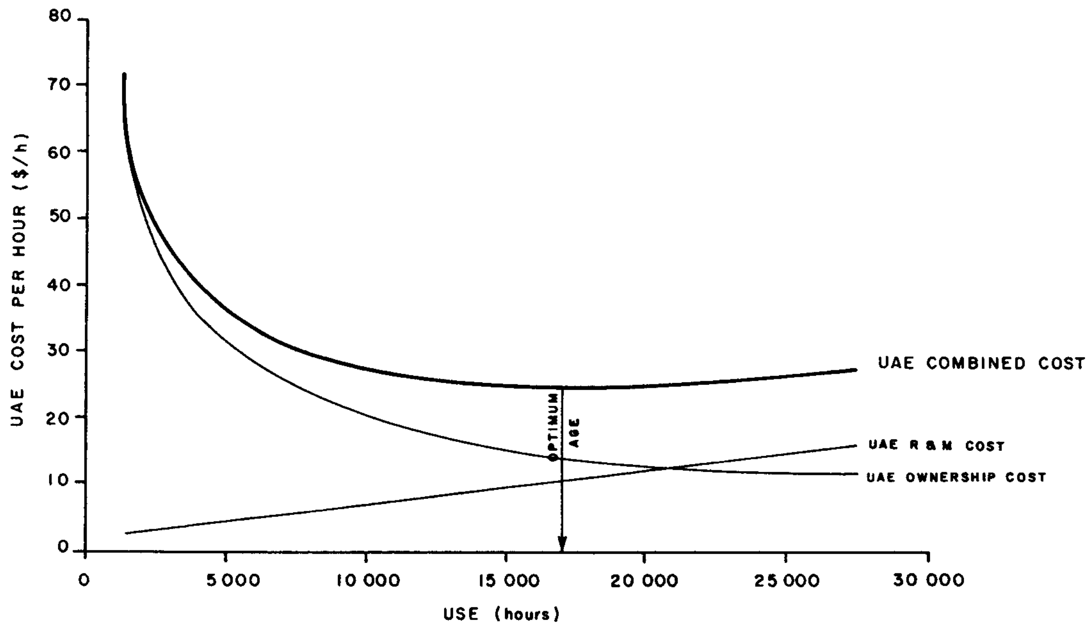


FIGURE G. Complex Model--Uniform Annual Equivalent Cost Per Hour. Kenworth 849 Series Logging Trucks (Kelsey Bay Division). Average Use = 1338 h/yr.

## RESULTS & DISCUSSION

### A. Calculated Equipment Replacement Times Versus Corporate Guidelines

The fleet replacement ages calculated by the models and the MB corporate guidelines for equipment replacement planning are listed in Table 5. The comparison shows that overall corporate replacement guidelines are earlier than the model results when age in years is

These additional costs would be incurred in each year of machine life. The cost savings calculated by the complex model are more representative of the true cost to the company.

Simple model (before-tax, nondiscounted model):

4 machines * ($142.61/h - $125.43/h) * 1263 h/yr = <u>$86 794/yr</u>

Complex model (after-tax, discounted cash flow model):

4 machines * ($63.96/h - $56.96/h) * 1263 h/yr = <u>$35 364/yr</u>

## C. Comparison of the Economic Replacement Times of Both Models

Table 5 shows the economic equipment replacement times determined by the two models for similar fleets from the three logging divisions. Appendix II lists the regression equations chosen to estimate the repair and maintenance costs of the fleets. The suggested replacement times for the two models are similar and occasionally vary by one or two years at most.

The variation in replacement times shown in Table 5 for similar fleets at the three logging divisions results from different maintenance standards, operating conditions, terrain, logging applications, and logging systems. The variation illustrates that replacement times should be established on a divisional basis. In some larger, multi-area logging divisions replacement times may vary from area to area within the division.

The shape of the combined cost curve is different for each fleet of equipment. Figure I and Table 6 illustrate this.

