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UNCTAD MONOGRAPHS ON PORT MANAGEMENT

A series of monographs prepared for UNCTAD in collaboration with the International Association of Ports and Harbors (IAPH)

8

Economic Approach to Equipment Selection and Replacement

by

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INTRODUCTION TO THE SERIES

In the ports of industrialized countries, operating systems and personnel development are based on skills acquired through experience, on emulation of other industries and on the innovation which is easily undertaken in advanced industrial environments. These means are generally lacking in developing countries, and port improvements occur only after much deliberation and often through a process of trial and error. Some means are required by which ports in developing countries can acquire skills that are taken for granted in countries with a long industrial history, or can learn from the experience of others of new developments and how to meet them.

Formal training is one aspect of this, and UNCTAD has devoted considerable effort to developing and conducting port training courses and seminars for senior management and to preparing training materials to enable middle-management courses to be conducted by local instructors. It was felt that an additional contribution would be the availability of clearly written technical papers devoted to common problems in the management and operation of ports. The sort of text that will capture an audience in the ports of developing countries has to be directed at that very audience, and very few such texts exist today.

Following the endorsement of this proposal by the UNCTAD Committee on Shipping in its resolution 35 (IX), the UNCTAD secretariat decided to seek the collaboration of the International Association of Ports and Harbors, a non-governmental organization having consultative status with UNCTAD, with a view to producing such technical papers. The present series of UNCTAD Monographs on Port Management represents the results of this collaboration. It is hoped that the dissemination of the materials contained in these monographs will contribute to the development of the management skills on which the efficiency of ports in developing countries largely depends.

A. Bouayad
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FOREWORD

When UNCTAD first decided to seek the co-operation of the International Association of Ports and Harbors in producing monographs on port management, the idea was enthusiastically welcomed as a further step forward in the provision of information to managements of ports in developing countries. The preparation of monographs through the IAPH Committee on International Port Development has drawn on the resources of IAPH member ports of industrialized countries and on the willingness of ports in developed countries to record for the benefit of others the experience and lessons learnt in reaching current levels of port technology and management. In addition, valuable assistance has been given by senior management in ports of developing countries in assessing the value of the monographs at the drafting stage.

I am confident that the UNCTAD monograph series will be of value to managements of ports in developing countries in providing indicators towards decision-making for improvements, technological advance and optimum use of existing resources.

The International Association of Ports and Harbors looks forward to continued co-operation with UNCTAD in the preparation of many more papers in the monograph series and expresses the hope that the series will fill a gap in the information currently available to port managements.

C. Bert Kruk
Chairman
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CONTENTS

OVERVIEW

(i) Engineering economic analysis is usually involved with various projects, which are mutually exclusive, and compares them on the basis of some economic measure of effectiveness. In an effort to quantify the intangible factors as well, the projects under study are mainly compared in monetary terms. The objective of this paper is to present an analytical methodology for the comparison in monetary terms of the investment for alternative types of cargo-handling equipment.

(ii) The approach proposed is the only one widely recognized and - via the discounting cash flow method - provides a mathematical result which will be accurate, if properly and correctly interpreted. Its use is by no means restricted to port equipment and the technique has a wider application. In chapter II, a case study is presented to illustrate the procedure and sensitivity analysis is discussed.

(iii) Chapter III discusses how to calculate the economic life of equipment and worked examples are given. A graph has been prepared for certain assumptions which relates economic life to maintenance cost.

(iv) Chapter IV deals with the problems of determining whether to repair or replace damaged equipment and an example is given.

(v) Chapter V describes the basic elements of an Equipment Management Information System which are necessary to allow the evaluation of alternative types of cargo-handling equipment.

Chapter I

COMPARISON OF ALTERNATIVES: GENERAL CONSIDERATIONS

A. Introduction

1. Engineering economic analysis is mainly concerned with the comparison of alternative projects, on the basis of an economic measure of effectiveness. A non-recurring initial investment, recurring operating expenses, benefits and/or revenues, and a future scrap or resale value are usually associated with each project. The various alternatives are normally compared, introducing a large number of different criteria, including system performance and economic performance. Among the system performance characteristics that are of interest, quality, safety, and customer service are of primary importance. Among the economic performance characteristics normally considered, the initial investment requirements, return on investment, and the profile of the cash flow which includes benefits and costs, are important. Since the cash flow profiles are normally different for various alternatives, in order to compare their respective economic performance, one must compensate for the differences in the timing of cash flow. The concept of the time value of money is introduced and a number of mathematical operations, with an emphasis on modelling cash flow profiles, are examined.

2. Both a financial and an economic evaluation are generally required before a port investment project is approved. The former is essentially a computation of commercial profitability and is not in itself sufficient; it is the economic evaluation - the comparison of the social costs and benefits to the country - which determines whether or not a project is accepted.

3. The two evaluations are identical in several respects:

(a) They require an evaluation of a succession of costs and benefits over the whole useful life of the project;

(b) They take into account the time-value of money and future benefits and costs must be discounted back to their present-day value;

(c) They use common criteria to evaluate investments, namely one or more of the following[1]:

(i) Average rate of return;
(ii) Pay-back period;
(iii) Net present value;
(iv) Internal rate of return;
(v) Benefit/cost ratio.

B. Monetary considerations

4. The main emphasis is on the use of a logical methodology for selecting one investment plan from a number of alternatives available to the decision-maker. The criterion for selection will be the economic effectiveness. However, the decision-maker has a number of economic measures to consider. For example, faced with an increase in demand for a particular service, the management of a company may have to choose between either increasing the amount of overtime paid to employees or installing a new piece of equipment to meet the increased demand. Clearly, a comparison of costs for each of these alternatives over some time period or planning horizon is required, and one objective of management should be to select the alternative with the lowest cost.

