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Cost-benefit analysis in a port development project using a simulation model

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COST-BENEFIT ANALYSIS IN A PORT DEVELOPMENT PROJECT USING A SIMULATION MODEL

by

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The contents of this paper reflects my personal view and are not necessarily endorsed by the university.

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CONTENTS

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List of Tables

List of Figures

Chapter I. Introduction

Seaports are areas where there are facilities for berthing or anchoring ships and where there is the equipment for the transfer of goods from ship to shore or ship to ship. To use more modern jargon it is a ship/shore interface or a maritime intermodal interface.[1]

In this regard, the large complexity and cost of modern ports require sophisticated design of port financing strategies. The increasing role of international, multinational and governmental financing institutions demand formal approval of port development costs and benefits based on reliable projections of demand for, as well as supply of, service by port users. Formal feasibility, appraisal, and cost-benefit studies are therefore an increasingly common requirement.[2]

1. Objective

However, the performance of ports with respect to investment policy has not been satisfactory. In some parts of the world, too great expectations that port investments could act as catalysts in regional development programs have resulted in deplorable overcapacity. In other parts, ports have large undercapacity, resulting in costly queues of waiting ships. In both cases there are great national and world losses. Generally speaking, the influence of economic principles like cost/benefit analysis on seaport investment planning is much less, for example, on road and airport investment planning.[3]

In these circumstances, this paper will intend to present an investment appraisal approach of port development project as its objective by employing a case study particularly as to how a port development project could incorporate a simulation technique, which appears to be used more commonly in road transport, or airport, project than in maritime context[4], into the cost-benefit analysis. The simulation technique which will be employed later in the case study will be mainly concerned with the estimation of

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[1] Patrick M. Alderton, Sea transport, 1984, Thomas Reed Publications Ltd,. London, p. 168.

[2] Ernst G. Frankel, Port planning and development, 1987, John Wiley & Sons Inc., USA, p. 6.

[3] Jan Owen Jansson and Dan Shneerson, Port economics, 1982, The MIT press, USA, p. 3.

[4] Although the simulation techniques have been used, to some extent, in port operation, they seem to have been less used in the cost-benefit analysis.

ship turnaround times and the costs of the ship times since the benefits in the cost-benefit analysis would be expressed mainly in the form of reduced costs of ship turnaround times resulting from the improvements of the port concerned.

Thus, this paper will be focused on how the port under study can be analyzed using a simulation technique and how the results of the simulation model can be incorporated into the cost-benefit analysis in the case study.

2. Scope and Methodology

As far as the scope of this study is concerned, it will be confined, in terms of the theory, methodology and application, more to <u>economic analysis</u>, the purpose of which is to evaluate the proposed project by comparing estimated economic benefits and costs to the society or the nation concerned, than to financial analysis, the purpose of which is to evaluate the financial feasibility of a project.[5] The economic analysis appears to deserve to be studied here since it is more likely to involve uncertain and ambiguous factors such as valuation of social cost and benefit, shadow pricing problem, social discount rate and so on, whilst the financial analysis is likely to be, relatively, less uncertain.

On the other hand, the forecasting of cargo traffic will be outside the scope.

Since a study on forecasting cargo traffic, in terms of the theory, methodology and model building, might require a great deal of efforts, it should be conducted in another study due to the time constraint. Furthermore, as far as the case study is concerned, the forecasting process would not play an important role in the study. The port in the case study has a main function in providing a steel-making factory with facilities to import raw materials such as iron ores and coals for processing and to export the finished product, steel. The steel-making factory is expected to have no expansion program during the project life in the case study, that is, forty years as can be seen later in Chapter III, Simulation Model. As a consequence, the forecasting process would not play an important role in the case study. Thus, this subject should be studied in another research and outside the scope of this study.

As far as the methodology is concerned, a simulation model will be employed particularly for the estimation of ship turnaround times. A simulation model will be run under the conditions of the existing port system and under new conditions of an expanded port system, for instance, with a new berth, respectively, and the results of the two system will be compared in terms of ship turnaround times, berth occupancy rates and finally cost-benefit analysis. In other words, it will be assessed that to what extent the ship turnaround times and berth occupancy rates would

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[5] See, E. G. Frankel, op. cit., pp. 249 - 250.

be reduced as a consequence of the expansion program and how these improvements can be economically justified, in terms of the costs and benefits to the nation concerned.

Although there can be some other probabilistic approaches as to the estimation of ship turnaround times, for example a queuing theory model, there appear to exist some shortcomings in the application which could be overcome, to a great extent, by a simulation technique.

More detailed discussions in this respect will be handled in the next chapter.

Chapter II. Theory

This chapter will deal with a general theory of cost-benefit analysis briefly and how this theory can be applied in a port development project. In the general theory, the basic concept and the methods for evaluating expected profitability will be described. As to the application of the cost-benefit analysis in a port development project, the identification of cost and benefit items, the quantification theory and methodology will be discussed.

1. General Theory of Cost-Benefit Analysis

1.1 Methods for evaluating expected profitability

It deserves to be mentioned here that what methods have been developed and what are their merits and drawbacks as far as the theory and practices are concerned.

There have been numerous important contributions to the theory and practice of cost-benefit analysis. A satisfactory classification of the various contributions is indeed a daunting task.[1]

However, the methods for evaluating the soundness of project can be classified mainly into four groups, namely average rate of return method, payback method, internal rate of return method and net present value method.[2]

(a) Average rate of return method

This accounting measure represents the ratio of the average annual profits after taxes to the average investment in the project. Once the average rate of return of a proposal has been calculated, it may be compared with a required rate of return to determine if a particular proposal should be accepted or rejected. The principal virtue of the average rate of return is its simplicity; it makes use of readily available accounting information. The principal shortcomings of the methods are that it is based upon accounting income rather than upon cash flows and that it fails to take account of the timing of cash inflows and outflows. The time value of money is ignored; benefits in the last year are valued the same as benefits in the

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[1] Anandarup Ray, Cost-benefit analysis : issues and methodologies, 1984, The Johns Hopkins Univ. press, Baltimore, USA, p. 3.

[2] See J. C. Van Horne, Financial management and policy, 1983, Prentice-Hall Inc., USA, pp. 108-112.

first year.

(b) Payback method

The payback period of an investment projects tells us the number of years required to recover our initial cash investment. It is the ratio of the initial fixed investment over the annual cash inflows for the recovery period. If the payback period calculated is less than some maximum acceptable payback period, the proposal is accepted; if not, it is rejected.

The major shortcoming of the payback method is that it fails to consider cash flows after the payback period; consequently, it cannot be regarded as a measure of profitability. In addition to this shortcoming, the method does not take account of the magnitude or timing of cash flows during the payback period. It considers only the recovery period as a whole.

The payback method continues in use, nevertheless, frequently as a supplement to other, more sophiscated methods. It does afford management limited insight into the risk and liquidity of a project. The shorter the payback period, supposedly, the less risky the project and the greater its liquidity. There is some merit to its use in this regard, but the method does not take into account the dispersion of possible outcomes - only the magnitude and timing of the expected value of these outcomes relative to the original investment. Therefore it cannot be considered an adequate indicator of a risk. When the payback method is used, it is more appropriately treated as a constraint to be satisfied than as a profitability measure to be maximized.

(c) Net present value (NPV) method

Because of the various shortcomings in the average-rate-of-return and payback methods, it generally is felt that discounted cash flow methods provide a more objective basis for evaluating and selecting investment projects. These methods take account of both the magnitude and the timing of expected cash flows in each period of a project's life. The two discounted cash flow methods are the internal-rate-of-return and the net-present-value methods.

With the present-value method, all cash flows are discounted to present value, using the required rate of return. The net present value of an investment proposal is

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1 + k)^t} \qquad (2.1)$$

where k is the required rate of return and NCF is net cash flow, which is cash inflow minus cash outflow. If the sum of these discounted cash flows is zero or more, the proposal is accepted; if not, it is rejected. Another way to express the acceptance criterion is to say that the project will be accepted if the present value of cash inflows exceeds the present value of cash outflows.

(d) Internal rate of return (IRR) method

The internal rate of return for an investment proposal is the discount rate that equates the present value of the expected cash outflows with the present value of the expected inflows. It is represented by that rate, r, such that

$$\sum_{t=0}^{n} \left[\frac{NCF_t}{(1 + r)^t} \right] = 0 \qquad (2.2)$$

where n is the last period in which a cash flow is expected. The acceptance criterion generally employed with the internal rate of return method is to compare the internal rate of return with a required rate of return, known also as the cutoff, or hurdle, rate. If the internal rate of return exceeds the required rate, the project is accepted; if not, it is rejected. In some circumstances, there will be more than one internal rate of return that equates the present value of cash inflows with the present value of cash outflows. This can occur when there are net cash outflows in more than one period and the outflows are separated by one or more periods of net cash inflows. But the existence of multiple IRR is unusual. For the typical capital budgeting project, a unique IRR exists.

With the internal rate of return method, we are given the cash flows, and we solve for the rate of return that equates the present value of the cash inflows with the present value of the outflows. We then compare the IRR with the required rate of return, to determine whether the proposal should be accepted. With the NPV method, we are given the cash flows and the required rate of return, and we solve for the net present value. The acceptability of the proposal depends on whether the NPV is zero or more.

(e) Comparison of NPV and IRR

In evaluating a group of investment proposals, we must determine whether the proposals are independent of each other. A proposal is mutually exclusive if the acceptance of it precludes the acceptance of one or more other proposals. A contingent or dependent proposal depends upon the acceptance of one or more other proposals. The addition of a large machine may necessitate construction of a new wing to house it. Contingent proposals must be part of our thinking when we consider the original, dependent proposal. Recognizing the dependency, we can make investment decisions accordingly.

In general, the NPV and IRR methods lead to the same acceptance or rejection decision. However,important differences between the methods should be identified. When two investment proposals are mutually exclusive, so that only one can be selected, the two methods may give contradictory results. The conflict between these two methods is due to differences in the implicit compounding of interest. The IRR method implies that funds are compounded at the internal rate of return. The NPV method implies compounding at the required rate of return used as the discount rate. In addition to the problem of different implicit compounding rates, a problem arises if the initial cash outlays are different for two mutually exclusive investment proposals. Because the results of the IRR method are expressed as a percentage, the scale of investment is ignored. In contrast, the results of the NPV method are expressed in absolute terms. Thus, the NPV method always provides correct rankings of mutually exclusive investment projects, whereas the IRR method sometimes does not. With the IRR method, the implied reinvestment rate will differ, depending upon the cash flow stream for each investment proposal under consideration. For proposals with a high internal rate of return, a high reinvestment rate is assumed; for proposals with a low internal rate of return, a low reinvestment rate is assumed. Only rarely will the IRR calculated represent the relevant rate for reinvestment of intermediate cash flows. With the NPV method, however, the implied reinvestment rate - namely, the required rate of return is the same for each proposal. In essence, this reinvestment rate represents the minimum return on opportunities available to the firm or country concerned. Not only is it consistently applied, but it is the only theoretically correct opportunity cost that can be employed if our objective is value maximization. In addition, the NPV method takes account of differences in the scale of investment, and for this reason, it also is superior to the IRR method. Another shortcoming is the possibility of multiple internal rate of return.[3]

1.2 Some general issues

The general issues related to the cost-benefit analysis can be classified mainly into four areas, namely shadow pricing problem, valuation of cost and benefit problem, discount rate problem and risk and uncertainty problem.

This section will discuss those topics briefly based on the literaure.

(a) Shadow pricing issues

When prices are explicitly used to exchange items freely, they are called market prices. When the prices are implicit in exchanges that should be made to maximize a particular objective function (or to minimize a cost function), they are called 'shadow prices'.[4]

First complaint against cost-benefit analysis is that it tends to give two much importance to shadow pricing, that is, to the adjustments of financial inflows and outflows to transform them into economic terms. The necessity for the shadow pricing, however, can be justified as in the following.

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[3] J. C. Van Horne, op. cit., pp. 112 - 117.

[4] R. N. Mckean, the Use of shadow prices : Cost-benefit analysis ; Selected reading, Edited by R. Layard, 1977, Penguin Books Ltd,. U.K., p. 119.

The establishment of net social benefits as the objective function entails that gains and losses be valued in some common unit. The prefix 'social' further requires the unit to reflect society's strength of reference the consumer's willingness to pay for a good. In many cases, however, these prices are not observable since there is no market for the outcome. In these circumstances the cost-benefit analyst must seek surrogate prices. He must find out what society would be willing to pay if there were a market.[5]

In order that the decision rule of CBA be consistent with the objective function of maximizing social welfare, it is necessary that the prices attached to the physical benefits and costs reflect society's valuations of the final goods and resources involved. Whatever society's objective function is, there will be a sacrifice involved in applying resources to one use rather than another. The relevant price for cost-benefit purposes is therefore the price which reflects this opportunity cost. There exists, then, some set of prices, called 'shadow' or 'accounting' prices, which reflect the true social opportunity costs of using resources in a particular project. Actual market prices may or may not approximate these shadow prices. In general we would expect the marginal cost of a final good to indicate society's valuation of that good, since the marginal cost reflects consumers' willingness to use resources in that use. As a first approximation, then, shadow prices are indicated by marginal costs. Because of external costs and benefits, shadow prices should reflect marginal social costs rather than marginal private costs.[6]

In practice, prices are not likely to reflect either marginal private cost or marginal social cost, owing to the existence of imperfectly competitive markets and external effects. It follows that market prices should, for valuation purposes, be adjusted to reflect marginal costs. Clearly, if market prices are to be corrected so that they reflect marginal cost, there is a practical problem of estimating marginal costs and a conceptual problem of justifying the procedure in face of the 'second best' theorem. Problems of this kind have led some economists to a rejection of correcting procedures altogether. They use market prices because they are easily observed and because the necessary adjustments themselves yield more cost than benefits.[7]

Markets put millions of persons into the business of providing information about substitution possibilities. Markets induce millions of people to adjust their purchases and sales to prices, so that those prices reflect (approximately) what an extra unit would be worth to all users. Because of market imperfections, there are no doubt more approximate exchange

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[5] D. W. Pearce, Cost-benefit analysis, 1978, McMillan Press Ltd., H.K., pp. 10 - 11.

[6] D. W. Pearce, op. cit., pp. 52 - 53.

[7] D. W. Pearce, op. cit., pp. 53 - 54.

ratios in principle, but in most cases it would be extremely expensive to acquire the improved information. Therefore, as the shortcomings of market prices and the possibilities of deriving shadow prices are discussed, one thing should be kept in mind : the existence of defects in market prices does not mean that some derived price or alternative procedure would automatically be better.[8]

(b) Valuation issue

Difficulty in measuring costs and benefits sometimes makes it impossible to judge a project's merit with much confidence.

CBA purports to describe and quantify the social advantages and disadvantages of a policy in terms of a common monetary unit. Therefore, CBA attempts to allow for all the gains and losses as viewed from the standpoint of society. It is emphasis on the 'social' view that generates many of the philosophical problems of CBA. First, most cost-benefit analyses restrict the set to the individuals of one nation. More important, only the individuals comprising present society are counted. Second, cost-benefit analysis tends to equate the social view with what society wants. In other words, consumers' sovereignty is paramount and net benefits will reflect society's expressed preferences. Clearly, acting in accord with revealed preferences may not be conducive to the best interests of society.[9]

Regarding the valuation of costs and benefits, some traditional approach focuses on changes in total consumption a project is expected to produce over time. These changes can be expressed either in domestic values or in border values.