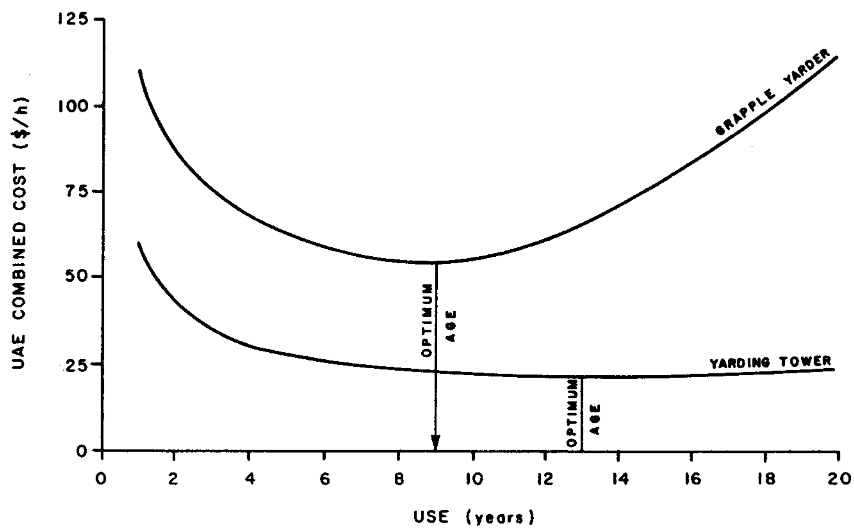


FIGURE I. Different Shapes of Average Combined Cost Curves. (Note the relative steepness of curves.)

TABLE 6. Uniform Annual Equivalent Costs for a Yarding Tower and a Grapple Yarder. Comparison of Combined Cost Curves.
Average annual usage: yarding tower, 1265 h/yr
grapple yarder, 1263 h/yr

| | Yarding Tower | | Grapple Yarder | |
|---|---|---|---|---|
| YEARS | USE (HOURS) | UAE ($/h) | USE (HOURS) | UAE ($/h) |
| 1 | 1 265 | 59.33 | 1 263 | 117.26 |
| 2 | 2 530 | 40.76 | 2 526 | 86.92 |
| 3 | 3 795 | 34.07 | 3 789 | 74.11 |
| 4 | 5 060 | 30.45 | 5 052 | 66.56 |
| 5 | 6 325 | 28.13 | 6 315 | 61.75 |
| 6 | 7 590 | 26.51 | 7 578 | 58.81 |
| 7 | 8 855 | 25.32 | 8 841 | 57.34 |
| 8 | 10 120 | 23.90 | 10 104 | 57.11 |
| 9 | 11 385 | 22.92 | **11 367 †** | **56.96** |
| 10 | 12 650 | 22.25 | 12 630 | 58.18 |
| 11 | 13 915 | 21.82 | 13 893 | 60.56 |
| 12 | 15 180 | 21.59 | 15 156 | 63.96 |
| 13 | **16 445 †** | **21.53** | 16 419 | 68.27 |
| 14 | 17 710 | 21.59 | 17 682 | 73.40 |
| 15 | 18 975 | 21.77 | 18 945 | 79.28 |
| 16 | 20 240 | 22.06 | 20 208 | 85.86 |
| 17 | 21 505 | 22.43 | 21 471 | 93.09 |
| 18 | 22 770 | 22.88 | 22 734 | 100.92 |
| 19 | 24 035 | 23.40 | 23 997 | 109.33 |
| 20 | 25 300 | 23.99 | 25 260 | 118.27 |

† Denotes optimum life.
(Hours have not been rounded off.)

For some fleets, the average combined cost per hour will increase slowly after the replacement time is reached and for others, it will increase rapidly. The grapple yarder is more sensitive to timely replacement than the yarding tower. This allows some flexibility in replacement planning when capital funds are limited. Machines, such as highlead yarders and logging trucks, with slowly increasing combined costs can be retained without incurring significantly higher costs. Conversely, machines with rapidly increasing combined costs, such as grapple yarders and log loaders, should be replaced at or close to the optimum replacement age to achieve the minimum ownership and repair costs over the machine's lifetime.

The average combined costs given by the complex model are approximately one half the average combined costs from the simpler model. Most of the difference results from the complex model reducing R & M and capital costs to an after-tax basis. For example, a $1.00 R & M expense before-tax is equivalent to a $0.50 expenditure after-tax at a 50% corporate tax rate. Discounting constitutes a minor component of the difference. For example, a $100.00 expense expected one year hence is equivalent to $96.15 today ($100.00 ÷ (1 + 0.04)), after discounting at a 4% interest rate.