5. Factors which affect a decision but cannot be expressed in monetary terms are often called intangibles. Almost all real-world business decisions involve both monetary and intangible factors. Although considerable investigation and study are required, many of the non-economic factors involved in a decision can be finally expressed in monetary terms. For instance, in the above example, additional cost of maintenance can be expressed as the cost of training maintenance personnel for the installation and repair of the new machinery. Other factors involved,

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1 For a more detailed discussion on evaluation methods, see the UNCTAD publications, *Appraisal of port investments* (TD/B/C.4/174) and *Port development; A handbook of planners in developing countries* (TD/B/C.4/175/Rev.1)

however, are not so easily reduced to monetary values. For example, there is a social cost associated with staff having to work either extra overtime or on shifts.

C. Comparison of alternatives

6. To evaluate investments, multiple factors are involved. Therefore to compare mutually exclusive alternatives, the conversion of all costs and benefits into monetary terms becomes essential. A systematic approach that can be followed in comparing investment alternatives is summarized below:

(a) The set of feasible, mutually exclusive investments to be compared must be defined;

(b) The time-period or the planning horizon to be used in the economic study must be decided upon;

(c) The cash flow profiles for each alternative must be developed;

(d) The time value of money must be specified;

(e) The alternatives using the measure of merit or effectiveness must be compared;

(f) A sensitivity analysis must be performed as a supplementary exercise;

(g) The preferred alternative will be selected.

7. The procedures outlined for comparing alternatives are intended to help evaluate the quantitative aspects of various alternatives. It is a fact, however, that non-quantitative aspects of each investment such as safety, personnel considerations, and environmental effects must be also taken into consideration by experienced managers when evaluating the alternatives.

D. Defining the planning horizon

8. In comparing investment alternatives, it is important to compare them over a common period of time. We define that period of time to be the planning horizon. In a sense, the planning period or horizon defines the width of a "window" that is used to view the cash flows generated by an alternative. In order to make an objective evaluation, the same window must be used in viewing each alternative.

9. In some cases the planning horizon is easily determined; in other cases the duration of one or more projects is uncertain and causes concern over which time period to use. Some commonly used methods for determining the planning horizon in economic studies include:

(a) Least common multiple of lives for the set of feasible and mutually exclusive cases;

(b) Shortest project life among the projects;

(c) Longest project life among the alternatives.

10. In the literature on economic analysis, the method most commonly used in selecting the planning horizon is the least common multiple of lives approach. If, for example, the lives of two alternatives had been 8 and 6 years, then the period of time to be used would be 24 years. The first piece of equipment is replaced three times (3 x 8) and the second four times (4 x 6) to give a total of 24 years.

11. If the shortest project life is used to define the planning horizon, estimates are required for the other alternatives with longer lives, of the asset values for the unused portions of their lives. If the longest life is used, then some difficult decisions must be made concerning the period of time between the projects' shortest and longest times. Consequently, when the shortest life alternative reaches the end of its life, it must be replaced with some other asset capable of performing the service required.

E. Interest calculations

1. Time value of money

12. If someone is offered either $100 today or $100 a year from today, he will undoubtably choose the former. Someone else could even choose to receive $98 today rather than $100 a year from now. The use of money is a valuable asset, so valuable that people are willing to pay, in order to have money available for their use. Money available ***now*** rather than a year later means that there is more time for its possible use.

13. Let us suppose that two sets of cash flows exist each having the same arithmetical sum. Let us further suppose that either these cash flows occur over different periods or the flow of the cash is different over the same period, and that a decision is required as to which alternative is best. To take a decision that makes sense, the cash flows must be altered so that they can be compared properly. This can be done by a mathematical manipulation of the cash flows, known as discounting, by which the future cash flows are discounted to give their value now for each of the alternatives. This technique is known as discounted cash flow (DCF).

14. The relation between the current or present value of a single sum of money and its future value can be expressed in a mathematical way. Assuming that time is measured in years, if a single sum of money has a present value of P, its value in n years would be equal to $F_n = P + In$, where F_n is the accumulated value of P over n years, or the future value of P, and In is the increase in the value of P over n years. In is referred to as the accumulated interest in borrowing and lending transactions and is a function of P, n, and the annual interest rate, i. The present value of a future sum of money is F_n - In.

2. Future worth factor

15. To illustrate the mathematical operations involved in modelling cash-flow profiles using compound interest, we first consider the investment of a sum of money, P, in a savings account for n interest periods. Let the interest rate per interest period be denoted by i, and let the accumulated total in the fund for n periods in the future be denoted by F_n. Then, the amount in the fund after n periods equals $P(1 + i)^n$. For easy reference, for calculating the values of F (the future worth) when given values of P (the present worth), the quantity $(1 + i)^n$ is referred to as the future worth factor. The above discussion can be summarized as follows:

Let P = the equivalent value of an amount of money at time zero, or present worth,

F_n = the equivalent value of an amount of money at time n, or future worth,

i = the interest rate per interest period,

n = the number of interest periods.

Thus, the future worth is related to the present worth as follows:

$$F_n = P\ (1 + i)^n$$

or,

$$P = F_n / (1 + i)^n$$

3. Discount rate

16. An important step in evaluating investment alternatives involves the specification of the interest or discount rate to be used. Even though a project may be financed entirely from internal sources of funds, the use of an interest rate is recommended. The reason for doing so is to reflect the cost of investing money in a particular project instead of investing it elsewhere and earning a return on the investment. The cost of forgoing other investment opportunities is referred to as the opportunity cost.

17. Except where other intangible benefits are involved, the discount rate should be greater than the cost of securing additional capital. It should be greater than the cost of capital by an amount that will cover unprofitable investments that a firm must make for non-monetary reasons. Examples of these would include investments in safety devices, antipollution equipment and recreational facilities for employees.

18. The discount rate that is specified establishes the firm's minimum attractive rate of return for a project to be justified. If the present worth was negative for a project, that is the total discounted cash flow for costs and benefits was negative, the project would not be recom-

mended. Some ports follow a standard discount rate in their economic studies while others maintain a flexible policy.

F. Elements of economic analysis of projects in the public sector

19. Knowing how to evaluate and select projects operated by the public sector is at least as important to today's engineer as a similar knowledge relating to the private sector. The analytical methods for public and private projects are very similar, even though there are some differences between the two. The methods most frequently used in evaluating national or local government projects are cost-benefit and cost-effectiveness analysis. The cost-benefit methods require that costs and benefits be evaluated on a monetary basis.