It has been customary in traditional practice to express costs and benefits in domestic prices, converting the foreign values of traded inputs and outputs to domestic values by using a shadow exchange rate. This involves the reverse process of converting domestic values of nontraded inputs and outputs to border values by using conversion factors, which remove the distortions in their relative price.[10]

Sometimes the measurement of the relevant costs and benefits may require the careful examination of the best alternative options. An agricultural project, for example, may use undeveloped land for which there is no readily apparent market. The opportunity cost of such land may be mistaken to be zero, or very low, unless its best alternative use is identified. Thus, the project may show a high NPV simply because the alternative uses of the land (for growing other crops, for example) have not been considered. A high NPV may therefore reflect an adequate search for

[8] R. N. Mckean, op. cit., p. 124.

[9] D. W. Pearce, op. cit., pp. 8 - 10.

[10] A. Ray, op. cit., pp. 12 - 13.

alternative projects rather than a potentially valuable project.[11]

(c) Discount rate issue

Another controversial area in cost-benefit analysis is the question of which discount rate is appropriate. It seems to have long been a favorite topic among economists. In a sense, this issue seems to be trivial.

In traditional analysis, it is the valuation reflected in the market interest rate that is used for reference. If all individuals participate in the capital market and if there are no distortions in that market, that interest rate will indeed reflect a common valuation within the present generation. This common consumption rate of interest may also equal the private return to investment at the margin. In practice, the equality of these interest rates may not of course be attained. If costs and benefits are expressed in terms of investments, the shadow interest rate will equal the rate at which the value of investment falls over time - the "accounting rate of interest." This accounting rate of interest is the cut-off rate for social analysis of projects, that is, the social rate return on investments at the margin, when investment is the chosen numeraire. This is also the "opportunity cost of capital," or the "marginal productivity of capital," in terms of the objective function used in that framework.[12]

There is considerable disagreement over the proper derivation of a social discount rate (SDR). In general, the theories are threefold. First, the social time-preference rate (STPR) school of thought argues that the SDR should reflect society's preference of present benefits over future benefits. Within this school of thought there is disagreement over how such a rate is derived. The second theory suggests that the SDR for use in public projects should reflect the rate of return forgone on the displaced project. The assumption is usually made that this forgone project is in the private sector, so that the appropriate rate of discount is the rate of return on marginal projects in the private sector. Third, there is a presumption that the STPR will be less than the opportunity cost rate. Since both rates are relevant to the public investment decision, it has been argued that some 'synthetic' rate reflecting both influences is required.[13]

In equilibrium between transformation and social indifference curve between period, however, the social time-preference rate will be equal to the opportunity cost rate. If equilibrium

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[11] A. Ray, op. cit., pp. 18 - 19.

[12] A. Ray, op. cit., pp. 15 - 17.

[13] D. W. Pearce, op. cit., p. 40.

condition prevail, the disagreement between the first two schools of thought disappears, and the necessity for the estimation of 'synthetic' rates also disappears. Unfortunately, equilibrium of this kind does not prevail. Imperfections in capital markets and the possibility that individuals do not behave collectively in the same way as they do individually prevent the actual achievement of equilibrium point.[14]

(d) Risk and uncertainty issues

The treatment of risk in cost-benefit analysis remains an area of controversy.

The economic analysis of projects is necessarily based on uncertain future events and inaccurate data, and therefore inevitably involves probability judgments, whether made explicit or not. The basic elements in the cost and benefit streams such as input and output prices and quantities or the economywide shadow pricing parameters, are seldom reasonably represented by single values.

It is convenient to distinguish risk from uncertainty, although the two terms are frequently used synonymously in the practical literature. A risk situation exists when the value of a variable is not known but its probability distribution is known. Uncertainty, on the other hand, pertains to a situation in which the provability distribution is not known at all.[15]

Various ways of allowing of risk and uncertainty have been proposed. The first approach proposes the addition of a 'risk premium' to the discount rat. the effect of introducing a risk premium is to make risk a compound function of time. The two criticisms that can be advanced here are (a) that there is no particular reason for supposing risk will behave in this orderly fashion, and (b) the procedure requires that risk be assessed in the form of a discount rate, providing no easy guide of the decision-maker as to how this is to be done. A second procedure requires that the probability distribution be specified in terms of its 'moments' (i.e. the mean and variance, with higher moments usually being ignored). Use of 'expected values' does not really make allowance for risk, however, since two distributions can have the same mean but significantly different dispersions. The argument that governments are able to 'pool' risks has led a number of writers to suggest that risk can be ignored in public project appraisal. High-risk projects offset low-risk projects, so that the addition of a new project to an existing set of projects, each of different riskiness, means that the new project

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[14] See D. W. Pearce, op. cit., p. 42.

[15] D. W. Pearce, op. cit., p. 60.

can be treated as if it had zero risk. This view is usually presented in the context of the opportunity cost argument concerning the choice of discount rates : in this case, the relevant discount rate becomes the rate of private projects with certain returns. There is, however, no logical necessity for linking the risk argument with the opportunity cost discount rate argument. A more straightforward approach is to present costs and benefits in terms of ranges. Thus, the cost-benefit analyst may conduct a sensitivity analysis, which shows how the overall result responds to changes in assumptions about discount rates, different shadow prices and so on. Unfortunately, ranges of this kind tend to be very wide, and the decision-maker must be forgiven if he feels that an analysis of this kind is not of great assistance. The analyst could reduce the sensitivity results to 'optimistic', 'pessimistic' and 'best' estimates, the latter being the one which has the highest subjective probability attached to it.[16]

It is desirable, therefore, that cost - benefit analyses consider the range of possible variations in the values of the basic elements, and present clearly the extent of the uncertainties attaching to the outcome.

A simple method of doing so is to determine how sensitive the NPV is to changes in the variables or, alternatively, how much a variable must change for the NPV to be reduced to zero. Sensitivity analysis, however, does not show the combined net effect of changes in all variables or the likelihood of various changes occurring together. Risk analysis, or probability analysis, can throw light on these questions by specifying, as well as possible, probabilities for the several values that may be attained by each variable in the project analysis, as well as how changes in one variable are correlated with changes in the others.[17]

Apart from the problems mentioned above, some other issues can be summarized as in the following arguments.

The limitations of data and time and competing priorities often impose serious constraints on the quality and quantity of economic work. Cost-benefit analysis in practice can rarely be conducted in a manner comparable to lengthy research projects. Practical analysts must learn how to use the limited resources at hand most efficiently, avoiding excessive detail and spurious precision and employing proxies and shortcuts suitable for the projects they are concerned with.[18]

It is also sometimes suggested that cost-benefit analysis is not useful unless it is applied systematically across all public sector projects. The domain of cost-benefit analysis is certainly quite restricted in practice. Valuation problems are

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[16] D. W. Pearce, op. cit., pp. 60 - 64.

[17] A. Ray, op. cit., pp. 19 - 20.

[18] A. Ray, op. cit., pp. 6 - 10.

also important. Many popular fallacies tend to nullify the sound and painstaking work that often precedes the application of shadow pricing: " the shadow exchange rate equals the official rate when the balance of payments is healthy," " unemployment of labor means that the shadow wage rate is less than the market rate," and so on. Moreover, most of the shadow prices needed for project evaluation can be properly estimated only by project economists. There are only a few national parameters that the project analyst can take as given.[19]

Furthermore, a common complaint against cost-benefit analysis is that it collapses a large and intricate story into a single number, such as the internal or economic rate of return or the NPV. The rate of return or the NPV is a relative statement of a project's merit, not an absolute one. Such measures may sometimes be quite sensitive to the precise way in which the alternatives compared have been defined. Decision-makers should also understand the nature of the information used, the degree of confidence that can be placed on it and the basic approach used in the evaluation of costs and benefits in the first place.[20]

In spite of the shortcomings, it is more likely that an investment project would employ the cost-benefit analysis theory and techniques as a necessary step as to the economic appraisal because better alternatives do not seem to be developed and to be applicable. Thus, the author believes that this phenomena would be continued in the future again.

2. Appraisal of Port Investment

Port investments are made mostly by public or semi-public port authorities. Such investments should be judged not purely on the basis of commercial or financial profitability but rather on the extent to which they serve the development aims of the country. This makes the appraisal process more complex and presents certain problems in correctly quantifying the costs and benefits of the investment project.[21]

For each investment project, there are different consequences for employment, types of service rendered, consumption, savings, foreign exchange earnings, trade possibilities and even income distributions as seen from the macro-economic point of view. As a result, a straightforward calculation of commercial profitability is generally not a sufficient criterion for investment choice in the case of a port. International banks usually insist on both a financial and an economic evaluation

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[19] A. Ray, ibid.

[20] A. Ray, pp. 6 - 10.

[21] UNCTAD, Appraisal of port investments, 1977, p. 2.

before granting a loan for port investment project. For instance, by 30 June 1985, the World Bank had been involved in some 150 port projects in 120 countries. The World Bank usually finances 50 to 60 % of the total cost of a project when it is the only foreign exchange financier. When reviewing projects proposed for financing, the Bank is confronted by two basic issues : those of economic and of financial appraisal.[22] The latter is essentially a computation of commercial profitability. However, it is the result of the former - a comparison of the social costs and benefits to the economy of the country - which determines whether or not a loan is granted.[23]

This section will confine its discussions to the economic appraisal of a port development project rather than to the financial appraisal.[24] To begin with, the identification of the costs and benefits will be handled. The estimation of the costs and the benefits will be followed particularly as to the methodology and the practical difficulties suggesting an advisable way of overcoming the difficulties. Some other issues will also be discussed.

2.1. Identification of the costs and the benefits

The identification of the costs and benefits is the necessary process and one of the most crucial steps that should be taken in the economic appraisal of a port development project. Before the quantification of the costs and the benefits is proceeded, it should be clarified that what type of the costs and the benefits there appear to be in the project.

As mentioned before, the economic analysis compares the relative worth of each alternative in terms of the stream of real costs and benefits to the national economy through the useful life discounted to the base year.[25] In these circumstances, the costs of a port development may be conceived as those resources that could be put to an alternative use by society or those direct costs borne by society due to peculiarities in decision-making.[26]

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[22] See Jean C. Grosdidier De Matons, Economic and financial appraisal of port projects at the World Bank: a review of policy and practice, Maritime Policy and Management, 1986, Vol. 13, pp. 259 - 275.

[23] UNCTAD, op. cit., p. 3.

[24] As to the difference between the two appraisal, see UNCTAD, op. cit., p. 4. and Jean C. Grosdidier De Matons, ibid.

[25] K. A. Sundarum, Port master plans and feasibility studies, Ports '86, Edited by P. H. Sorensen, 1986, American Society of Civil Engineers, New York, p. 104.

[26] Roger S. Figura, Public seaport operations : a dynamic cost-benefit model, J. of Maritime Policy and Management, 1979, Vol. 6, p. 220.

The illustration of the costs can be the capital cost, the maintenance cost and the operating cost of the infrastructure and the superstructure which would be installed as a result of the investment program to meet the demand for cargo.

The benefits can be considered as cost savings accruing to societies or nations concerned due to the port improvements. These savings come from a reduction in congestion and turnaround time in the case of improved berthing and handling facilities, and a reduction in congestion and shipping costs per ton of cargo when channel deepening takes place, permitting the use of larger vessels or abolishing tidal restriction on existing vessel sizes.[27]

Although there exist some guidelines and itemized lists as to what benefits and costs can be considered in a port development project[28], it might be difficult to generalize them since the costs and benefits can be different depending upon the purpose of the analysis, circumstances and the methodologies employed in the analysis. However, if it is assumed that the objective of a port investment plan is to find out the optimum point where the summation of the port cost and the ship cost is minimum for facilitating cargo flows concerned, the following statements can be justified. As regards the cost, major items should be the investment cost such as the capital cost, the maintenance cost and the operating cost as the reflection of the increased port cost. In the same manner, the major benefits should be the cost saving effect resulting from improved port efficiencies, for instance, the reduction in shipturnround time, as the reflection of reduced ship time cost.

2.2 Quantification of the costs and the benefits

The difficulties of cost-benefit analysis in this field do not lie so much in measuring the costs involved as in measuring the benefits. It might be thought that all that was needed was the consideration of differences in the market process of sea transport services between the situation which exists with the investment and that which might reasonably be expected to exist without it.[29]

The difference between the shadow price in the conditions which

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[27] S. R. C. Wanhill, On the cost-benefit analysis of port projects, J. of Maritime Policy and Management, 1978, p. 322.

[28] See UNCTAD, op. cit., pp. 5 - 11 and R. S. Figura, op. cit., p. 220.

[29] R. O. Goss, Towards an economic appraisal of port investments : Studies in maritime economics, Edited by R. O. Goss, 1968, Cambridge University Press, U.K., p. 162. It is frequently known as 'with' and 'without' principle, where 'with' refers to the case of investment and 'without' to the no-investment.

would exist without the investment and the shadow price in the conditions which are estimated to exist with the investment is a preliminary measure of the change in social costs per ton of cargo. However, it must be admitted that this technique of using shadow prices has at least five disadvantages. First it does not allow for differences in uncertainty between shipping and industry generally, and it is from the latter that estimates of the opportunity cost of capital must be derived. Secondly, the use of differences in shadow prices as calculated on a shipowner's view of net cash flows involves taking taxes, tax allowances and investment grants into account. Thirdly, the costs of a conventional (i.e. non-unitized) cargo liner carrying heterogenous cargoes will, to some extent, depend on the 'mix' of commodities carried, because different commodities have different cargo handling costs, speeds and stowage factors. Fourthly, it might be that, if the port investment being considered was very large in relation to the level of world trade being carried in ships of the type concerned, an actual surplus of such ships might result. Fifthly, the calculations ideally require the prediction of real costs and output levels in each year of the ship's life, and no data, not even historical data, on exist this subject.[30]

Although some difficulties in the cost-benefit analysis can be overcome by the use of calculated shadow prices as representing the social costs of sea transport and the application of techniques developed in other contexts, this task might be very costly and time-consuming and , to some extent, unfortunately make the results biased. This is likely to make some practitioners in the cost-benefit analysis be reluctant to using shadow prices and prefer market prices based on the assumption that the market is competitive enough for the market prices to reflect the true costs of the society or the nation for the pricing purpose.

This topic has been the subject of lengthy academic controversy and it is not proposed to enter into detailed discussion here. Instead, more attentions will be drawn on the quantification of the benefit with particular reference to the economic analysis of maritime congestion which seems to explain most benefits of port development project in the form of reduced ship turnaround time.

Economists agree that the economic appraisal of a project consists in comparing the cost with the benefits to be derived from it, and, among other things, the selection of the project that will provide the maximum return. There are, however, differences in methodologies between the various schools of thought. These different methodologies can be briefly classified into three groups, namely an engineering approach of which facilities are necessary to accommodate traffic, a role of ports approach as centers of regional development and a macro-economic

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[30] R. O. Goss, op. cit., pp. 166 - 169.

and social effects approach of port development.[31] Among them, the last approach has been developed from the early fifties and has been the subject of many publications, particularly under the sponsorship of the London School of Economics; combined with the development of the use of queuing theory, refined in the light of marginalism, it has given to port investments a corpus of literature which deserves respect.[32]

In this respect, it is important to review maritime congestion as an economic phenomenon, in terms of its theory and methodologies and to understand to what extent the theories and the methodologies can be employed and under what circumstances they should be.