As shown in Table 5, fleets have cost histories both longer and shorter than the optimal replacement ages. More confidence can be placed in a fleet replacement time when it falls within the range of historical data. For fleets with short histories, the forecasted replacement times may change as more repair experience is gathered over a longer period.

Some of the equipment fleets consisted of only two machines and others included up to eighteen machines. More confidence can be placed in the replacement ages for the larger fleets. In fleets with few machines, one machine could contribute most of the repair cost data. If it is not possible to have several machines in a fleet, then it is better to analyze the machines on an individual basis.

The simple, before-tax, nondiscounted model is easier to understand than the complex, after-tax, discounted cash flow model. Given the similarity of results, the simple model is recommended. If a company is to have an effective replacement program, it is important for supervisors to understand the technique used to determine replacement ages. However, if the company's Financial Analysis Department is determining replacement ages, then the after-tax, discounted model may be more suitable. In any case, the computer program solves both models simultaneously.

## D. Evaluating Capital Expenditure for Replacing Equipment

The program calculates Net Present Value (NPV) and Internal Rate of Return (IROR) for the ranking of equipment replacement alternatives. Both methods are discounted cash flow analyses in that the time value of money is considered. Money received in the future has less value than cash in hand today and therefore future cash flows are 'discounted' when converted to current dollars.

A negative cash flow (outflow) results from the purchase of the replacement machine and a series of positive cash flows (inflows) result from the savings in repair and maintenance costs over the life of a newer machine. When the replacement machine reaches the end of its economic lifetime, an additional positive cash flow is generated when it is sold. The newer machine is expected to exhibit a lifetime repair and maintenance cost pattern similar to the cost pattern of the machine it has replaced. The existing machine would experience higher annual repair and maintenance costs and a higher level of cumulative usage if it is not replaced. Meanwhile a new machine would be expected to have lower annual repair and maintenance costs similar to the early repair history of the original machine. The annual repair and maintenance cost savings for each year of the feasibility analysis is the difference between the rising cost of repairing and maintaining the older (original) machine and the cost of repairing and maintaining the newer (replacement) machine.

Net present value is the discounted value of the after-tax positive cash flows minus the present value of the negative cash flow (investment cost). Usually, the company's cost of capital (as a percentage) or opportunity cost is used to discount the future cash inflows and outflows. If the present value of the revenues is greater than the expenses, or the net present value is greater than zero, then the project is financially attractive. However, a discount rate is needed and it is often difficult to estimate a realistic one. Another problem with net present value is that to compare different projects they must have the same project lives. This is rarely the case, so usually several replacement cycles of the project must be analyzed in order to achieve comparable results and it may not be valid to assume the company will go through these replacement cycles.

The IROR method overcomes the problems of obtaining a discount rate and the unequal project lives. The method involves applying various discount rates until one is found that makes the present value of the cash inflows just equal the present value of the outflows. Thus if x dollars are invested in a project, then the project savings will yield a rate of return of y percent as well as pay off the initial investment. Differences in project life do not affect the comparison between projects. However, this method makes the implicit assumption that the company can reinvest the cash generated by the project at the same interest rate that the project is returning and this may not be valid.

Both analyses are readily and quickly calculated by the program and a sensitivity analysis can be carried out by varying any of the following parameters:

- replacement machine purchase price;
- replacement machine resale price;
- capital cost allowance;
- corporate income tax rate;
- NPV minimum acceptable rate of return; and
- machine lifespan (investment term), maximum 10 years.

The priority of a grapple yarding crane replacement versus a highlead yarding tower replacement at Kelsey Bay division was examined. This comparison was based solely on the expected savings in repair and maintenance costs. The optimum replacement age of the grapple yarder was determined to be approximately 11 400 hours or 9 years. The highlead tower had an optimum replacement age of 16 450 hours or 13 years.

Using the ownership costs from Table 2 and a 15% minimum acceptable rate of return, the NPV method calculated a net present value of $259 100 saved over the next 10 years if the grapple yarder was replaced at 11 400 hours. On the other hand, the NPV of the highlead-tower replacement decision would generate a net loss of $4500 over the next 10 years indicating that replacing the grapple yarder crane was the preferred project.