20. Each benefit and cost must be quantified in monetary terms. Benefits, or the positive effects of an investment, refer to desirable consequences. Costs are the negative effects. The annual benefits and costs are determined for the life of the project and the present worth of the sums of the discounted benefits and costs are then calculated. The measure of merit is chosen. Cost-benefit analysis frequently uses the benefit-cost ratio (B / C) or, to a lesser extent, a measure of benefits less costs (B - C).

Chapter II

CASE STUDY

A. Introduction

21. An important prerequisite for the success or failure of a container terminal is, among others, the choice of proper equipment. The equipment is not only the biggest single capital expenditure, but in practice it determines the operational procedures and performance of the terminal.

22. This equipment consists of the ship-to-shore gantry cranes, transfer equipment and the stacking area handling equipment. There are various alternatives for the transfer/stacking area equipment. The objective of this exercise is to illustrate a systematic mathematical approach for choosing between two alternative types of equipment. For this case study, a comparison is made between rubber-tyred gantry cranes (RTG) and straddle carriers with transfer to and from the quay made by tractor trailer equipment.

B. Assumptions

23. The following are the assumptions made for this case study:

(a) Benefits of the two stacking systems are the same; [2]

(b) Labour costs are excluded on the assumption that the greater number of straddle carrier operators are paid less than the RTG operators;

(c) Costs of land are excluded;

(d) Payments for annual maintenance are made at the beginning of each year;

(e) Revenue from salvage is received at the end of the year and reported at the beginning of the next year unless noted otherwise.

The currency used in the analysis is the C£ (Cyprus pound). For reference C£ 1 is approximately equal to 2 United States dollars.

24. To illustrate the mathematical calculations performed, an example is worked out:

Consider a container terminal that is expected to handle approximately 140,000 boxes per year and the two mutually exclusive alternatives for yard stacking are:

Equipment type A - rubber-tyred gantry cranes (economic life 15 years)

Equipment type B - straddle carriers (economic life 10 years)

The planning horizon based on the least common multiple of economic life will be 30 years. The discount rate used for evaluating investments for the terminal is 10 per cent. Also assume that for this example there is no difference in the cost of pavement or surfacing for the two systems, and that no additional equipment is needed for either alternative. For most equipment the cost of maintenance tends to increase with the age of the equipment and this rate of increase is referred to as the j factor.

25. Costs associated with the purchase and operation of rubber-tyred gantry cranes are as follows:

Units required	: 6
Capital expenditure (CE)	: 6 x 320,000 = C£ 1,920,000.
Salvage value (20 per cent of CE)	: C£ 384,000.
Annual maintenance/repair/ fuel (10 per cent of CE), which includes the cost of spare parts	: C£ 192,000/annum with 8 per cent

2 Straddle carriers offer more speed and flexibility, while RTG make better use of the land and can use gravel beds for container stacking.

annual increase (j factor)

26. Similarly for straddle carriers the costs are as follows:

Units required	: 8
Capital expenditure (CE)	: 8 x 200,000 = C£ 1,600,000
Salvage value (20 per cent of CE)	: C£ 320,000
Annual maintenance/repairs/ fuel (18 per cent of CE)	: C£ 288,000 with j = 8 per cent

C. Calculations

27. The actual and the discounted cash flows are given in table 1 for the two types of equipment. This table has been prepared using a spread-sheet package on a microcomputer. The maintenance costs are at their lowest level in the year following the purchase of the equipment and increase to their maximum in the year the equipment is replaced. The discounted value for each year is determined by multiplying the cost by the discount factor which is calculated given:

$$1 / (1 + \text{discount rate})^{\text{no. of years - 1}}$$

A table of discount factors is reproduced in annex 1. The cash flow for each year is shown as the actual and the discounted value. For example, for equipment A the maintenance cost has risen from C£ 192,000 in year 1 to C£ 261,200 (192,000 x 1.08^4) in year 5. The discounted value is C£ 178,400 (261,200 x 0.6830 (discount factor for 10 per cent and 5 years)). The total discounted cash flow or present worth is the accumulated sum of the discounted values.

28. The present worth is the amount of money required now to pay all future costs of acquiring and operating the equipment over the planning period. Thus the actual cash flow rather than the book flow must be used. If the company's own funds are used for the equipment's purchase, then all cash flow occurs in the year of purchase. If external funding is used for purchasing, the cost flows are the down payment in the purchase year and subsequent loan and interest repayments in the following years. Depreciation would only be a factor in cost benefit analysis where it would be used to reduce taxes and would thus reduce the negative tax flow.

29. For the two types of equipment the recommended alternative is the one with the lower total discounted cost i.e. -

A. For rubber-tyred gantry cranes = C£ 5,414,800

B. For straddle carriers = C£ 6,339,400

Since the total cost for A is less than the total cost for B, alternative A should be selected.

30. In any comparison it is important to bring all costs into the comparison. For example, when selecting different container-handling systems, all the costs of each system must be considered, including differences in transfer equipment and paving requirements. Common elements for different systems can be excluded for comparison purposes. Finally, local conditions and operational experiences play an important role, and managers should also consider them carefully.