The theories and methodologies of maritime congestion have, to a great extent, been adopted mainly from road transport area, where many of the basic ideas were originally developed. In spite of the variety of the approaches in the economic analysis of maritime congestion, generally they can be grouped into two classes. One is a deterministic approach and the other is a probabilistic approach. Probably an example of the former might be a type similar to the standard model of traffic congestion under deterministic conditions in the case of road transport done by Walters and Johnson[33], and the illustration of the latter can be seen from a simulation model and , to a certain extent, from a queuing theory model.

The standard model of congestion under deterministic conditions assumes that the throughput of the facility one is interested in, which might be a given stretch of road, an airport, or in the marine context, a port, can be treated as if it were a flow. The object of the exercise is then to derive a relationship between the output of the system, for example, the rate of berthing at a port and the cost of achieving that output. The form in which costs are incurred, as the volume of traffic varies, is greater or lesser delays; that is, the costs are time costs. However, it might be thought that this model, which requires that traffic is treated as a deterministic flow, is not entirely appropriate for marine purposes. The arrival rate of vessels at a given place and time is not predictable with complete certainty and when vessels arrive they do so in discrete units of varying characteristics (size, speed, manoeuvrability) rather than as a homogeneous flow.[34]

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[31] See, Jean C. Gosdidier De Matons, op. cit., pp. 259-261.

[32] Jean C. Gosdidier De Matons, op. cit., p. 261.

[33] See, A. Walters, The theory and measurement of private and social costs of highways congestion, Econometrica, 1961 and C. Johnson, On the economics of road congestion, Econometrica, 1965.

[34] A. H. Vanags, Maritime congestion : an economic analysis, Edited by R. O. Goss, 1982, University College Cardiff Press, U.K., pp. 193 - 198.

For the reasons mentioned above, it appears that the maritime congestion would rather be analyzed based on the probabilistic model such as a queuing theory model and a simulation model than on the deterministic model.

As far as a queuing model of maritime congestion is concerned, in particular, it is assumed that vessels arrive at the facility, perhaps a port, in discrete units and that the arrival rate is a random variable. For concreteness, consider a port and its approaches as the system under study and assume that the rate of arrival of ships is random and can be described by a Poisson distribution[35] which has its mean α, the expected rate of arrivals per unit of time. Furthermore, we assume that the rate at which ships can be berthed is also Poisson distributed with a mean rate of berthing per unit of time. Obviously, in more realistic models the rate of arrival and berthing might be more complicated than this; they might vary with the time of the day and might not be independent of each other. More complicated assumptions can be handled, if not analytically, then possibly by simulation methods.[36]

Under the assumptions of a Poisson distribution or a constant distribution in the rate of arrival and berthing, the expected value of ship's waiting time can be analytically or mathematically derived. This mathematical process can be found in operation research textbooks or other books which are dealing with the queuing theory. Thus, it does not seem to be necessary that the mathematical process is to be referred to here. However, it appears to deserve to be mentioned here that more general distributions of arrival and service form can be incorporated into the queuing theory, to a certain extent, as to the estimation of the waiting time of ship.

In making the queuing models more general a distribution must be used which is more flexible than the constant or negative exponential distributions in that at least the mean and standard deviation can be made equal to that of the practical problem and

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[35] The probability density function of a Poisson distribution can be expressed as in the following form.

$$p(x) = \frac{e^{-\alpha} \cdot \alpha^{x}}{x\ !}, \quad x = 0, 1, 2 \cdots, \infty$$
$$= 0 \quad \text{otherwise}$$

where, x : the number of random events per unit time
α : mean of x and also variance of x

When the number of random events per unit time takes the form of a Poisson distribution, mathematically the time interval between two consecutive random events or the interarrival time takes the form of a negative distribution. The illustration will be presented in the next chapter, Chapter III, Simulation Model.

[36] A. H. Vanags, op. cit., p. 199.

yet maintain some of the properties of the negative exponential distributions which made its mathematical development tractable. A. K. Erlang of the Copenhagen Telephone Company first studied such a distribution, now known as Erlang distribution or a gamma distribution in more general form[37]. He considered the distribution of a time which is divided into a fixed number of 'phases' each phase having a negative exponential distribution. If there are β 'phases' and the average length of each phase is $1/\alpha$ units, then the distribution function can be expressed in the following form.

$$f(x) = \alpha^{\beta} \cdot x^{\beta-1} \cdot \frac{e^{-\alpha x}}{(\beta - 1)!} \qquad (2.3)$$

where, $E(x) = \beta/\alpha$ and $Var(x) = \beta/\alpha^2$

The appropriate values of α and β for the representation of a distribution taken from a practical situation by the Erlang distribution (equation 2.3) can be found by equating moments. For instance, if μ is the mean of the actual distribution and σ its standard deviation then $\mu = \beta/\alpha$ and $\sigma = \sqrt{\beta}/\alpha$
by division,

$$\beta = \mu^2/\sigma^2 \qquad (2.4)$$

The value of β must be an integer of the Erlang distribution and there is no guarantee that the value given by equation (2.4) will be an integer, in such cases the integers nearest above and below the value given by the equation should be used, to give bounds on the actual distribution.[38]

This Erlang distribution has the negative exponential form when $\beta=1$ and the deterministic form when $\beta=\infty$. Thus, the negative exponential distribution and the deterministic (or constant) distributions are the two extreme cases of the Erlang distribution. In this respect, approximation techniques, as to the estimation of waiting time, have been developed for the values of the phase parameter, β, by using linear interpolation methods between the two extreme cases ($\beta=1$ and $\beta=\infty$).

Generally, the linear interpolation technique is likely to overestimate the average waiting time and the percentage error to be least at the high utilizations. In other words, the results of the linear interpolation technique seem to have good approximation to actual average waiting time in the case of high utilization rate whereas in the case of low utilization rate, the results seem to overestimate it.[39]

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[37] When the phase parameter, β, of a gamma distribution takes an integer value, the distribution is called Erlang distribution.

[38] E. Page, Queuing theory in OR, 1972, Butterworths, London, pp. 67 - 68. As to the testing process, examples will be presented in the next chapter, Chapter III, Simulation Model.

[39] See, E. Page, op. cit., pp. 68 - 87.

Although the queuing theory model can be employed in the economic analysis of maritime congestion, there appear to remain at least four problems with its applicability to the cost-benefit analysis. Firstly, the queuing theory model does not seem to consider different sizes of vessels which are calling at port facilities since the model is likely to be based on homogenous size of vessel. In reality, the vessels can be very often different in their sizes even in the case of a specialized berth.

Secondly, in the case of a multi-server queuing model, which have at least two servers, for example, two berths, there appear to be difficulties sometimes in incorporating into the model how many berths should be counted particularly when the sizes of the berths are different. For instance, supposing that a port under study have three berths, the sizes of which are 10,000 DWT, 20,000 DWT and 25,000 DWT, it is ambiguous that which size of berth should be the basis for counting the number of the berths in the model and that how many berths should be counted in the model.

Thirdly, when the distribution of the arrival rate and service rate take more general form such as Erlang distribution rather than negative exponential or constant distributions, there exist possibilities of overestimating the average waiting time in spite of the approximation techniques as noted before. Furthermore, when it is known by some statistical tests[40] that practical situation cannot be represented by these distributions on which the queuing model is based, there are no reasons of using the queuing model for the practical purpose.

Fourthly, whilst the queuing model provides us with the expected value of the waiting time, what matters in the cost-benefit analysis should be the estimation of the cost of ship waiting time, which would be expressed as the product of a waiting time of an individual ship and the cost of the waiting time. Thus, in the cost-benefit analysis, the benefit in the form of reduced cost of ship turnaround time should reflect different sizes of vessel and the costs individually, which might not be applicable in the queuing model where the average value is more likely to be concerned.

In this context, the better alternative for overcoming those problems mentioned above could be a simulation model which can reflect the practical situation, to a great extent, and be more applicable to the cost-benefit analysis than the queuing model. For this reason, the case study will employ a simulation approach as its methodology in the following chapters.

2.3. Some other issues

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[40] Examples of the statistical test will be presented in the next chapter, Chapter III, Simulation Model.

Economic benefits, or savings, resulting from investment in ports accrue mainly to shipping; in many countries, shipping is foreign; it is therefore important that the benefits are passed back to the investor in the form of reduced freight rates or the elimination of congestion surcharges. In this respect, the World Bank has conducted studies on the distribution of benefits from port investment, by selecting a few projects for an ex post study. The results of the study were not alarming from the borrowers' point of view : they showed that the benefits from the projects accrued mainly to the host country. The fact that not all the benefits accrue to it is not abnormal. After all, the merchant fleet of the host country will also benefit from port investments in other countries, and in the field of international transport, one cannot expect to recoup all expenses immediately.[41]

E. T. Laing[42] also examined the similar problem, that is, the question of who gains from reduced freight rates passed on by shipowners who derive benefit from port investment. He concluded his research stating the following remarks.

Most of the gains of port investment are benefits to ships, and most of these benefits are likely to be passed on in freight rate lower (to someone) than they would otherwise have been. The benefits that 'escape' are profits retained by shipowners, of which there is little published evidence : benefits taken in the first place by higher port prices, a subject which has not been examined here; and benefits lost to other countries' traders - a consequence of averaged freight rate. It should, however, be obvious that benefits 'lost' in this way will often be cancelled out by similar 'windfall' benefits from improvements carried out by other port on the route.[43]

On the other hand, R. O. Goss proposes that the problem of the international division of benefits should depend for its solution upon the long-run elasticities of supply and demand in international seaborne trade.[44]

In practical cases where time and data availabilities are limited, the analyst can conduct the economic appraisal based on the assumption that the benefits resulting from a port investment would accrue mainly to the host country since the lost benefits could be compensated or cancelled out by similar gains from other countries' port improvements.

As in other projects, there are also problems of treating the

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[41] Jean C. Grosdidier De Matons, op. cit., pp. 265 - 266.

[42] See E. T. Laing, The distribution of benefits from port investment, Maritime Policy and Management, 1977, 4, pp. 141-154.

[43] E. T. Laing, op. cit., p. 145.

[44] R. O. Goss, op. cit., p. 182.

uncertainties perhaps necessarily involved in port projects. Although various techniques of treating them have been developed, these are also likely to be exposed, to a certain extent, to the subjectivity of the analysts. However, the treatment of the uncertainty should be included in the cost-benefit analysis in order that the decision-maker who determines whether the investment should be conducted or not would not be misguided by interpreting the results of the cost-benefit analysis with absolute confidence. Thus, the uncertainties or risk involved in the results should be given to the decision-maker for better understanding.

The existence of uncertainty in the port planning process is often recognized by planners, but treated in different ways. One way of including uncertainty in the planning process is to always use conservative estimates, in order to 'be on the safe side'. Taken to the extreme, this would mean that the most unfavorable possible value for each parameter should be used in the calculations. Another way of including uncertainty is to add a 'risk premium' to the discount rate. This risk premium can only be arbitrarily assigned and it is hard to see how this value can have any resemblance to the real uncertainty involved. An approach approved by UNCTAD involves the drawing up of three forecasts: an optimistic one, a pessimistic one, and a moderate one. But without a statement about the probability of each occurring, their use is limited. Another way, probably an advisable one, is a probabilistic approach. Instead of attributing point values to the parameters selected as sensitive, ranges of possible values are assigned in the form of probability distributions. Once the probability distributions are established, they are mathematically aggregated to yield a probability distribution for higher-level variables of the final result. The planners now have the possibility for conducting a 'probabilistic' sensitivity test on the result by shifting the distributions one at a time and recording the effect on the final result.[45]

In conclusion, the process of the cost-benefit analysis in a port development project can be briefly summarized as the following steps.

The first step is obviously market research; if there is no great demand of the proposed facilities there is proportionately little case of providing them. The second step is the calculation of shadow prices. For this, ships' capital and operating costs, load factors and (ideally) output levels over time are required. The next step is the selection of the proper discount rate for cost-benefit calculations. With the results of the market research, the shadow prices and a rate of discount, present values can be calculated.[46]

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[45] Wolfhard H. Arlt, The treatment of uncertainty in port planning, 1986, Hamburg Port Training Institute, Hamburg, pp. 7-11.

[46] R. O. Goss, op. cit., pp. 176 - 178.

Chapter III. Simulation Model

This chapter will deal with a simulation model by employing a case study. The case study concerned is the Port of Pohang in South Korea, where expansion program is being considered.

The main objective of the simulation model is to estimate waiting time distribution of the vessels not only in the existing port system but also in the expanded port system. In other words, ship turn-around time in the existing port will be compared with that in the expansion case. Before going into details, the meaning of simulation in this study should be mentioned here.

Simulation is an activity whereby one can draw conclusions about the behavior of a given system by studying the behavior of a corresponding model whose cause-and-effect relationships are the same as (or similar to) those of the original system. Stochastic process simulation (also called discrete event simulation or Monte-Carlo simulation) refers to the use of mathematical models to study systems that are characterized by the occurrence of discrete random events. These individual events are represented by random variables whose values are generated by a computer. The randomness that is encountered in a real system can therefore be synthesized allowing the behavior of the original system to be reproduced artificially.[1]

1. System Analysis

1.1. Case description

The Port of Pohang is located in the southeastern part of Korea at latitude 36° 02' N and longitude 129° 26' E. The main function of the port is to provide the steel-making company, Pohang Steel Co. (POSCO), with the facility to import raw materials such as iron ore and coal for processing and to export the finished product, steel.

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[1]Gottfried, Elements of stochastic process simulation, 1984, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp. 8-9.

As can be seen in table 1, piers no. 1 and 2 handle the raw materials and the other piers the finished products and general cargoes.

Table 3.1. General description of the port

pier no.	length (m)	draft (m)	cargo	equipment
1	1290	18.0	iron ore & coal steel	one 1800 t/h five 1500 t/h unloaders
2	980	5.5-12.0	"	two 1000 t/h one 700 t/h ul.
3	547	7 - 9.5	steel	four 15t cranes
4	420	10 - 11	steel	35t,two 30t,25t cranes
5	855	9.1-10	steel	30t,two 25t cr.
6	352	5.0	general cargo	
7		9 - 11	general	
8		9.5-11	general	

Source : POSCO (Pohang Steel Co.)

Large ocean-going vessels for carrying iron ore and coal use 3 berths (berth nos. 11, 13 and 14) on pier no.1 and 1 berth (berth no. 23) on pier no. 2. All the vessels for carrying iron ore and coal are chartered from Korean shipping companies by POSCO. The company suffered from the demurrage of 3,636,641 US $ in 1987 due to the waiting time in the port.

In order to reduce the demurrage cost and facilitate larger vessels, the company is now considering one new, large berth which can handle a 250,000 DWT vessel.

The existing port situation for iron ore and coal can be seen in table 3.2.