The IROR method calculated a 24% internal rate of return for a grapple-yarder replacement after 11 400 hours of use. In other words, the savings in repair and maintenance costs would yield a 24% rate of return on the investment of a new machine. For the highlead tower, the IROR was only 15% for a replacement after 16 450 hours of use. Using IROR, the grapple-yarder replacement is favoured over the highlead-tower replacement.

The comparison of replacement projects using the NPV and IROR methods was based only on the expected savings of repair and maintenance costs resulting from a newer, less problem-prone machine. Other, equally important questions must be considered. What are the key machines to the division? What is the effect on overall production if these key machines are not replaced? What are the potential losses in productivity if technological advances available in new machines are not utilized? Can two or more machines be replaced by one new machine and achieve similar or greater productivity? Are there significant differences in operating costs between machines?

In a logging division environment, these questions must be reviewed by a panel including the mechanical supervisor, divisional accountant, and woods foreman. Only after each machine has been considered in light of all these factors will the optimum ranking of replacement alternatives develop.

## CONCLUSION

Discrepancies were found between corporate guidelines for equipment replacement age and those determined by economic replacement theory. The discrepancies resulted from different annual usage rates, maintenance standards, terrain, logging conditions, and logging systems. Corporate guidelines are valuable for forecasting longer-term capital expenditures. However, variation between logging divisions in usage rate and operating environment makes them ineffective for planning divisional equipment replacement of individual machines.

The importance of on-time replacement varies with machine type. Those with steeply rising R & M cost histories are much more sensitive to timely replacement and should be replaced on time, or higher than necessary machine costs will be incurred.

The two models used to determine replacement times gave similar results. As it is important for the user to fully understand the model, the simpler model is recommended.

The replacement ages calculated on the basis of economic theory are a valuable tool for managers. However, they cannot and should not overrule the normal equipment review process carried out by maintenance and production personnel. Production plans, productivity increases, standardization, logging systems, major overhauls, and changing technology are just as important in determining which machines to replace. Economic replacement theory is a guide, not a rule, and is only one part of the overall replacement analysis.

The computer program, user's manual, and training seminar are available to member companies.

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## APPENDIX I

### Detailed Descriptions of the Simple and Complex Equipment Replacement Models

This Appendix describes the derivation of both the "simple" (before-tax, nondiscounted cash flow) and "complex" (after-tax, discounted cash flow) equipment replacement models.

### A. Description of the Before-tax, Nondiscounted Cash Flow Replacement Model (Simple Model)

The cumulative combined cost of repair, maintenance, and ownership of an individual machine to year y is generalized by:

$$C_y = R_y + O_y$$

Where
- $y$ = machine age (years)
- $C_y$ = cumulative combined cost of repairing, maintaining, and owning the machine to year y
- $R_y$ = cumulative cost of repairing and maintaining the machine to year y
- $O_y$ = cumulative cost of owning the machine to year y

For each year of machine life, $C_y$ is calculated. Maximum machine age for the models was set arbitrarily at 20 years. The optimum replacement point is given when the combined per unit cost, $C_y/U_y$, is minimum.

If $u$ = fleet average annual usage rate (e.g., h/yr, km/yr, etc.)

then: $U_y$ = cumulative usage to year y (i.e., $U_y = y * u$)

(asterisks idicate multiplication when used in formulae)

#### $R_y$ Cumulative Repair and Maintenance Cost

$R_y$, the cumulative repair and maintenance cost to year y, is determined from the regression equation used to correlate actual repair and maintenance costs to machine use. The data are compiled for an individual machine or for a fleet of machines. For this report, data for fleets of 2 to 18 machines were analyzed. Given a usage level, $U_y$, the regression equation is used by the program to estimate the cumulative cost of repair and maintenance. The form of the R & M equation used in both models is:

$$R_y = A + B * U_y^1 + C * U_y^2 + D * U_y^3$$

A, B, C, and D are regression coefficients which may have positive, negative, or zero values depending on the shape of the curve fitted to the data. The historic usage levels, $U_y$, were transformed (squared and cubed) prior to the regression analysis to generate equations which would better fit the data. A backwards stepwise regression analysis was employed to generate three equations and the best fitting equation was chosen for the analysis. (See report page 8).