Table 1

Comparison of equipment by discounted cash flow method
(assuming 10 per cent discount rate)

EQUIPMENT A 5414.8 - Total discounted cost (C£ '000)

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Capital cost	1920.0									
Maintenance	192.0	207.4	223.9	241.9	261.2	282.1	304.7	329.1	355.4	383.8
Salvage										
Total	2112.0	207.4	223.9	241.9	261.2	282.1	304.7	329.1	355.4	383.8
Discounted	2112.0	188.5	185.1	181.7	178.4	175.2	172.0	168.9	165.8	162.8
Year (cont.)	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Capital cost						1920.0				
Maintenance	414.5	447.7	483.5	522.2	563.9	192.0	207.4	223.9	241.9	261.2
Salvage						384.0				
Total	414.5	447.7	483.5	522.2	563.9	1728.0	207.4	223.9	241.9	261.2
Discounted	159.8	156.9	154.1	151.3	148.5	413.7	45.1	44.3	43.5	42.7
Year (cont.)	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*
Capital cost										
Maintenance	282.1	304.7	329.1	355.4	383.8	414.5	447.7	483.5	522.2	563.9
Salvage										384.0 *
Total	282.1	304.7	329.1	355.4	383.8	414.5	447.7	483.5	522.2	179.9
Discounted	41.9	41.2	40.4	39.7	39.0	38.3	37.6	36.9	36.2	13.5

EQUIPMENT B 6339.4 - Total discounted cost (C£ '000)

Year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Capital cost	1600.0									
Maintenance	288.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	575.7
Salvage										
Total	1888.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	575.7
Discounted	1888.0	282.8	277.6	272.6	267.6	262.8	258.0	253.3	248.7	244.2
Year (cont.)	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Capital cost	1600.0									
Maintenance	288.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	575.7
Salvage	320.0									
Total	1568.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	575.7
Discounted	604.5	109.0	107.0	105.1	103.2	101.3	99.5	97.7	95.9	94.1
Year (cont.)	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*
Capital cost	1600.0									
Maintenance	288.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	575.7
Salvage	320.0									320.0 *
Total	1568.0	311.0	335.9	362.8	391.8	423.2	457.0	493.6	533.1	255.7
Discounted	233.1	42.0	41.3	40.5	39.8	39.1	38.3	37.6	37.0	18.0

* salvage funds received at end of year.

D. Sensitivity analysis

31. In the above exercise it was assumed that all the values of the parameters of the economic models were known with certainty. In particular, correct estimates of the values for the length of the planning horizon, the discount rate, the costs - i.e. each of the individual cash flows - were assumed to be known. Often these values are not known with certainty and this effect of uncertainty should be investigated. For port investments, cargo tonnage, cargo mix and productivity forecasts are not accurately known. This uncertainty in demand for and supply of port services gives rise to a risk factor in port investments. The effect of uncertainty can be studied by means of sensitivity analysis.

32. This sensitivity analysis can take two main forms. The simpler method is to repeat the analysis a number of times, each time one of the parameters is set at a value corresponding to a 'risk position'. For evaluating equipment, this would give a number of discounted cash flows for different cases.

33. Another approach, for cost-benefit analysis, is to calculate how far each of the input factors will have to change before the project's net present value falls to zero. If the Internal Rate of Return (IRR) method is being used, i.e. determining the discount rate that will make the net present value zero, the calculation will show how far the input factors have to change before the project IRR falls to the minimum acceptable level.[3]

34. For equipment evaluation, a computer spread-sheet model can be prepared and easily used to evaluate various scenarios. The opportunity is provided to change any parameter or combination of parameters influencing the situation *ad infinitum* and subsequently study the results obtained. For evaluating uncertainty for equipment choice, it is suggested that the cost of equipment, annual maintenance/repair/fuel and annual increase in maintenance/repair costs can be altered to determine the conditions for which one type of equipment becomes more advantageous than another.

35. For the case study, a 17 per cent increase in the price of equipment A or a 15 per cent reduction in the price of equipment B would make equipment B a better selection. Similarly a 30 per cent increase in the cost of maintenance/repair/fuel for equipment A (cost increases from 10 per cent to 13 per cent of the initial cost) or a 25 per cent reduction in these costs for equipment B would make equipment B a better selection (cost decreases from 18 per cent to 13.5 per cent). If the number of straddle carriers (equipment B) has been over-estimated and only six straddles are required, the total discounted cost for this alternative would be C£ 4,754,500 and thus the straddle system would be the recommended alternative. These limits will assist decision-makers in selecting the equipment to be purchased.

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3 For a more detailed discussion on sensitivity analysis, see the UNCTAD publications, *Appraisal of port investments* (TD/B/C.4/174) paragraphs 90 - 95 and *Port development; A handbook of planners in developing countries* (TD/B/C.4/175 Rev.1) paragraphs 193 - 196.

Chapter III

ECONOMIC LIFE CALCULATIONS

36. To determine the economic life of a piece of equipment requires the calculation of the discounted value of all future costs associated with each replacement policy. In general the costs to be included are all costs that depend on the age of the machine. Costs that do not change with the age of the machine, such as labour costs and power, need not be considered. The costs are incurred over a period of time, and must be discounted to the present in the normal way.

37. For economic life calculations the assumption is made that costs increase each year for items of equipment that deteriorate, because of increased maintenance. The following rules apply for minimizing costs:

Rule 1: If the cost of replacing every $n+1$ years is less that the cost of replacing every n years, the item should not be replaced.

Rule 2: If the cost of replacing every $n+1$ years is greater that the cost of replacing every n years, the item should be replaced.

38. We may take a one-year period and call it i and the costs incurred during that period C_i. We may assume that each cost is paid at the beginning of the period in which it is incurred, that the initial cost of new equipment is A, and that the cost of money or discount rate is r.

39. The discounted value K_n of relevant future costs associated with the policy of replacing equipment after every n years is given by summing the discounted costs for the first piece of equipment with the discounted costs for the second piece of equipment, and so on. Operational research text books [4] show that the discounted value K_n is given by:

$$K_n = \frac{A + \sum_{i=1}^{n} C_i \,/\, (1+r)^{i-1}}{1 - 1 \,/\, (1+r)^{n}}$$

Thus, if K_n is less than K_{n+1}, then replacing the equipment each n years is preferable to replacing each $n + 1$ years. K_n is the amount of money required now to pay all future costs of acquiring and operating the equipment when it is renewed every n years.

40. The annual payment or weighted average cost for different replacement periods is given by:

$$\text{Weighted average cost} = \frac{A + \sum_{i=1}^{n} C_i \ (1+r)^{i-1}}{\sum_{i=1}^{n} 1 \,/\, (1+r)^{i-1}}$$

The minimum weighted average cost will then give the optimum replacement period, that is, the period that will minimize the discounted cash flow for operating the machine. The economic life can be defined as the period to the time where the weighted average cost is at its minimum.