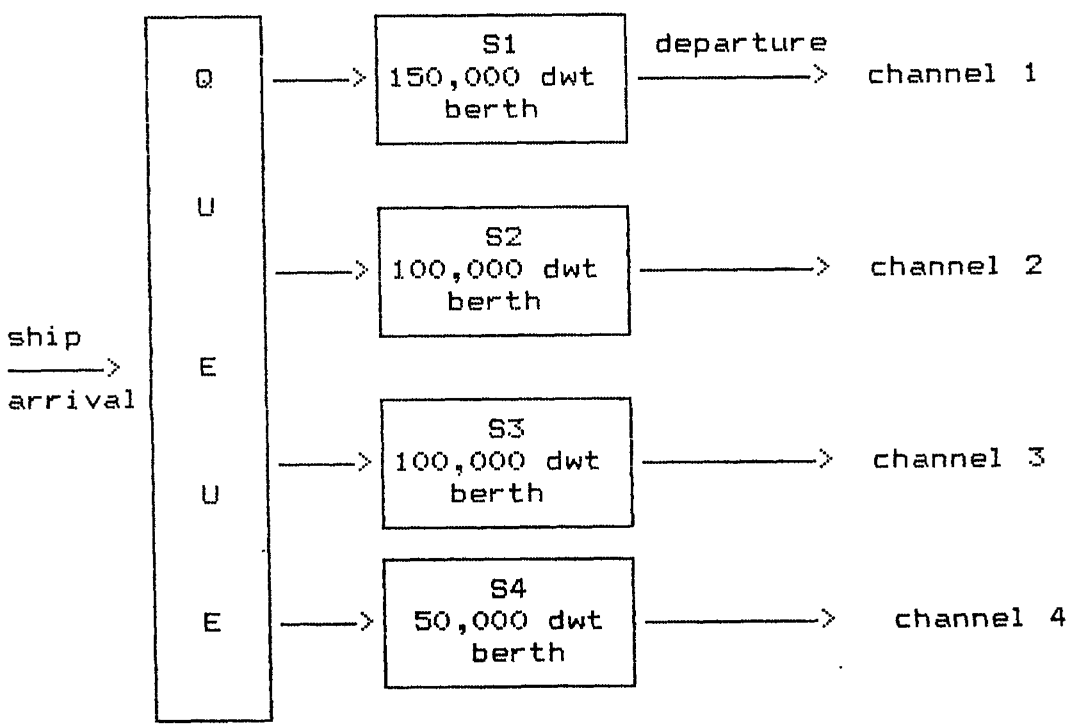
As mentioned before, when an iron ore or coal vessel arrives in the port, she is supposed to berth at one of the berths depending on her size and availability of berth. When all the berths are occupied, she has to wait in the mooring area until a berth is available. Once she finishes the discharging of cargo, she is supposed to leave the berth immediately.

The system can be graphically presented as in Fig. 3.1.

Table 3.2. Raw material terminal

pier no.	berth no.	min. draft (m)	max. size (d.w.t.)	handling equipment
1	11	18.0	150,000	1800 t/h*1 1500 t/h*1
	13	16.0	100,000	1500 t/h*2
	14	"	"	"
2	23	12.0	50,000	1000 t/h*2

Figure 3.1 The Port System



The Figure shows us that the system is a four channelled - single phase waiting line system[2]. In other words, a ship is served in

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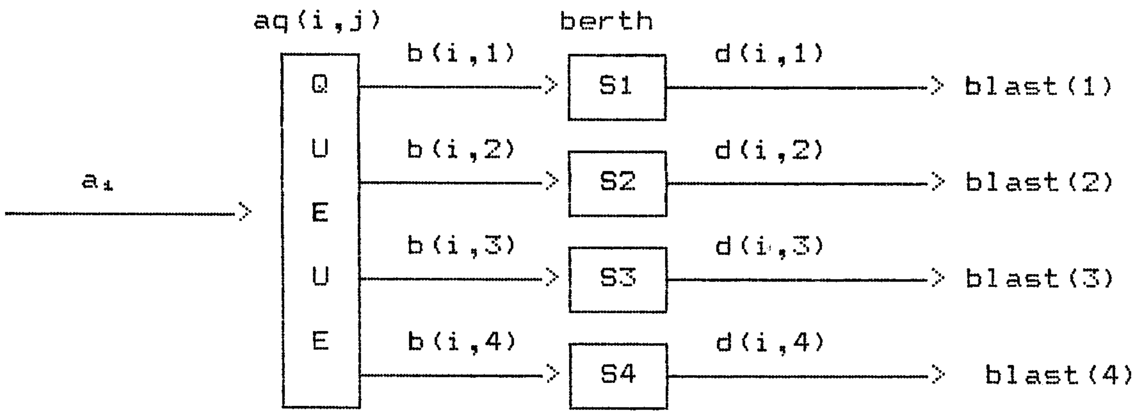
[2]See J. J. Evans and P. B. Marlow, Quantitative Methods in Maritime Economics, 1986, Fairplay Publications Ltd, London, p 126.

one of the four berths (multi-channel or multi-server) and when she finishes being served, the ship is supposed not to berth again for another service but to leave the port (single phase).

Now, the main objective of the simulation is to estimate ship turnaround time in parallel with a ship's arrival and departure. The simulation should show us when each ship arrives in the port and how long she waits in the queue and when she unberths. So, each ship's arrival time, waiting time in the queue, berthing time and departure time from the berth can be calculated.

Before introducing the algorithmic process, the graphical presentation is introduced again in Fig. 3.2. supplemented with variables from Fig. 3.1.

Figure 3.2 The Queuing System



where i : serial number of ship
j : berth number ($1=S_1$, $2=S_2$, $3=S_3$, $4=S_4$)
a_i : ith ship arrival time
aq(i,j) : ith ship arrival time with jth berth allocation
b(i,j) : berthing time
d(i,j) : departure time
blast(j) : the last ship's departure time in jth berth

The algorithm for calculating waiting time can be expressed in the following formulae.[3]

$$a(i)=a(i-1)+AT, \text{ where } AT : \text{interarrival time (random variable)} \quad (3.1)$$

$$d(i,j)=b(i,j)+ST, \text{ where } ST : \text{service time (random variable)} \quad (3.2)$$

$$aq(i,j)=a(i) \quad (3.3)$$

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[3]Gottfried, Op. Cit. pp 184-217.

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If aq(i,j) >= blast(j), then b(i,j)=aq(i,j)
      if not, b(i,j)=blast(j)                          (3.4)

wt(i)=d(i,j)-a(i,j), where wt(i) : waiting time
                                   in system           (3.5)