## $O_y$ Cumulative Ownership Costs

$O_y$, the cumulative cost of ownership has three components.

$$O_y = D_y + I_y + L_y$$

Where $D_y$ = cumulative loss in market resale value of the machine to year y

$I_y$ = cumulative cost of insuring the machine to year y

$L_y$ = cumulative opportunity cost to year y

$D_y$, the cumulative loss in market resale value (simple model only) is modelled after a method used in the Systematic Analysis of Vital Equipment (S.A.V.E.) developed by Canadian Forest Products Ltd. in 1972. The rate of machine market resale value loss declines with machine age (Figure J).

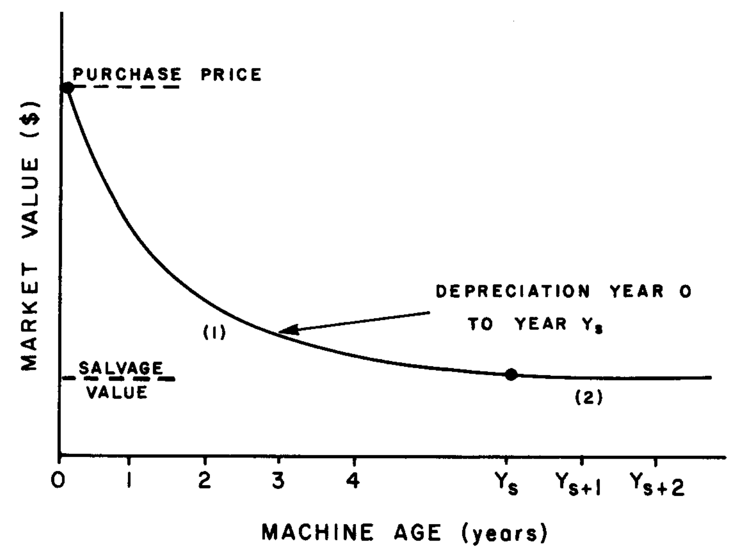


FIGURE J. Accelerated Decline of Market Resale Value--Simple Model.

Key to Figure J.

1. During the first year, the machine exhibits the largest drop in value, usually between 25% and 40% of the initial value, depending on the machine type and the application. Between the second year and the year $Y_s$, when the market resale value becomes constant, the rate of decline in market resale value steadily slows. The constant market resale value (salvage value) and related machine age were determined from information supplied by equipment distributors and auctioneers.

2. After machine age $Y_s$, the market resale value remains constant.

The following was used to calculate machine market resale values between year 1 and year $Y_s$ of the analysis. Machine market resale values were also used in the calculations of insurance and opportunity costs.

$$Q = \text{market resale value factor}$$

$$Q = \frac{(P - S)(Y_s - 1)}{(1 - d_1)P - S} - Y_s$$

Where $P$ = purchase price inclusive of all taxes, freight, and preparation but excluding operating supplies such as wire rope, fuel, etc.

$S$ = salvage or constant market resale value

$Y_s$ = year or machine age when market resale value reaches constant or salvage value

$d_1$ = percentage decline in market resale value during the first year, expressed as a decimal. For each machine type, $d_1$ was determined from interviewing equipment distributors and auctioneers.

The market resale value factor, Q, was used to calculate the remaining market resale value for each year (i.e., $y = 1,2,3...Y_s$) of machine age. This procedure simulates the real life case of rapid market resale value decline early in machine age.

$$M_y = \frac{(P - S)(Y_s - y)}{Y_s + (Q * y)} + S$$

Where $M_y$ = market resale value in year y

The cumulative loss in market resale value for each year, y, of the analysis then is:

$$D_y = P - M_y$$

When the machine age is greater than $Y_s$, then the cumulative loss in market resale value remains constant at:

$$D_y = P - S$$

The second component of cumulative ownership cost, $I_y$, is the cumulative insurance cost for each year. $I_y$ is a function of the average market resale value of the machine calculated year by year (using values of $M_y$ above). The <u>cumulative</u> insurance cost to each year y is:

$$I_y = \sum_{j=1}^{y} \frac{M_{j-1} + M_j}{2} * i$$

Where
$I_y$ = cumulative insurance cost to year y
$i$ = insurance rate expressed as a decimal. Usually about 1 to 5 percent.
$y$ = machine age ($y = 1 \ldots 20$ years)
$M_{j-1}$ = market resale value at beginning of each year j (from $M_{j-1}$ and $M_y$ above)
$M_j$ = market resale value at the end of each year j