41. The calculation of economic life can be illustrated by an example. The minimum weighted average cost is the factor to determine the useful life of the equipment. The following cash flows shown in table 2 are assumed to occur for the next 15 years. The annual increase in equipment maintenance cost is 8 per cent. The last column gives the average annual cost for the various replacement periods - thus replacing the equipment every five years would result in an average

4 For example, see Churchman, C.W., Ackoff, R.L. and Arnoff, E.W., ***Introduction to Operations Research***, John Wiley & Sons, Inc., New York, 1964, pages 484 to 488.

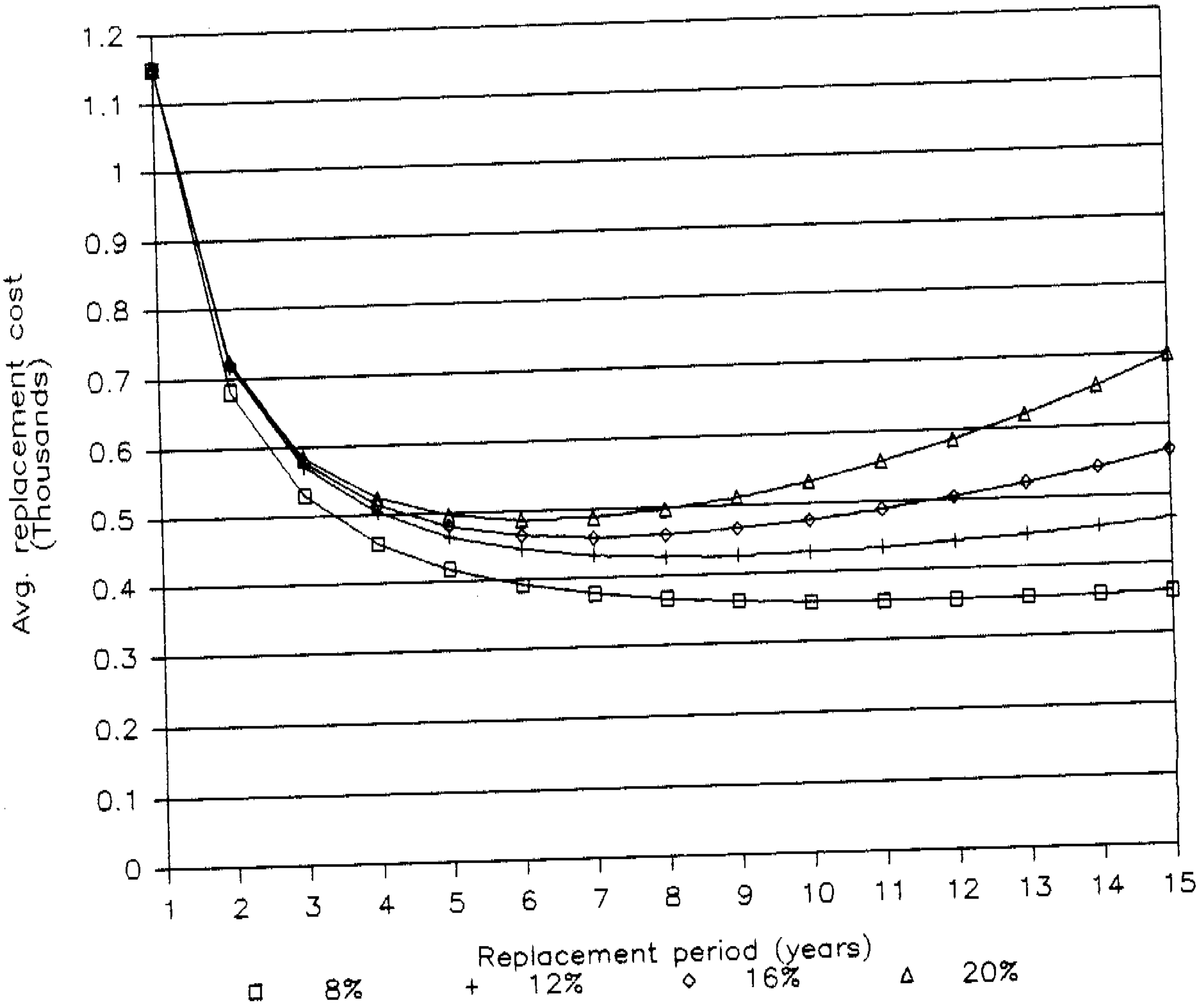
annual cost of C£ 42,113. In this case - provided other factors remain unaltered - the economic life of the equipment is 11 years (since this year has the lowest weighted average cost of C£ 36,150). The equipment should therefore be replaced at the end of its 11th year.

Table 2
Calculation of economic life for new equipment
(assuming no residual value and a 9 per cent discount rate)

Life	Capital	Maint.	Total	Rate 0.09	Disc. cost	Accum. DCF	Sum of factors	Wt.av. cost
1	100000	16000	116000	1.000	116000	116000	1.000	116000
2	0	17280	17280	0.917	15853	131853	1.917	68766
3	0	18662	18662	0.842	15708	147561	2.759	53481
4	0	20155	20155	0.772	15564	163125	3.531	46194
5	0	21768	21768	0.708	15421	178546	4.240	42113
6	0	23509	23509	0.650	15279	193825	4.890	39640
7	0	25390	25390	0.596	15139	208964	5.486	38091
8	0	27421	27421	0.547	15000	223964	6.033	37124
9	0	29615	29615	0.502	14863	238827	6.535	36547
10	0	31984	31984	0.460	14726	253554	6.995	36247
11	0	34543	34543	0.422	14591	268145	7.418	***36150***
12	0	37306	37306	0.388	14457	282602	7.805	36207
13	0	40291	40291	0.356	14325	296927	8.161	36385
14	0	43514	43514	0.326	14193	311120	8.487	36659
15	0	46995	46995	0.299	14063	325183	8.786	37011

42. Figure 1 illustrates the weighted average cost for equipment with an initial cost of 1000 monetary units and with maintenance costs of 15 per cent of the initial cost in the first year. Four curves for various rates of increase of maintenance costs are shown. The discount rate used is 10 per cent. The calculations are based on the assumption that the equipment is replaced with similar equipment. In practice technical improvements are often made and the resulting productivity improvements will justify the earlier replacement of the equipment.