wt2(i)=b(i,j)-a(i,j), where wt2(i) : waiting time
                                     in queue          (3.6)
```

In formula (3.1), consecutive arrival time can be calculated by adding the interarrival time up to a previous ship's arrival time. In formula (3.2), the consecutive departure time is a summation of berthing time and service time. Formula (3.3) means arrival time after berth allocation which is the same as a(i) and it is introduced simply for later calculation. Depending upon ship size and berth availability, the berth is allocated. Formula (3.4) shows us the berthing time. If a ship for jth berth arrives later than the last departure time in jth berth, it means the berth is empty and the ship can berth immediately. If not, it means the berth is occupied and the ship has to wait until the berth is available. Formulae (3.5) and (3.6) are the expression of waiting time in the system and the queue as a difference between arrival time and departure time, and berthing time, respectively. Assessing these waiting time distribution will be the main objective of the simulation model.

The values of all the variables, except interarrival time and service time (AT and ST), are determined mathematically in the formulae or decision-making process[4], for instance berth allocation aq(i,j). However, two random variables, namely interarrival time and service time, should be generated by the computer itself. In other words, once the two random variables are generated by computer, all the other values are fixed by the formulae.

So the most crucial part in validating the simulation model would be the generation of the random variables. The success of the model will lie in the extent of similarity of the random variates to real values.

Usually in a simulation model, the identification of real distribution is expressed as system parameters. System parameters are values which can be specified a priori. These quantities usually represent physical constants, design parameters, constants of proportionality, etc., over which the decision maker has little or no control.[5]

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[4]In most situations there are certain variables whose values ca be specified by the analyst(or the "decision-maker") at the beginning of a problem, independent of any other considerations. These variables are known as decision variables. See Gottfried, Op. Cit. p.4.

[5]Gottfried, Ibid.

The system parameter estimation will be handled in the next section.

1.2. The System Parameter Estimation

As mentioned before, the most crucial part in simulation is random number generator. In order to make the simulation more realistic, it should be ensured that random variates generated by computer can, to a great extent, represent empirical distribution in a real system. The common way to do it is to collect empirical data, estimate the parameter of the empirical distribution from the most similar theoretical distribution and statistically test the similarity between them. In case empirical distribution is statistically well matched with the theoretical one, the theoretical distribution will be used for random number generation. If not, the empirical distribution should be generated in the computer.

The system parameter estimation will be carried out as to the random variates, namely interarrival time distribution and service time distributions. There are one interarrival time distribution and four service time distributions from ship arrival time in the port and service time in each berth.

To begin with, the raw data set on ship arrival and service times was collected from 1987's port record book in the Port of Pohang. The data set contained ship's arrival time in the port and service hours in each berth. In 1987's record, 191 ships carrying iron ore and coal called at the port and 174 ships finished discharging whilst the other 17 ships were being served or waiting. So, those 174 ships which finished discharging were selected as a complete set of data for analysis. First of all, 173 interarrival times were calculated from 174 ship arrival times. Then, service times from each berth were calculated resulting in 4 service time distributions. Of 174 ships, 60 ships called at S1 (the biggest berth), 47 ships at S2, 56 ships at S3 and 11 ships at S4 (the smallest berth).

The mean value and standard deviation were calculated from each distribution as can be seen in table 3.3.

Table 3.3 Mean and standard deviation of empirical distribution

unit : hour

	interarrival	service (S1)	service (S2)	service (S3)	service (S4)
mean	47.0770	134.8905	112.6391	130.675	153.380
s.d.	40.51437	35.89293	35.95031	58.89993	92.17526

It is common in a queuing system of the port system kind that interarrival time distribution takes the form of exponential distribution and service time distribution gamma distribution, where the probability density functions are represented by the following formulae.

Exponential distribution

$$f(x)=\alpha \cdot e^{-\alpha \cdot x}, \text{ where mean} = \mu = 1/\alpha \qquad (3.7)$$

Gamma distribution

$$f(x) = \frac{\alpha^{\beta} \cdot x^{(\beta-1)} \cdot e^{-\alpha x}}{(\beta-1)!} \qquad (3.8)$$

where

α : positive constant, β : positive integer valued constant

$\mu = \beta/\alpha$, $var = \sigma^2 = \beta/\alpha^2 = \mu/\alpha$

(Note that the gamma distribution is reduced to the exponential distribution when $\beta=1$)

From table 3.3 and Eq. 3.8, it can be seen that the shape parameter (α and β) can be estimated from each distribution because there are two unknown variables in two equations. For instance, the parameters of interarrival time distribution were estimated by the following process.

From Eq. (3.8),

$\alpha = \mu / \sigma^2 = 0.028680798$

$\beta = \alpha \cdot \mu = 1.35020798 \approx 1$

In the same manner, the other parameters of service time distributions were estimated. The results are shown in table 3.4.

Table 3.4 Estimated parameters

	interarrival	service (S1)	service (S2)	service (S3)	service (S4)
α β	0.028680798 1	0.105 14	8.715E-02 10	3.767E-02 5	1.805E-02 3

From the table, it can be hypothesized that the interarrival time distribution can be represented by exponential distribution with α=0.028680798 and service time distribution in berth S1, gamma distribution with α=0.105 and β=14 and so on.

This hypothesis was tested by employing chi-square goodness-of-fit test the statistics of which are expressed by Eq. (3.10).

chi-square goodness-of-fit statistic,

$$X^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad (3.10)^{*}$$

where, k : no. of classes or cells
O_i : no. of observed values in ith class
E_i : no. of expected values in ith class
with k - 1 degree of freedom (d.f.)

For instance, the chi-square value of the interarrival time distribution showed us that the hypothesis cannot be rejected at the 5 % significance level as can be seen in table 3.5 and figure 3.3.

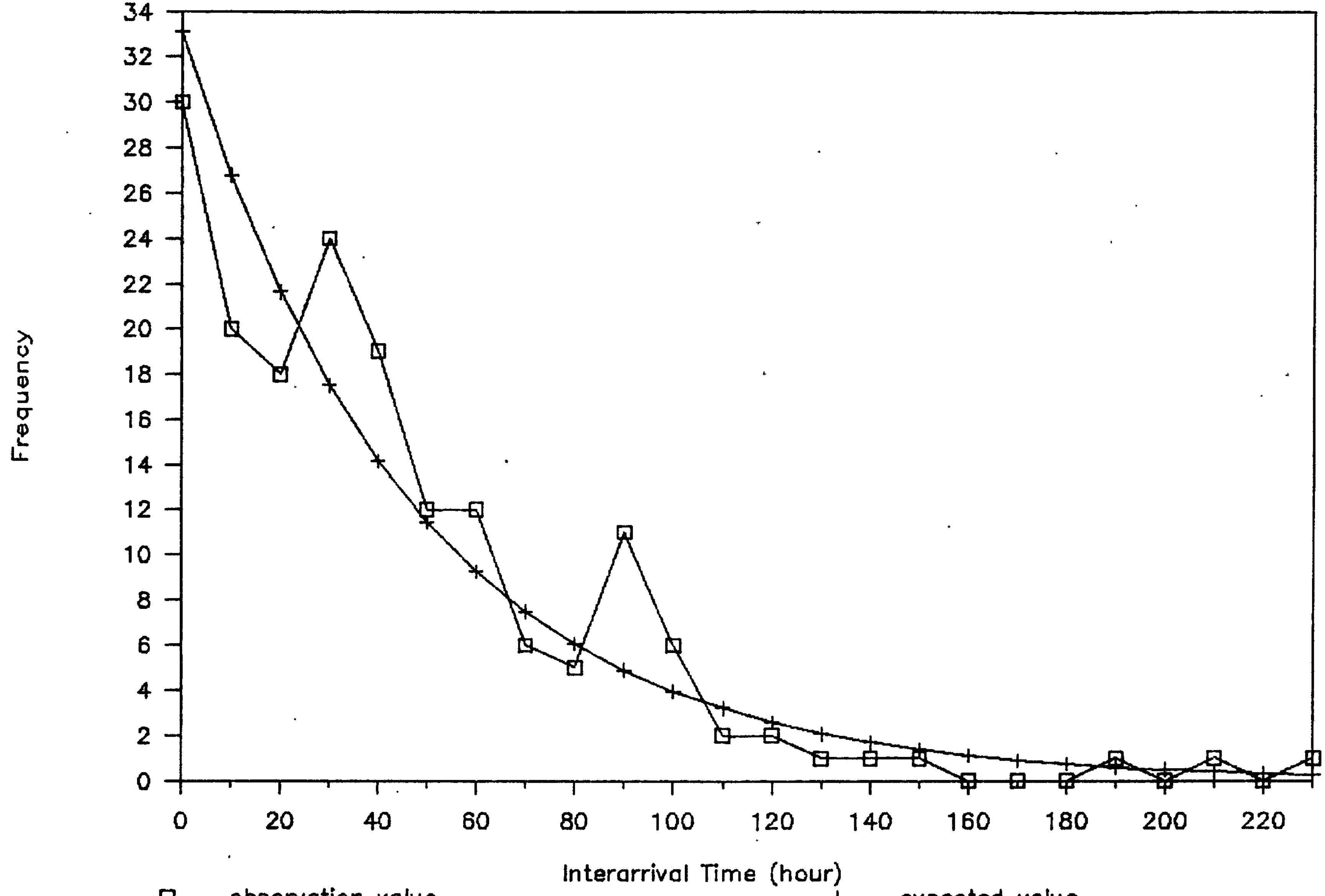
Table 3.5 X^2 Test results of interarrival time

class (i)	boundary (hour)	observation (O_i)	expected (E_i)