The third component of cumulative ownership cost, $O_y$, is the cumulative opportunity cost, $L_y$. The <u>cumulative</u> opportunity cost for each year y is:

$$L_y = \sum_{j=1}^{y} \frac{M_{j-1} + M_j}{2} * h$$

Where
$L_y$ = opportunity cost for year y
$h$ = hurdle rate or opportunity cost of capital
$M_{j-1}$ = market resale value at beginning of each year j (from market resale values calculated above)
$M_j$ = market resale value at the end of each year j

The cumulative combined cost, $C_y$, for each year y thus becomes:

$$C_y = R_y + D_y + I_y + L_y$$

For each year of the analysis, the cumulative combined cost, $C_y$, is expressed per unit of cumulative usage, $U_y$, for each year.

$$C_y \,/\, U_y \qquad \text{(i.e., \$/h, \$/km, \$/tonne)}$$

The machine age yielding the minimum $/unit usage is the recommended economic replacement age.

## B. Description of the After-tax, Discounted Cash Flow Replacement Model (Complex Model)

The Uniform Annual Equivalent (UAE) after-tax, present value cost of repair, maintenance, and ownership is calculated for each year, y, of the analysis. The year yielding the minimum UAE combined cost indicates the year to replace. The general form for UAE is:

$$UAE_y = CRF_y \; * \; [\, R_y + O_y \,]$$

Where $y$ = machine age (years)

$UAE_y$ = uniform annual equivalent cost for year y

$CRF_y$ = capital recovery factor. A factor applied to a present value sum of money to yield a series of equal annual payments for a given number of years in the future at a given rate of interest.

This factor is calculated for each year of the analysis and applied to the cumulative after-tax, present value of repair, maintenance, and ownership costs of a machine to give the annual cost of owning and maintaining the machine for a life of y years.

$$CRFy = \frac{r(1 + r)^y}{(1 + r)^y - 1}$$

Where $r$ = real cost of capital determined from the bank interest rate and the inflation rate

$$r = \frac{(1 + \text{bank rate})}{(1 + \text{inflation rate})} - 1$$

Rates are expressed as decimals, e.g., $r = 0.03$. Historically, the real cost of capital, r, has been 3 to 4 percent.

## $R_y$ Cumulative Repair and Maintenance Costs

Ry = cumulative after-tax, present value of the repair and maintenance cost to year y. (See simple model description and report page 8 for further details regarding the regression equation relating usage and cumulative repair and maintenance costs.)

$$R_y = (1-c) * \sum_{j=1}^{y} \left[ ( R_j - R_{j-1} ) * \frac{1}{(1+r)^j} \right]$$

Note that the discounting, $(1+r)^j$, is applied on a year-to-year basis, thus the need to calculate repair and maintenance costs, $(R_j - R_{j-1})$ on an annual basis.

Where $R_j$ = cumulative repair and maintenance cost to year j obtained from the regression equation described in the simple model description

$c$ = corporate income tax rate

$r$ = real cost of capital

$(1+r)^j$ = discounting factor to discount a future value to its present value equivalent (e.g., \$100 received two years hence is equivalent to $\$100/(1 + 0.10)^2$ = \$82.64 today at a 10% rate of interest).

## $O_y$ Cumulative Ownership costs

$O_y$ = cumulative ownership cost to year y. $O_y$ has two components:

$$O_y = D_y + I_y$$

$D_y$ = cumulative after-tax, present value loss in market resale value. The machine market resale value changes at three rates depending on machine age (Figure K).