Figure 1
Replacement Cost as a Function of Age



43. By taking different maintenance values as a percentage of the purchase price [5] and different j factors, a family of curves can be calculated to determine the economic life of equipment. The discount rate used for calculating these curves is 10 per cent. These curves are shown in figure 2. The assumption is that the equipment has no residual value. For a given ratio of maintenance cost to purchase cost and a j factor, the economic life can be determined from this graph. For example, assume we have a piece of equipment costing $US350,000 with an estimated maintenance cost for the first year of $US35,000. The ratio of maintenance cost to purchase cost is 0.1. Also assume that the maintenance cost will rise by 12 per cent per year. From the curve in figure 2, the economic life for this piece of equipment is 10 years.

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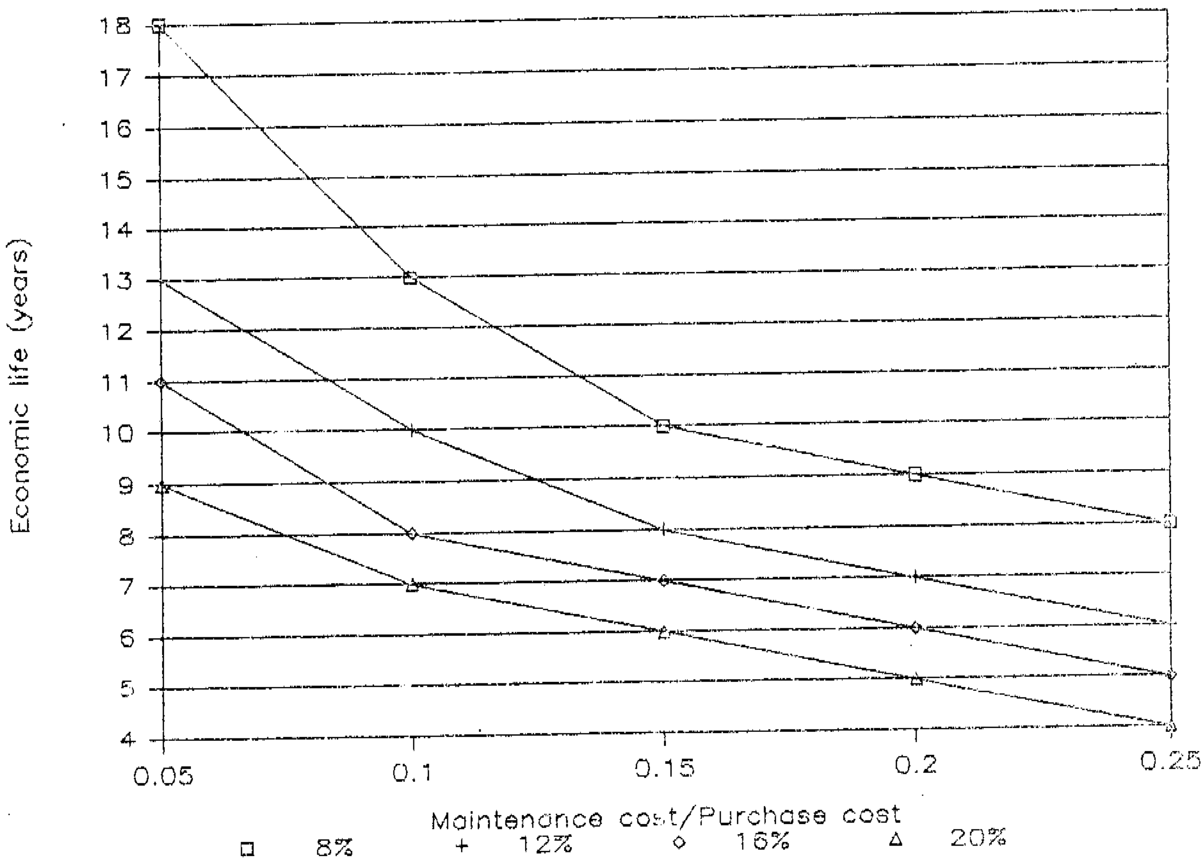
5 Annex 2 gives typical ratios for different types of equipment based on the UNCTAD publication, Operating and Maintenance Features of Container Handling Systems; UNCTAD/SHIP/622; United Nations; Geneva; March 1988.

Figure 2
Optimum Replacement Period



44. For equipment that has a salvage value the formula for the discounted value of all future costs associated with replacing equipment after every ***n*** years is given by:

$$K_n = \frac{A + \sum_{i=1}^{n} C_i \,/\, (1+r)^{i-1} \; - \; S_n \,/\, (1+r)^n}{1 - 1 \,/\, (1+r)^n}$$

where S_n is the salvage value of the equipment at the end of the nth year.

45. A hypothetical example is illustrated in table 3. The column with the heading 'Sum' is the value of the initial cost plus the accummulated discounted maintenance minus the discounted salvage value. For this example, the minimum discounted value occurs at 10 years and therefore the best policy is to replace the equipment every 10 years.

Table 3
Schedule of discounted costs for new equipment
(assuming residual value and a 9 per cent discount rate)

Life	Capital	Maint.	Salvage	Rate 0.09	Disc. maint.	Accum. DMC	Disc. salvage	Sum	K_n
1	100000	16000	80000	1.000	16000	16000	73394	42606	516000
2	0	18000	60000	0.917	16514	32514	50501	82013	518020
3	0	20000	52000	0.842	16843	49347	40154	109194	479306
4	0	22000	44000	0.772	16988	66335	31171	135165	463568
5	0	24000	36000	0.708	17002	83338	23398	159940	456882
6	0	26000	28000	0.650	16898	100236	16695	183540	454609
7	0	28000	20000	0.596	16695	116931	10941	205991	454760
8	0	30000	12000	0.547	16411	133342	6022	227320	456343
9	0	32000	10000	0.502	16060	149402	4604	244798	453689
10	0	34000	8000	0.460	15655	165057	3379	261677	***453051***
11	0	36000	6000	0.422	15207	180263	2325	277938	453801
12	0	38000	4000	0.388	14726	194990	1422	293567	455521
13	0	40000	2000	0.356	14221	209211	652	308559	457924
14	0	42000	1000	0.326	13700	222911	299	322611	460378
15	0	44000	0	0.299	13167	236077	0	336077	463260

46. In real life, however, ports are required to analyse a situation where facilities and equipment exist and operate already and the question is whether these existing facilities and equipment should be retained or replaced. To calculate the remaining life of existing equipment, the original purchase price and maintenance costs for previous years should be used along with the expected future maintenance costs. The economic life can then be calculated and the remaining life will be the economic life minus the age of the equipment. When this calculation is made there will probably be some equipment that is older than its economic life. This equipment is more costly to operate than new equipment and should be replaced.