1	0 - 10	30	33.1075
2	10- 20	20	26.7717
3	20- 30	18	21.6483
4	30- 40	24	17.5054
5	40- 50	19	14.1553
6	50- 60	12	11.4464
7	60- 70	12	9.2559
8	70- 80	6	7.4845
9	80- 90	5	6.0522
10	90-100	11	4.8940
11	100-110	6	3.9574
12	110-120	2	3.2000
13	120-130	2	2.5876
14	130-140	1	2.0924
15	140-150	1	1.6920
16	150-160	1	1.3682
17	160-170	0	1.1064
18	170-180	0	0.8946
19	180-190	0	0.7234
20	190-200	1	0.5850
21	200-210	0	0.4730
22	210-220	1	0.3825
23	220-230	0	0.3093
24	230-240	1	0.2501
X^2 value = 25.25969 < critical point(0.50)=35.2			

* T. H. Wonnacott and R. J. Wonnacott, Introductory statistics for business and economics, 2nd ed., 1977, John Wiley & Sons, Inc., USA, pp. 501-11.

Fig. 3.3 Interarrival Time Distribution

real vs. exponential distribution



In the same manner, the results of 4 service time distributions can be seen from table 3.6 and figure 3.4 to table 3.9 and figure 3.7.

Table 3.6 X^2 Test results of service time(S1)

class (i)	boundary[7] (hour)	observation (O_i)	expected (E_i)
1	60- 80	2	1.0200
2	80- 90	4	4.9800
3	90-100	4	7.0200
4	100-110	1	4.9800
5	110-120	10	7.0200
6	120-130	3	6.9600
7	130-140	11	6.0000
8	140-150	8	7.0200
9	150-160	5	4.9800
10	160-170	7	4.0200
11	170-180	0	1.9800
12	180-200	2	1.0200
13	200-210	1	1.9800
14	210-220	2	1.0200
X^2 value = 19.9933 < critical point(0.05,d.f.=13)			

Table 3.7 X^2 Test results of service time(S2)

class (i)	boundary (hour)	observation (O_i)	expected (E_i)
1	50- 60	0	2.0210
2	60- 70	7	4.9820
3	70- 80	2	3.9950
4	80- 90	8	4.9820
5	90-100	3	2.0210
6	100-110	2	2.0210
7	110-120	8	8.9770
8	120-130	3	4.9820
9	130-140	3	4.0420
10	140-150	3	3.9950
11	150-170	1	2.9610
12	170-190	5	1.0340
13	190-200	2	0.9870
X^2 value = 25.0990 > critical point(0.05,d.f.=12)			

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[7]Equidistant class range was impossible because the denominator in Eq. (3.10), E_i, was found to have zero value in certain cells. In this case, that cell was merged into a neighboring cell.

Fig. 3.4 Service Time Distribution

In the First Berth (150,000 dwt)

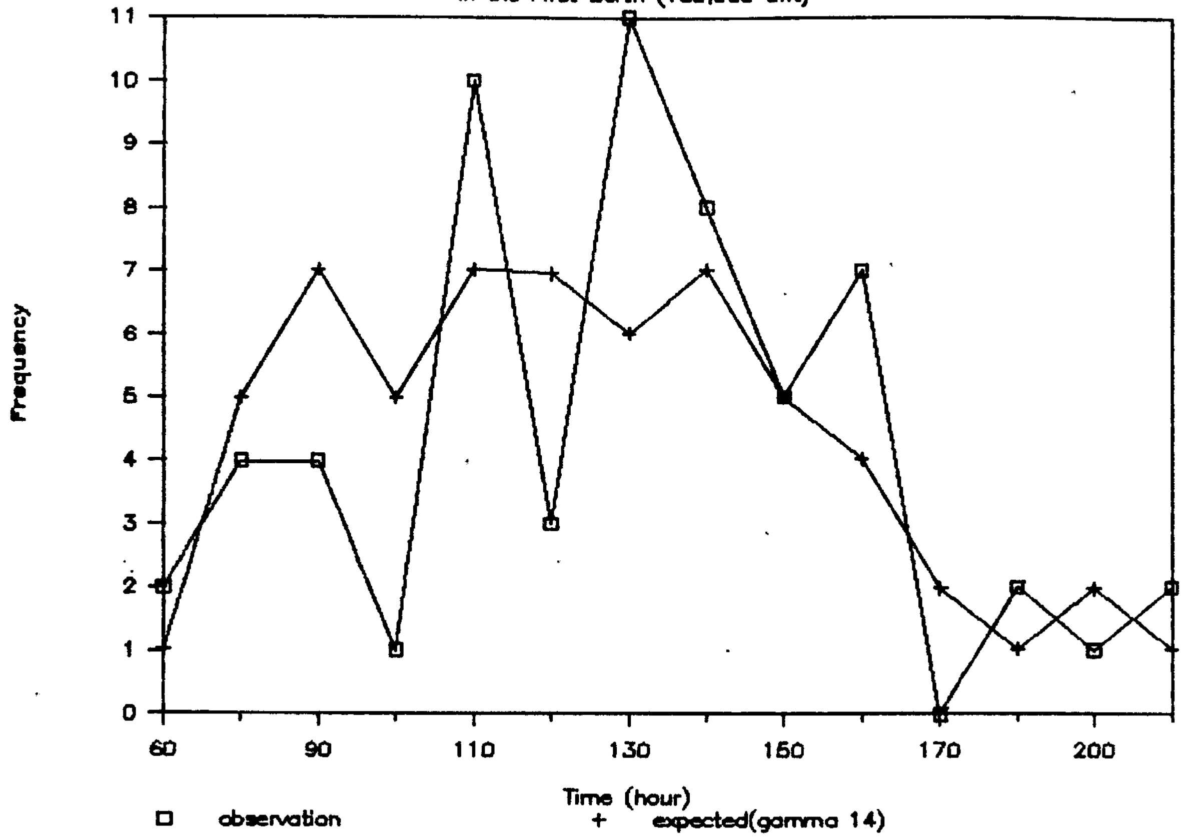


Fig. 3.5 Service Time Distribution

In the Second Berth (100,000 dwt)

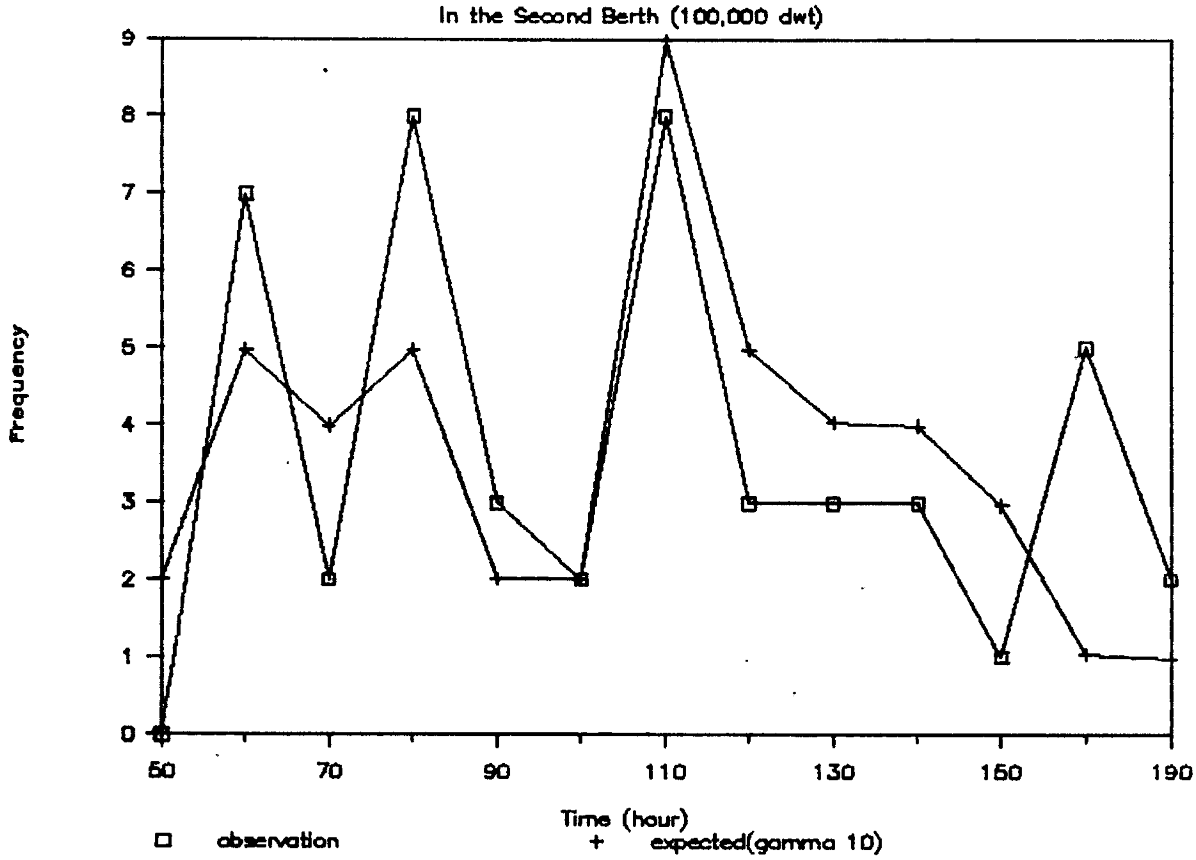


Table 3.8 X^2 Test results of service time(S3)

class (i)	boundary (hour)	observation (O_i)	expected (E_i)
1	30 -40	0	1.0080
2	40- 50	0	2.9680
3	50- 60	0	2.0160
4	60- 70	4	2.0160
5	70- 80	6	3.9760
6	80- 90	5	5.9920
7	90- 100	5	5.0400
8	100-110	2	4.9840
9	110-120	7	3.0240
10	120-130	0	1.9600
11	130-140	5	4.0320
12	140-150	8	1.9600
13	150-160	3	1.0080
14	160-170	2	2.0160
15	170-180	1	2.0160
16	180-190	1	2.9680
17	190-200	1	2.0160
18	200-210	2	1.0080
19	210-220	2	2.0160
20	220-230	1	1.9600
21	230-340	0	1.0080
22	340-400	1	1.0080
X^2 value = 45.67947 > critical point (0.50)=32.7			

Table 3.9 X^2 Test results of service time(S4)

class (i)	boundary (hour)	observation (O_i)	expected (E_i)
1	40- 50	0	1.0010
2	50- 70	0	2.0020
3	70-100	2	1.0010
4	100-130	2	1.0010
5	130-160	2	0.9900
6	160-170	2	1.0010
7	170-250	0	1.0010
8	250-270	2	1.0010
9	270-370	0	1.0010
10	370-450	1	1.0010
X^2 value = 10.02342 < critical point(0.05,d.f.=9)			

Consequently, it is statistically shown that the interarrival time distribution and two service time distributions (S1 & S4) can be represented by theoretical distribution (exponential and gamma), whilst the other two service time distributions (S2 & S3) cannot. This implies that a computer has to generate random variates based on 3 theoretical and 2 empirical distributions.

Fig. 3.6 Service Time Distribution

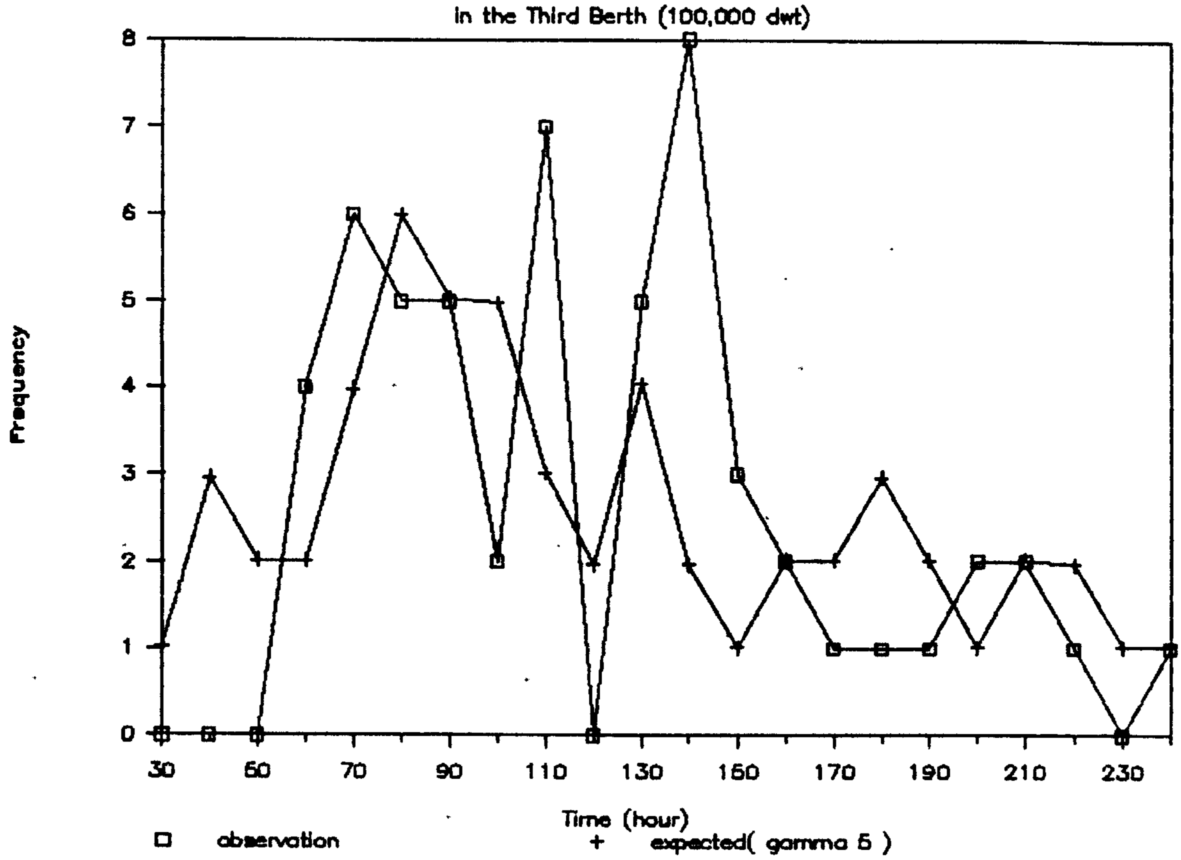
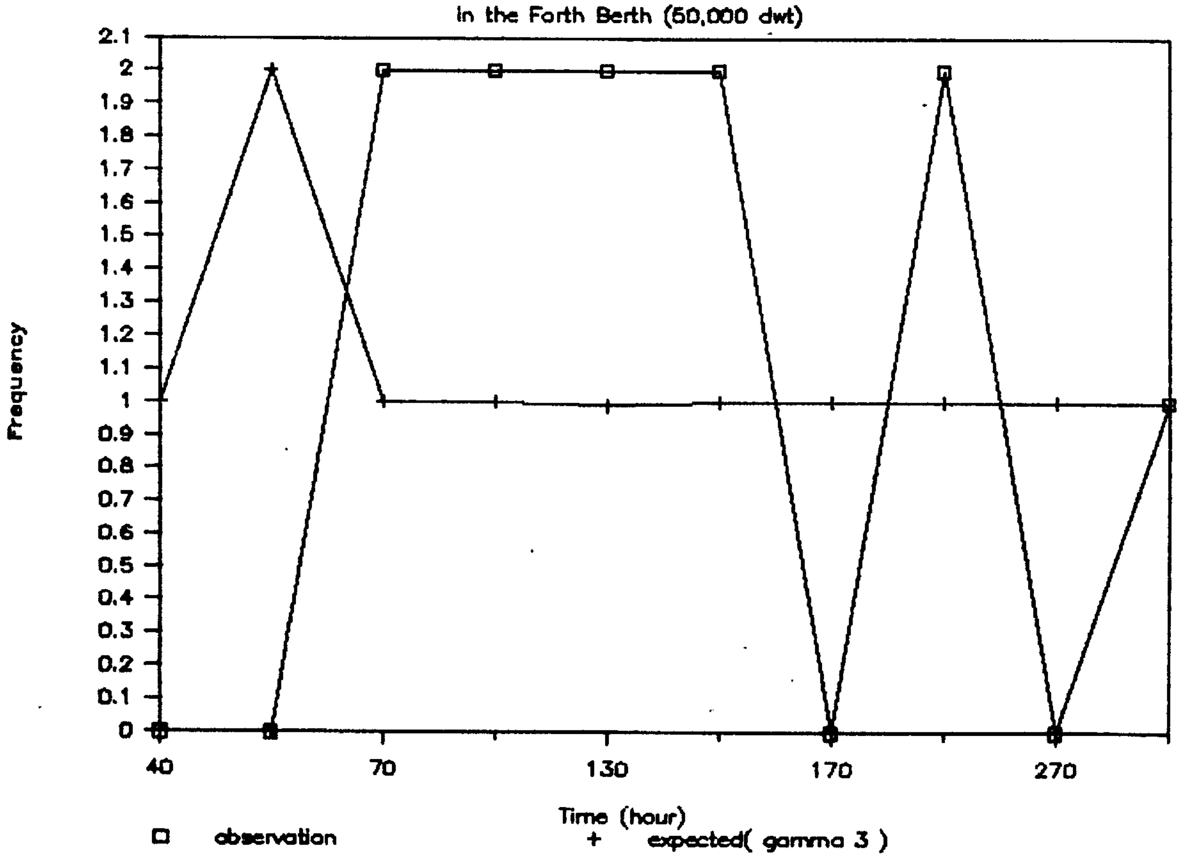


Fig. 3.7 Service Time Distribution



2. Model Description

It deserves to be mentioned here, before describing the simulation model, that there are different types of simulation model and into which our model can be classified. This classification will require the understanding of specific terminology.

Firstly, the state of a system is the collection of variables necessary to describe a system at a particular time, relative to the objectives of a study.[8] In a study of a port, examples of possible state variables are the number of berths, the number of ships in the port, and the time of arrival of each ship in the port. Systems can be categorized into two types, discrete and continuous. A discrete system is one for which the state variables change only at a countable (or finite) number of points in time. A continuous system is one for which the state variables change continuously with respect to time. A port can be an example of a discrete system since state variables, for instance, the number of ships in the port, change only when a ship arrives or when a ship finishes being served and departs. An airplane moving through the air is an example of a continuous system since such state variables as position or velocity change continuously with respect to time. A simulation model can also be distinguished as static or dynamic and deterministic or stochastic. A static simulation model is a representative of a system at a particular time. Monte Carlo simulation models are typical of this type. A dynamic simulation model is a representative of a system as it evolves over time, e.g., a simulation model of a bank's activities over an 8-hour day. A simulation model is said to be deterministic if it contains no random variables. On the other hand, a simulation model is stochastic if it contains one or more random variables. For a deterministic model there is a unique set of model output data for a given set of inputs. The output data of a stochastic model are themselves random and thus only estimates of the true characteristics of the model.[9]

The simulation to be considered in this case study will be a <u>discrete, dynamic and stochastic</u> one.

2.1. Random Number Generator

The key to simulating discrete, random events is the ability to generate random numbers on a computer. These numbers are not really random, since they are generated in reproducible sequences by deterministic techniques. The numbers appear random, however, and are able to satisfy a variety of statistical tests for

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[8] A. M. Law and W. D. Kelton, Simulation Modeling and Analysis, 1982, McGraw-Hill, USA, pp. 2-4.

[9] A. M. Law and W. D. Kelton, Ibid.

randomness. For all practical purposes, then, we can assume that these numbers are truly random. Such numbers are referred to as pseudorandom numbers.[10]

The results of system parameter estimation shows us that the port system is likely to have one exponential distribution (interarrival time distribution) , two gamma distributions (S1 & S4) and two empirical distributions (S2 & S3).

The basis for generating these random variables is uniformly distributed random numbers that fall within the interval (0 , 1) with equal likelihood. These uniformly distributed random numbers can be used to generate other random numbers which are governed by different (nonuniform) types of distribution which are exponential, gamma and empirical distribution in our case.