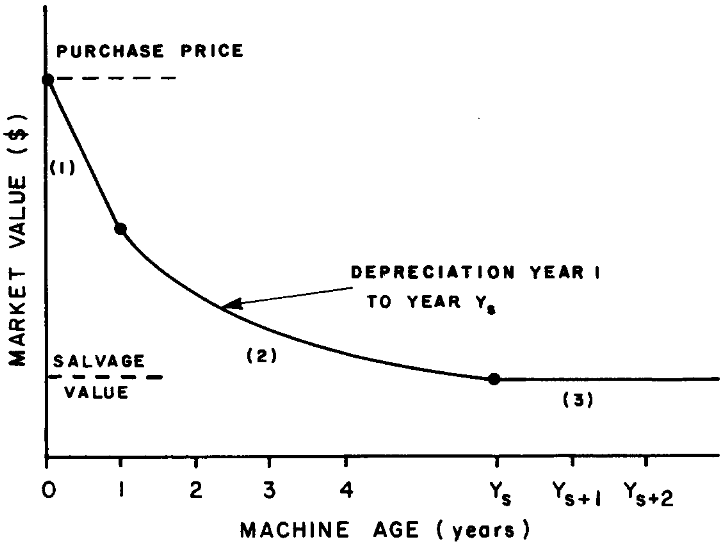


FIGURE K. Three Rates of Change of Declining Market Resale Value--Complex Model.

Key to Figure K.

1. During the first year, the machine exhibits the largest drop in value, usually between 25% and 40% of the initial value, depending on the machine type and the application. The percentage of initial decline, $d_1$, was determined from interviewing equipment distributors and auctioneers for each machine type.

2. Between the second year and year $Y_s$ (when the market resale value becomes constant), the rate of decline in market resale value steadily slows and the declining balance method is used to calculate remaining market resale value. Information from distributors and auctioneers was used to determine constant market resale value (salvage value) and associated machine age.

3. After machine age $Y_s$, the market resale value remains constant.

Market resale values are calculated for each year of machine age. After year 1, the remaining market resale value, $M_1$, is:

$$M_1 = P * (1-d_1)$$

Where $P$ = machine purchase price

$d_1$ = percentage decline in market resale value during the first year expressed as a decimal (determined from equipment distributors and auctioneers)

For machine age 2 years to $Y_s$, the remaining market resale value is calculated using a declining balance method. Given the market resale value after year 1, $M_1$, the final salvage value, S, and the age when market resale value reaches salvage value, $Y_s$, the factor for declining balance is:

$$d = 1 - \left[\frac{S}{P(1 - d_1)}\right]^{\frac{1}{(Y_s - 1)}}$$

= annual loss of market resale value factor

Where $S$ = constant market resale value or salvage value

$Y_s$ = machine age when market resale value reaches salvage value

$P$ = machine purchase price

$d_1$ = decline in market resale value after the first year

Then market resale value after year 2 to year $Y_s$ is:

$$M_y = M_{y-1} * (1-d)$$

There is no further decline in market resale value when the machine age exceeds the age, $Y_s$, when market resale value becomes constant (salvage value). The remaining market resale value beyond age $Y_s$ is:

$$M_y = S$$

Where $y$ = machine age equal or greater than $Y_s$

The cumulative, after-tax, present value of market resale value loss, $D_y$, is calculated for each year y = 1 to 20 as follows:

$$D_y = \left( P - \frac{M_y}{(1+r)^y} \right) * CTF$$

Where
- $P$ = machine purchase price
- $M_y$ = market resale value at the end of year y
- $(1+r)^y$ = discounting factor to determine the present value of market worth for year y
- $CTF$ = capital tax factor. A factor applied to a capital expenditure to determine the after-tax, discounted cost.

$$CTF = 1 - \frac{ca}{a + r}$$

Where
- $c$ = corporate income tax rate (arbitrarily set at 50%)
- $a$ = capital cost allowance rate for the equipment class
- $r$ = real cost of capital

Thus

$$D_y = \left(P - \frac{M_y}{(1+r)^y}\right) * \left(1 - \frac{ca}{a + r}\right)$$

The second component of ownership cost is insurance, $I_y$. For any year, y, the cumulative after-tax, present value cost of insurance is calculated as follows:

$$I_y = \sum_{y=1}^{y} \left[ \frac{M_{j-1} + M_j}{2} * i * (1-c) * \frac{1}{(1+r)^j} \right]$$

Where
- $I_y$ = cumulative, after-tax cost of insurance as a function of the average machine market resale value for each year y. Insurance costs are calculated annually then summed to give cumulative costs.
- $y$ = machine age from 1 to 20 years
- $i$ = insurance rate expressed as a decimal, usually about 1% to 5%
- $M_{j-1}$ = market resale value at beginning of year j (from market resale values calculated above)
- $M_j$ = market resale value at the end of year j
- $(1+r)^j$ = discounting factor to determine the present value of insurance cost for year j