Chapter IV

REPAIR OR REPLACE DECISION

47. This chapter presents a simplified version of the repair versus replace issue, a problem that every manager and engineer faces quite frequently. Damaged equipment is a fairly usual phenomenon during port operations. Bearing in mind the requirement for a continuous service as well as the concern of the port authority or the operating company to minimize cost, and depending on the extent of the damage, decision-makers are often called upon to decide quickly on whether a damaged piece of equipment should be repaired or replaced.

48. To illustrate the elements to consider, a hypothetical example is used. A five year-old piece of equipment has been damaged during port operations. After the accident the equipment is worth only C£ 15,000, mainly in the form of spare parts. Tenders were received for the repair work and the lowest acceptable bid is C£ 80,000. After repair the remaining economic life will be 6 years.

49. At the same time, the manager is considering replacing the damaged piece of equipment by purchasing a new one at a cost of C£ 130,000. The economic life of the new equipment is estimated to be 12 years. Although the productivity of the two options are identical, it is estimated that the maintenance cost of the repaired one will be greater compared with the new equipment due to its increased age and will be approximately C£ 1,000 more per year.

50. Delivery time for the new equipment is 10 months and the estimated time for repairing the damaged one is 3 months. In the meantime, the manager must replace the damaged piece of equipment by leasing another one for C£2,000 per month. With a discount rate of 9 per cent, what is the best policy for the manager?

51. Evidently the planning horizons for the two options are not identical - i.e. 6 years for repaired equipment and 12 years for the new one. One method by which these two options can be compared is to estimate the salvage value for the new equipment after 6 years which would be, let us say, C£50,000 and then to calculate the discounted cash flow. This salvage value is received at the end of the sixth year (beginning of seventh year).

52. Again a spread-sheet is used to set up the costs for each of the six years to compare the two alternatives, namely repairing the damaged equipment or replacing the equipment. This spread-sheet is shown in table 4. For both alternatives, maintenance costs are assumed to increase by 8 per cent per year. The rental charges of C£6,000 for the repair option and C£20,000 for the replace option have been discounted.

53. The total discounted cash flow for the "Repair option" is (C£158,900) and for the "Replace" one (C£173,800). In this particular case, it is more economic to repair the damaged equipment than to replace it. It is strongly advised, however, to perform a sensitivity analysis by changing the values of the various parameters to see how this affects the results. For example, if the new piece of equipment were available within two months, the replacement option would become more economic.

Table 4
Comparison of repair vs replace by discounted cash flow method

(9 per cent discount rate)

REPAIR **162.7 - Total discounted cash flow (C£'000)**

Year	*1*	*2*	*3*	*4*	*5*	*6*
Capital cost	80.0					
Rental [a]	5.9					
Maintenance	10.5	15.1	16.3	17.6	19.0	20.6
Salvage						
Total	96.4	14.0	16.3	17.6	19.0	20.6
Discounted	96.4	13.7	13.5	13.3	13.0	12.8

REPLACE **169.7 - Total discounted cash flow (C '000)**

Year	*1*	*2*	*3*	*4*	*5*	*6*
Capital cost	130.0					
Rental [a]	19.3					
Maintenance	2.2	14.0	15.2	16.4	17.7	19.1
Salvage	15.0					50.0
Total	136.4	14.0	15.2	16.4	17.7	-30.9
Discounted	136.4	12.8	12.5	12.3	12.1	-16.4

[a] Costs have been discounted.

Chapter V

ENGINEERING MANAGEMENT INFORMATION SYSTEM

54. The availability of relevant, accurate and comprehensive information is essential to determine the economic life of equipment and thus to establish an equipment replacement policy. Equipment planning is virtually impossible without this information. The components of an Engineering Management Information System (EMIS) are described in the following paragraphs.[6]

55. The basic element of the information system is the Job Card, also called the Work Card, Work Order Card or Job Sheet. This form is the acceptance and authorization by the management of the Engineering Department for a maintenance or repair job. The card describes the task to be performed and ultimately records the resources used for the job.

56. The Job Card is a printed card on which a planner from the Engineering Department has entered the following information:

- asset number and description of the machine or plant to be serviced;
- date of receipt of the request for service;
- date of issue of the Job Card;
- Names of the issuing officer and the nominated person responsible for the repair;
- statement of the nature of the job to be done (e.g. 'monthly service'; 'repair to damaged headlamp');
- space for the responsible technician to acknowledge receipt of the job and to note its completion;
- space for the supervisor to sign approval of the completed job.

To make the card more comprehensive the following information needs to be added by the nominated technician on the completion of the task:

- time of starting the job;
- time of completion;
- details of the number of staff employed on the job, their grades and their individual signing-on and signing-off times;
- spare part's and consumables used.

These data will provide the basis for calculating labour and material costs.

57. Detailed instructions for preventative maintenance jobs should be clearly set out on a separate worksheets as addenda to the Job Card or in a manual. The instructions should set out all the steps of the job and each step should be checked off as the step is completed.

58. The Job Card should have space to accommodate entries for costing purposes at a later stage. This will allow the cost of all materials, both consumables and spares, and the cost data relating to the labour element for the job to be recorded.