Among various methods of pseudorandom number generations, a simple, popular random number generator, known as the power residue method (it is also called the multiplicative congruential method)[11] will be used in the simulation model because the method can easily be implemented in a high-level programming language, such as FORTRAN. The basic idea of that method is to generate a deliberate overflow in the computer. It then retains the low-order bits and makes the value positive by adding the retained low-order bits to the maximum module of the computer since a negative value could have been obtained as a result of the overflow. The FORTRAN program of the random generation can be seen in "Function Rand(kx)" of the computer program in the Appendix.

In order to assess the randomness of pseudorandom number sequences, the chi-square test in combination with the frequency test[12] was carried out over several runs, resulting in accepting the hypothesis.

From the uniform random variates, the generation of non-uniform random variates, such as in our distributions, can be conducted by either the analytical integration method, known as inverse transformation method, or direct simulation techniques.[13] For instance, the exponential and empirical distributions are generated by the inverse transformation method whilst the gamma distribution is generated by the direct simulation technique. The flow chart in the following section and the computer program in the Appendix can be referred to for more detail.

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[10]Gottfried, Op. Cit. p 19.

[11]See Gottfried, Op. Cit. pp. 20-34.

[12]See Gottfried Op. Cit. pp. 34-38.

[13]See Gottfried Op. Cit. pp. 76-111.

2.2. The Flow Chart of the Simulation Program

The flow chart of the simulation model was drawn as can be seen in figure 3.8. The flow chart can be divided into three parts, namely the initialization part, the iteration process part and the output part. The initialization part deals with data input and the initialization of variables and function subroutine (FUNCTION RAND(kx)) as random generator in order to prepare the calculating process. The iteration process part generates each ship's arrival, allocates a berth for the ship based on the berth allocation policy of the port, generates service time also by random generator for the ship in the allocated berth and finally calculates the departure time. In the meantime, the program calculates the waiting time in the queue and the system based on Exp. (3.5) and (3.6). This process is continued until the final ship finishes being served. The output part shows us the individual ship's arrival time, berthing time, departure time and waiting time in the queue and the system. It also shows the summation of the waiting time, mean value and standard deviation, and the relative and cumulative frequencies of waiting time distribution in the system as well as in the queue. The detailed explanation will be followed stepwise.

To begin with part A in the flowchart, it is necessary to make declaration statements for storing enough memory in the computer and assign zero values to the variables which will be used in later processes. Then, the basic random generator, the uniformly distributed random generator (FUNCTION RAND in the flow chart), should be run by receiving the seed-value.[14] Once the basic random generator is run by seed-value, it produces uniformly distributed random numbers whenever it is called afterwards. For instance, the first ship's DWT and ST are generated by calling this generator and inverse transformation method or direct simulation. In other words, whatever distribution is required to be generated, it should use this basic random generator (Function RAND in the flow chart) and then can be transformed into the required types of non-uniform distribution. Thus, the first ship's DWT is generated by empirical distribution, a berth is allocated depending on the ship's size, service time (ST) is generated[15] and finally departure time and waiting time are calculated.

After this, the calculation process of arrival time, DWT, berth allocation, service time and waiting time is continued from the second ship to the last ship as can be seen in the flow chart from part B to part F. Part B deals with the generation of interarrival time as exponential distribution whilst part B2 explains the power residue method in 32 bit machine cases and part C generates DWT by empirical distribution.

Part D handles the berth allocation process. Although a bigger

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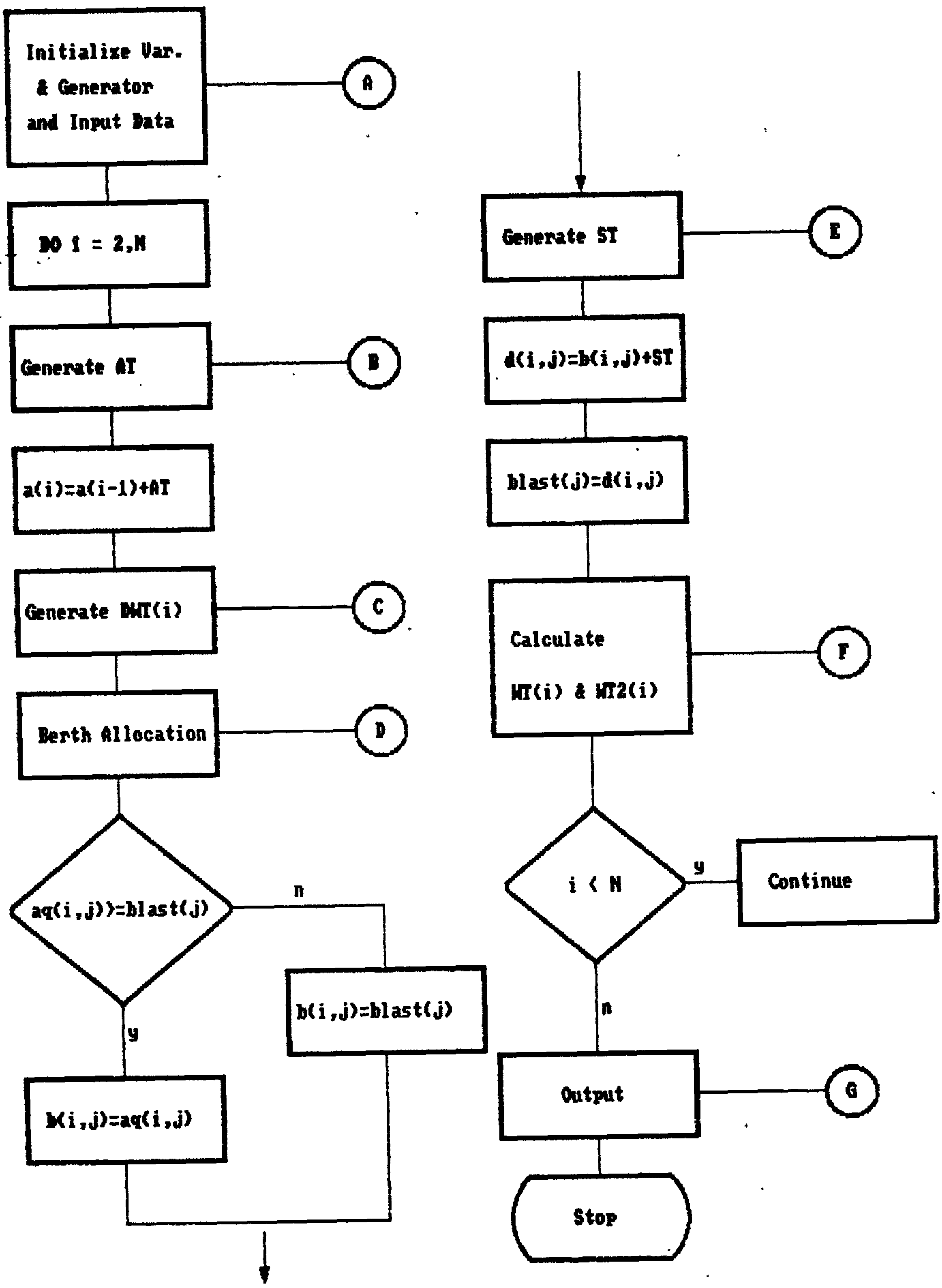
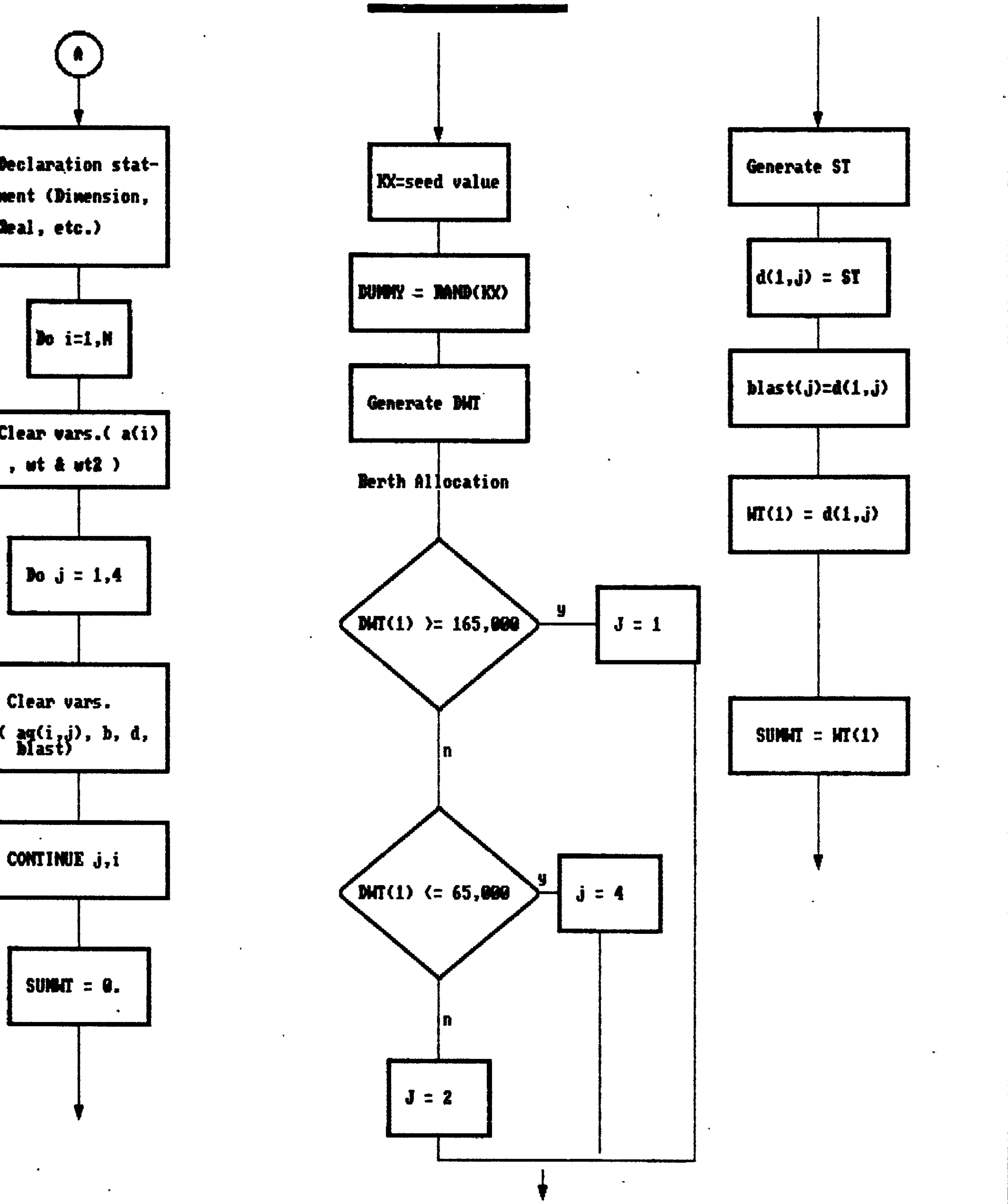
[14]See Gottfried, Ibid.

[15]The first ship's arrival time does not have to be calculated because the simulation starts from the moment of the first ship's arrival with 0 hour.

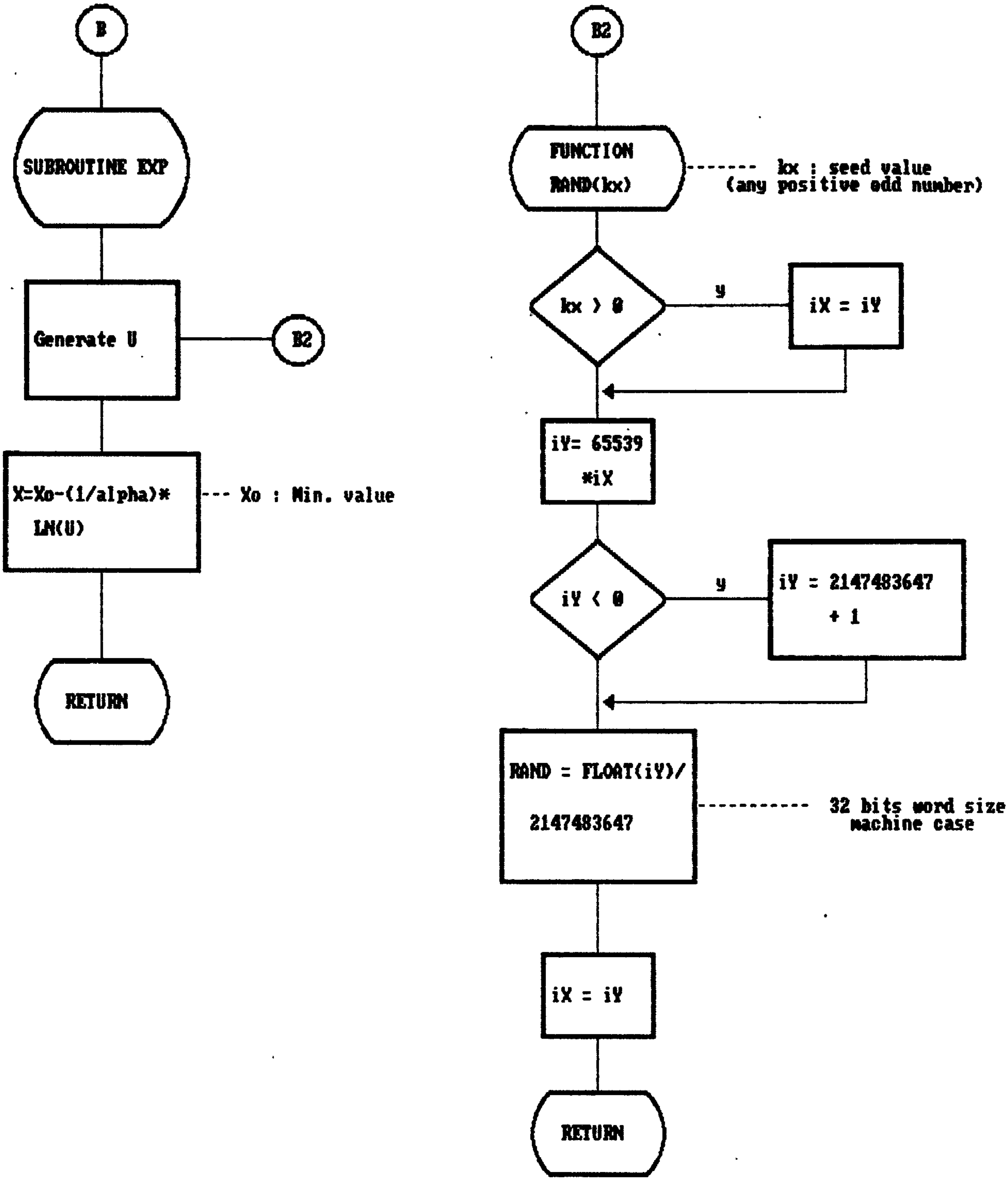
Figuare 3.8 FLOWCHART OF SIMULATION PROGRAM



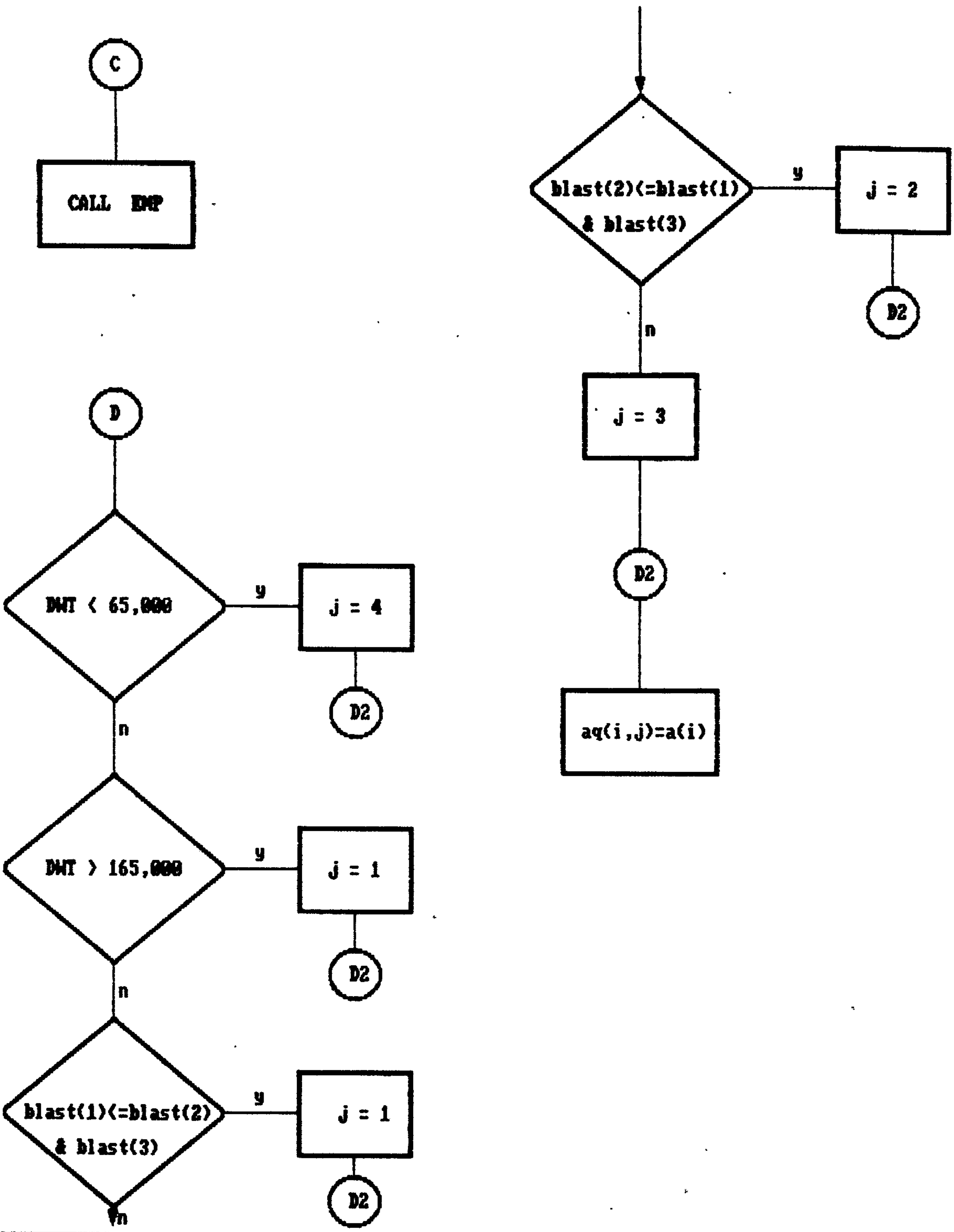
FLOWCHART OF PART A



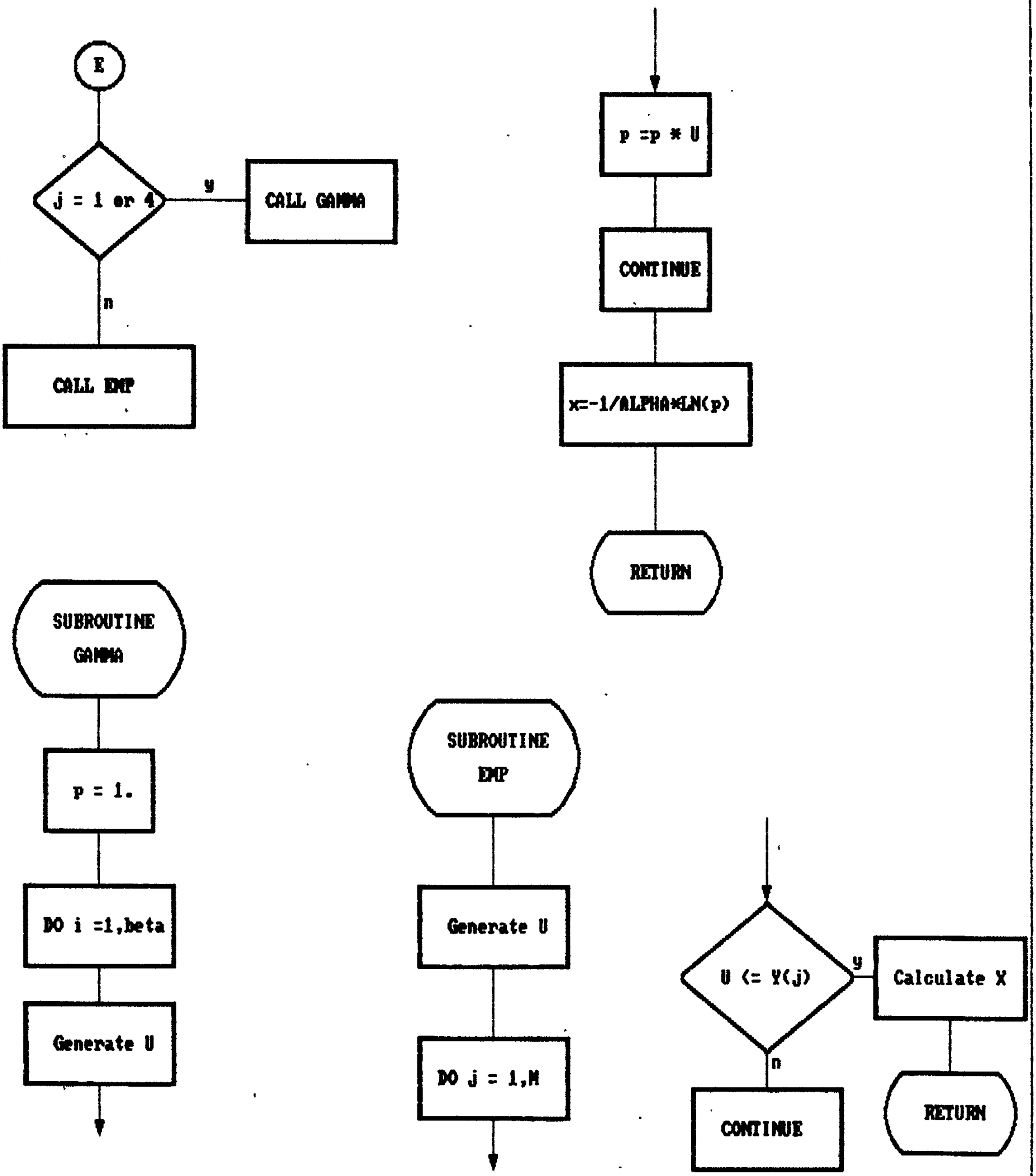
FLOWCHART OF PART B



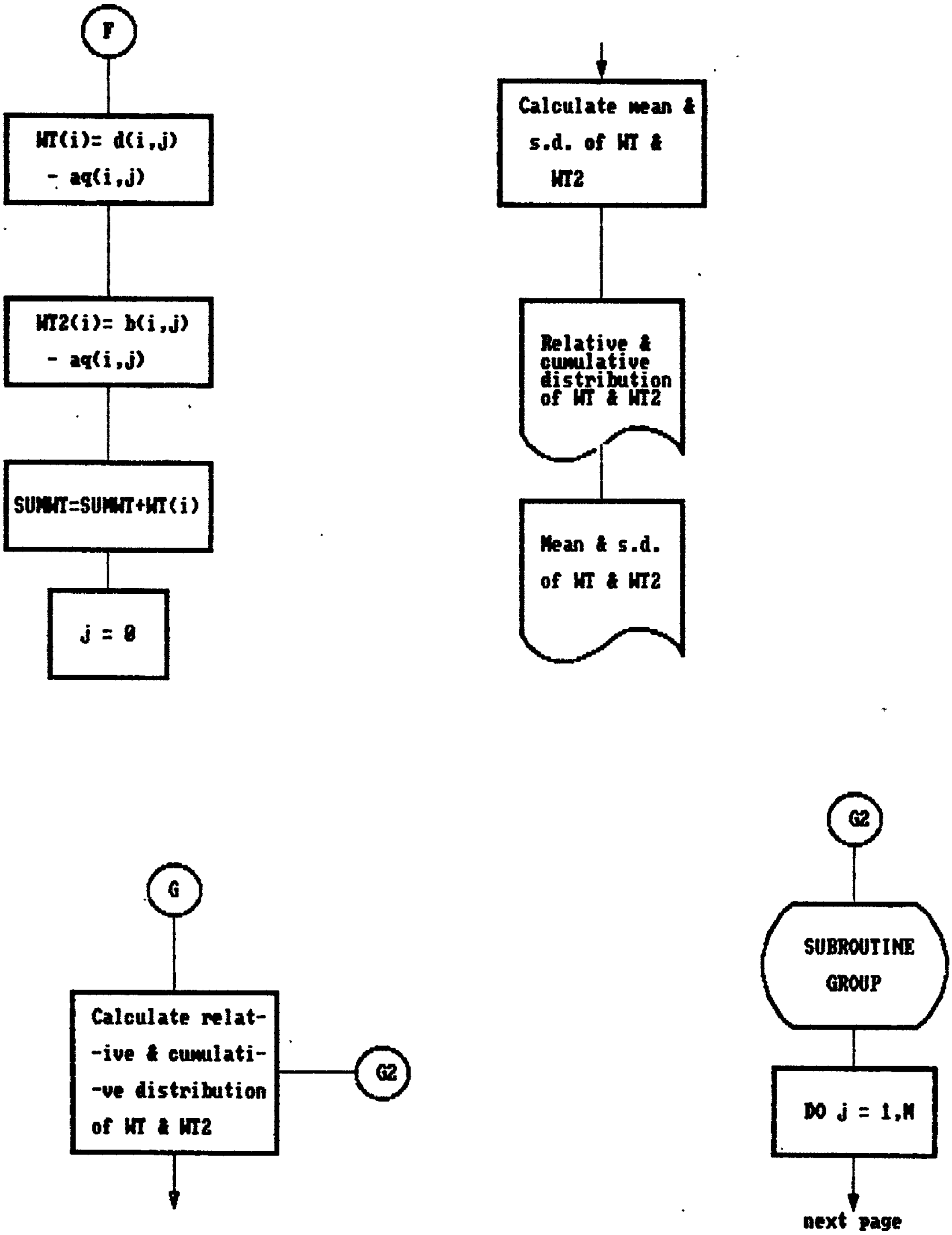
FLOWCHART OF PART C & D



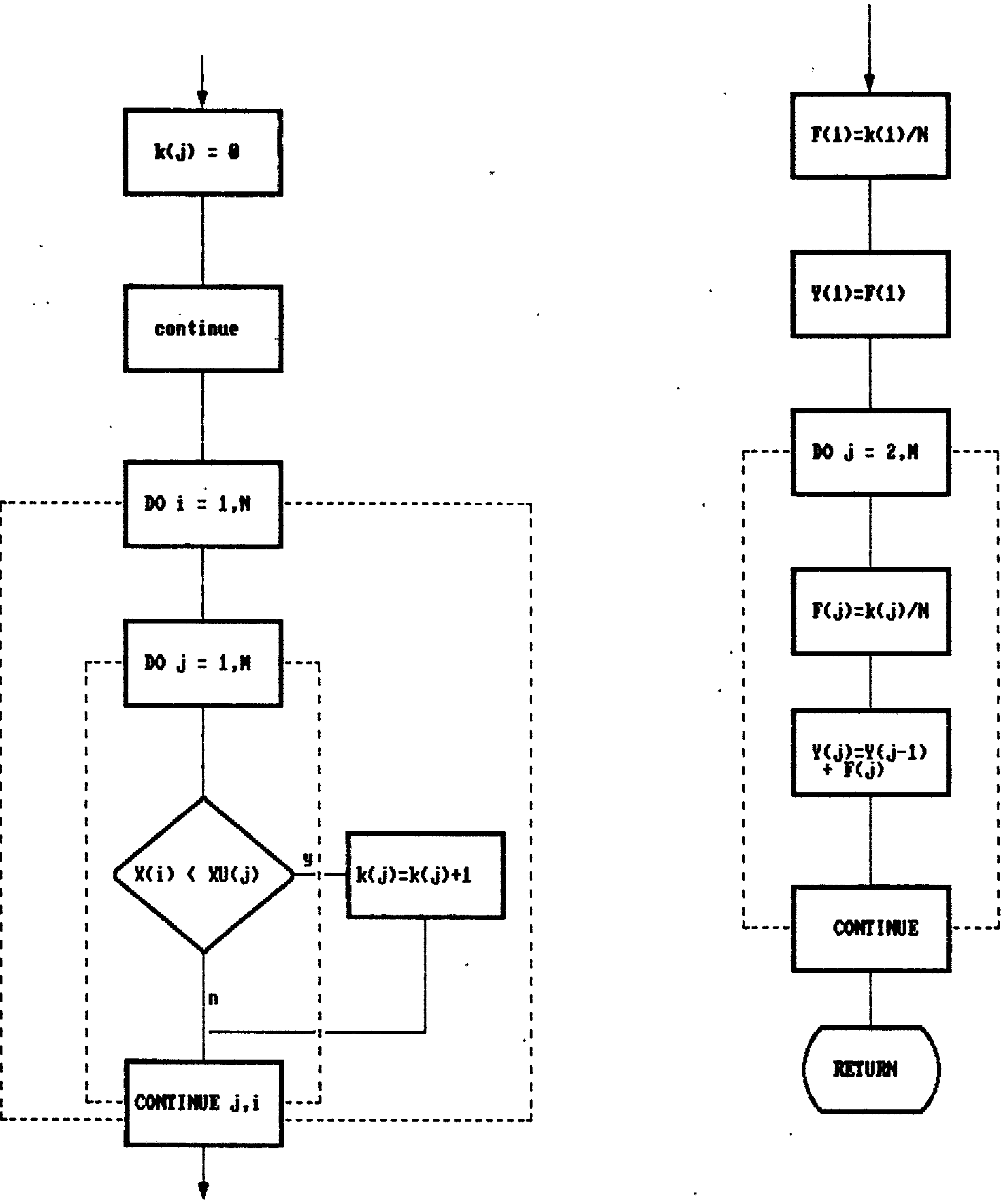
FLOWCHART OF PART E



FLOWCHART OF PART F & G



FLOWCHART OF PART G



ship is supposed to call a bigger berth and a smaller ship a smaller berth, sometimes exceptions were found in the raw data set. Discussions with people in charge of berth allocation came to the conclusion that in principle, berths should be allocated depending upon ship size and in the case of busyness, there can be compatibility for a certain range of ship size among S1, S2 and S3 as can be seen in the flowchart, part D. This principle seems to be applicable for whole simulation period. Thus, the berth allocation process should be considered as a decision variable. In the flowchart, 165,000 dwt size is selected as berth allocation criterion between S1 and the other two medium sized berths (S2 & S3) and 65,000 DWT size between S4 and the others and compatibility is assumed inbetween.[16]

Service time generation can be seen in flowchart E where S1 and S4 service times are generated by gamma distribution and S2 and S3 by empirical distributions. Flowchart F calculates waiting time in the system and in the queue as well as the summation.

Flowchart part G copes with output process where relative and cumulative distributions of waiting time as well as mean value and standard deviation are calculated with grouping process (part G2). Thus, when the last ship finishes being served, each individual ship's arrival, service, departure and waiting times are output and the distribution of waiting time as the objective of the program can be provided.

2.3 Computer Program

The flow chart was programed in FORTRAN 77 as can be seen in the Appendix. The program was developed using a personal computer although it can be used by bigger computer, for instance a mini computer or main frame.