The cumulative after-tax, present value combined cost of repair and ownership for each year becomes:

$$C_y = R_y + D_y + I_y$$

Applying the capital recovery factor (CRF) gives the uniform annual equivalent cost:

$$UAE_y = C_y * CRF = [R_y + D_y + I_y] * CRF$$

For example, if the cumulative after-tax, present value combined cost to the fifth year, (y = 5) is $125 000, then the uniform annual equivalent cost for each of the five years is:

$$UAE = \$125\ 000 * CRF = \$125\ 000 * \frac{r(1+r)^5}{(1+r)^5 - 1}$$

$$= \$125\ 000 * \frac{0.04(1+0.04)^5}{(1+0.04)^5 - 1}$$

= $28 078 per year at 4% real rate of interest

The machine age yielding the minimum uniform annual equivalent cost denotes the optimum replacement age.

## APPENDIX II

### R & M Regression Equations

(t in these equations is usage measured in hours)

**DIVISION: CHEMAINUS**

| | |
|---|---|
| 27-m highlead yarders | $\$RM = 22\ 221 + 7.961E{-4}\ t^2$ |
| American 7250 grapple yarder | $\$RM = 7\ 577 + 2.470E{-3}\ t^2$ |
| American 7220 grapple yarder | $\$RM = 23\ 907 + 3.220E{-3}\ t^2$ |
| Loaders (tank carrier) | $\$RM = -20\ 694 + 21.98\ t - 5.962E{-4}\ t^2 + 7.835E{-8}\ t^3$ |
| Loaders (rubber-tired carrier) | $\$RM = 38\ 568 + 3.911E{-3}\ t^2$ |
| Off-highway trucks | $\$RM = -4\ 409 + 6.593\ t + 7.610E{-4}\ t^2 - 1.031E{-8}\ t^3$ |
| Highway trucks | $\$RM = 16\ 102 + 6.241E{-4}\ t^2$ |
| D8-sized tractors | $\$RM = -8\ 356 + 16.97\ t - 2.696E{-3}\ t^2 + 3.661E{-7}\ t^3$ |

**DIVISION: KELSEY BAY**

| | |
|---|---|
| 27-m highlead yarder (rubber-tired carrier) | $\$RM = 51\ 221 + 1.586E{-3}\ t^2$ |
| 27-m highlead yarder (tank carrier) | $\$RM = -2\ 985 + 14.87\ t - 3.889E{-4}\ t^2 + 4.397E{-8}\ t^3$ |
| Grapple yarder | $\$RM = -25\ 055 + 39.13\ t - 5.752E{-3}\ t^2 + 5.421E{-7}\ t^3$ |
| Loader (tank carrier) | $\$RM = 86\ 404 + 1.374E{-3}\ t^2$ |
| Loader (rubber-tired carrier) | $\$RM = 561 + 19.01\ t + 3.986E{-4}\ t^2 + 6.410E{-8}\ t^3$ |
| KW 849 off-highway truck | $\$RM = 11\ 973 + 1.340E{-3}\ t^2$ |
| KW 850 off-highway truck | $\$RM = -1\ 232 + 14.33\ t + 9.471E{-4}\ t^2 + 7.830E{-9}\ t^3$ |
| TD 25C-sized tractors | $\$RM = -1\ 575 + 29.77\ t^2$ |

DIVISION: NORTHWEST BAY

| | | |
|---|---|---|
| 27-m highlead yarder | \$RM = | $12\,601 + 6.470E{-}4\ t^2$ |
| Grapple yarder | \$RM = | $19\,673 + 14.17\ t - 2.020E{-}4\ t^2 + 2.319E{-}8\ t^3$ |
| Loader (rubber-tired carrier) | \$RM = | $-11\,457 + 21.86\ t - 1.024E{-}3\ t^2 + 7.451E{-}8\ t^3$ |
| Highway trucks | \$RM = | $35\,400 + 8.621E{-}4\ t^2$ |
| D8-sized tractors | \$RM = | $1\,362 + 3.107\ t + 6.352E{-}4\ t^2 + 4.867E{-}8\ t^3$ |