59. The Job Card is clearly the basic data entry component of the system. The card is used by staff from the workshop, stores, finance and personnel (for calculating salaries and overtime payments). The card will then be returned to the Engineering Department for analysing the reliability, maintainability and future for that piece of equipment.

60. Another essential component of the EMIS is the scheduling system which sets out the maintenance plan for the next week or month. In its simpest form, the maintenance schedule

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6 For a fuller treatment of this subject, see the report *Management of Port Maintenance - A review of current problems and practices* which is available from HMSO Publication Centre, PO Box 276, London SW8 5DT, United Kingdom.

is chalked up on a blackboard or written on to a pre-formated wall timetable. The planned service intervals for equipment as recommended by the manufacturer form the basis for the programme, but the intervals can be modified with time and experience to reflect the needs and circumstances of the port. The routing section plans the work of an individual workshop or group of workshops in broad outline for the following week, generating Job Cards and requisitioning the necessary supplies. The day before, the planners will finalize the schedule, adjusting the preliminary plan as necessary, and issue the Job Cards and worksheets and manuals to individual technicians. The maintenance schedule is the planner's basic tool to allocate engineering resources and to ensure that work, both preventive and emergency repair, is tackled in order of priority to suit the operator's needs.

61. The EMIS also requires a set of comprehensive and permanent records which compile information relating to individual machines and groups of machines and their constituent systems and components. Collectively, these records constitute the database for the EMIS, upon which plans and decisions are based.

62. The first of these record systems is the Asset Register, the inventory of the port's plant, equipment, buildings and other assets. It lists every owned item and identifies it by code number and full description (e.g. equipment type, capacity, manufacturer, date of acquisition, location or storage position within the port). Linked to the Register should be the set of Asset History records. These provide a cumulative account of the working life of each asset, e.g. the hours of work of a cargo-handling machine, its preventive maintenance sessions, its breakdown and damage repairs, etc. Every maintenance job performed on that asset should be entered on the Asset History card or file, detailing all the spare parts used, consumable items exchanged, fuel used and so on.

63. The final essential element of the EMIS is an activity or function rather than a physical entity - namely the analysis of the collected data and the assembling of them in a form suitable for the various decision-making activities that follow. The central activity is the collation of related data and their aggregation into suitable groups, followed by interpretation of the assembled facts and figures, and circulation of that interpretation to appropriate managers. The analysed data are used to control maintenance work, to modify schedules and practices, to identify problems, to control costs and to determine economic life.

64. In summary a basic EMIS can be assembled from the components described: Job Cards (data entry), Maintenance Schedules (organizational framework for activities), Records (continuously updated database of facts and figures) and Analysis (interpretation and organization of data and feedback of information).

ANNEX 1

Discount factors [a]

Discount rate (per cent)

Year	6	7	8	9	10	11	12
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929
3	0.8900	0.8734	0.8573	0.8417	0.8264	0.8116	0.7972
4	0.8396	0.8163	0.7938	0.7722	0.7513	0.7312	0.7118
5	0.7921	0.7629	0.7350	0.7084	0.6830	0.6587	0.6355
6	0.7473	0.7130	0.6806	0.6499	0.6209	0.5935	0.5674
7	0.7050	0.6663	0.6302	0.5963	0.5645	0.5346	0.5066
8	0.6651	0.6227	0.5835	0.5470	0.5132	0.4817	0.4523
9	0.6274	0.5820	0.5403	0.5019	0.4665	0.4339	0.4039
10	0.5919	0.5439	0.5002	0.4604	0.4241	0.3909	0.3606
11	0.5584	0.5083	0.4632	0.4224	0.3855	0.3522	0.3220
12	0.5268	0.4751	0.4289	0.3875	0.3505	0.3173	0.2875
13	0.4970	0.4440	0.3971	0.3555	0.3186	0.2858	0.2567
14	0.4688	0.4150	0.3677	0.3262	0.2897	0.2575	0.2292
15	0.4423	0.3878	0.3405	0.2992	0.2633	0.2320	0.2046
16	0.4173	0.3624	0.3152	0.2745	0.2394	0.2090	0.1827
17	0.3936	0.3387	0.2919	0.2519	0.2176	0.1883	0.1631
18	0.3714	0.3166	0.2703	0.2311	0.1978	0.1696	0.1456
19	0.3503	0.2959	0.2502	0.2120	0.1799	0.1528	0.1300
20	0.3305	0.2765	0.2317	0.1945	0.1635	0.1377	0.1161
21	0.3118	0.2584	0.2145	0.1784	0.1486	0.1240	0.1037
22	0.2942	0.2415	0.1987	0.1637	0.1351	0.1117	0.0926
23	0.2775	0.2257	0.1839	0.1502	0.1228	0.1007	0.0826
24	0.2618	0.2109	0.1703	0.1378	0.1117	0.0907	0.0738
25	0.2470	0.1971	0.1577	0.1264	0.1015	0.0817	0.0659
26	0.2330	0.1842	0.1460	0.1160	0.0923	0.0736	0.0588
27	0.2198	0.1722	0.1352	0.1064	0.0839	0.0663	0.0525
28	0.2074	0.1609	0.1252	0.0976	0.0763	0.0597	0.0469
29	0.1956	0.1504	0.1159	0.0895	0.0693	0.0538	0.0419
30	0.1846	0.1406	0.1073	0.0822	0.0630	0.0485	0.0374

a Factors to be applied based on the assumption cash flow is at the beginning of the period and discounting is to the beginning of year 1.

ANNEX 2

Typical ratios of maintenance cost/purchase cost ('000 $US)

	Maintenance cost	Purchase cost	Ratio
Quay side gantry cranes	100.0	4500.0	0.02
Straddle carriers	60.0	500.0	0.12
Rubber-tyred gantry cranes	65.0	825.0	0.08
Small rail-mounted gantry cranes	80.0	1000.0	0.08
Terminal tractors	20.0	62.5	0.32
Fork-lift trucks (42 tons)	40.0	300.0	0.13
Reach stackers	35.0	425.0	0.08
40 foot trailers	2.5	12.5	0.20

Source: *Operating and maintenance features of container handling systems* (UNCTAD/SHIP/622) March 1988.

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