The source program should be compiled by certain compilers which keep negative values in the event of overflow. Most compilers seem to assign zero value to the overflowed bit by default where the power residue method cannot be applied resulting in all zero values in uniformly distributed random number series. The source program was compiled by MS FORTRAN compiler version 4.0 with IBM PC.[17]

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[16]As a result of several trials for different sizes, the criteria were selected because 165,000 and 65,000 DWT criteria showed the closest output to the raw data in terms of number of ships in each berth. For instance, the result of the criterion allocated 62 ships in S1, 64 ships in S2, 55 ships in S3 and 10 ships in S4 among 191 ships which were simulated in the program whilst in the raw data 60 ships were allocated in S1, 47 ships in S2, 56 ships in S3 and 11 ships in S4 among 174 ships.

[17]During the compilation, it was found that the version 4.0 compiler was the only one which produced random numbers whilst others produced zero values for the overflowed bits or error message

Chapter IV. Simulation Result

This chapter will present the result of the simulation model, the cost-benefit analysis of the investment project and the sensitivity analysis.

The simulation model result will show the estimated waiting time distribution in the system and in the queue not only in the existing port system but also in the expansion case (henceforth, old system and new system, respectively). Then, these results will be compared in the cost-benefit analysis in terms of required cost such as construction cost for infrastructure and superstructure and maintenance and operating cost and expected benefit, mainly resulting from reduction in ship turnaround time cost from the old system to the new system. Finally, the extent of risk in the project will be examined in the sensitivity analysis for major factors, for instance, the change of the parameter of the service time distribution in the simulation model and the change of the discount rate in the cost-benefit analysis.

1. The Simulation Model Result

1.1. Result with the old system

The simulation model was run in the old system with six random number distributions, namely one DWT, one interarrival time and four service time distributions. The distributions are as follows;

* DWT distribution - empirical distribution
* Interarrival time - exponential (α=0.028680798)
* S1 service time - gamma (α=0.105, β=14)
* S2 service time - empirical
* S3 service time - empirical
* S4 service time - gamma (α=1.805E-02, β=3)

From these distributions, each individual vessel's DWT, arrival time, berthing time, discharging duration (service time), departure time and waiting time in the system and in the queue were calculated. The results of the first year are shown in table 4.1.

The table presents serial ship number from the 1st to the 191st, arrival time in the port(a(i)), allocated berth number(1:S1, 2:S2, 3:S3, 4:S4), berthing time(b(i,j)), departure time from the berth(d(i,j)), waiting time in the system(wt(i)) and

Table 4.1 Results of the First Year Simulation
- Old System -

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
1	.0	4	.0	200.4	200.4	.0
2	14.2	1	14.2	95.4	81.2	.0
3	33.3	4	200.4	294.8	261.6	167.1
4	63.2	2	63.2	132.6	69.5	.0
5	64.2	3	64.2	223.7	159.6	.0
6	107.6	1	107.6	227.1	119.4	.0
7	131.6	2	132.6	246.9	115.3	1.0
8	185.7	4	294.8	398.6	212.9	109.1
9	229.6	3	229.6	432.5	202.9	.0
10	295.3	1	295.3	447.0	151.7	.0
11	302.3	2	302.3	451.3	149.0	.0
12	328.5	4	398.6	504.7	176.2	70.1
13	385.1	3	432.5	493.3	108.2	47.4
14	386.6	1	447.0	550.5	163.9	60.3
15	389.2	2	451.3	623.9	234.7	62.1
16	413.2	1	550.5	624.6	211.4	137.4
17	603.2	3	603.2	719.2	115.9	.0
18	650.9	1	650.9	747.8	97.0	.0
19	677.2	2	677.2	803.0	125.8	.0
20	730.5	1	747.8	907.1	176.7	17.3
21	753.1	3	753.1	839.8	86.7	.0
22	823.8	2	823.8	894.4	70.7	.0
23	906.2	3	906.2	1024.2	118.0	.0
24	912.6	2	912.6	997.8	85.2	.0
25	934.9	1	934.9	1020.4	85.5	.0
26	1015.5	1	1020.4	1180.5	165.0	4.9
27	1052.3	2	1052.3	1149.8	97.5	.0
28	1071.9	3	1071.9	1215.8	143.8	.0
29	1097.4	2	1149.8	1330.4	233.0	52.3
30	1099.2	1	1180.5	1358.4	259.2	81.3
31	1128.8	3	1215.8	1426.2	297.4	86.9
32	1161.5	2	1330.4	1412.5	251.0	168.9
33	1173.1	1	1358.4	1580.8	407.7	185.3
34	1200.9	2	1412.5	1500.1	299.3	211.6
35	1202.8	1	1580.8	1701.4	498.6	378.0
36	1302.6	3	1426.2	1568.6	266.0	123.6
37	1315.3	2	1500.1	1561.9	246.6	184.8
38	1325.3	2	1561.9	1659.3	334.0	236.6
39	1329.2	1	1701.4	1813.1	483.9	372.2
40	1334.6	3	1568.6	1716.7	382.1	234.0
41	1350.5	2	1659.3	1743.0	392.6	308.9
42	1382.6	3	1716.7	1918.1	535.5	334.1
43	1398.0	2	1743.0	1873.1	475.1	345.0
44	1419.6	1	1813.1	1936.7	517.1	393.6
45	1458.5	2	1873.1	1990.4	531.9	414.7
46	1471.6	3	1918.1	2032.4	560.8	446.5
47	1481.9	1	1936.7	2050.2	568.2	454.7
48	1486.6	2	1990.4	2079.9	593.2	503.8
49	1533.0	3	2032.4	2095.1	562.1	499.4
50	1561.8	1	2050.2	2179.3	617.5	488.4

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
51	1604.7	2	2079.9	2213.8	609.1	475.1
52	1653.9	3	2095.1	2180.5	526.6	441.2
53	1715.1	1	2179.3	2310.7	595.5	464.2
54	1747.9	3	2180.5	2261.9	513.9	432.6
55	1769.3	2	2213.8	2384.1	614.8	444.6
56	1833.9	1	2310.7	2489.4	655.5	476.7
57	1865.0	1	2489.4	2656.6	791.6	624.4
58	1889.8	1	2656.6	2750.2	860.4	766.7
59	1908.6	3	2261.9	2379.2	470.6	353.3
60	1931.6	3	2379.2	2490.9	559.3	447.6
61	1957.0	2	2384.1	2474.4	517.4	427.1
62	2018.7	2	2474.4	2592.4	573.6	455.7
63	2044.5	4	2044.5	2249.4	204.9	.0
64	2152.2	3	2490.9	2633.0	480.8	338.7
65	2152.4	2	2592.4	2705.2	552.8	440.0
66	2159.4	3	2633.0	2744.3	584.9	473.6
67	2174.7	2	2705.2	2797.7	623.0	530.5
68	2213.7	3	2744.3	2852.5	638.8	530.7
69	2264.2	1	2750.2	2954.0	689.8	486.0
70	2295.9	2	2797.7	2876.0	580.1	501.8
71	2334.4	3	2852.5	3082.0	747.7	518.1
72	2336.6	1	2954.0	3065.3	728.7	617.4
73	2373.7	2	2876.0	3019.4	645.7	502.3
74	2416.0	2	3019.4	3126.6	710.7	603.5
75	2444.0	1	3065.3	3161.8	717.8	621.2
76	2507.6	1	3161.8	3243.6	736.0	654.2
77	2551.8	3	3082.0	3146.1	594.3	530.2
78	2601.1	1	3243.6	3329.4	728.3	642.5
79	2828.4	2	3126.6	3188.0	359.7	298.3
80	2862.3	3	3146.1	3213.7	351.4	283.8
81	2903.1	2	3188.0	3302.3	399.2	284.9
82	2966.9	3	3213.7	3370.8	403.9	246.8
83	2993.9	2	3302.3	3424.9	431.0	308.4
84	3045.9	1	3329.4	3468.0	422.2	283.5
85	3047.6	1	3468.0	3619.9	572.3	420.4
86	3132.3	1	3619.9	3757.0	624.7	487.6
87	3211.6	3	3370.8	3519.5	307.9	159.2
88	3223.0	2	3424.9	3557.7	334.7	201.9
89	3317.5	3	3519.5	3669.3	351.8	202.0
90	3345.6	2	3557.7	3670.5	325.0	212.1
91	3351.4	3	3669.3	3892.7	541.3	317.9
92	3354.2	1	3757.0	3889.2	535.0	402.8
93	3377.6	2	3670.5	3731.1	353.5	292.9
94	3430.2	1	3889.2	4071.5	641.3	459.0
95	3430.7	2	3731.1	3849.3	418.6	300.4
96	3476.9	2	3849.3	3937.8	460.9	372.4
97	3479.5	3	3892.7	4005.4	525.9	413.2
98	3500.1	4	3500.1	3699.7	199.7	.0
99	3524.0	2	3937.8	4052.5	528.5	413.7
100	3572.6	3	4005.4	4228.2	655.6	432.8
101	3717.9	2	4052.5	4232.3	514.4	334.6
102	3755.8	1	4071.5	4179.9	424.1	315.7
103	3764.2	1	4179.9	4367.9	603.7	415.6
104	3807.4	3	4228.2	4316.5	509.1	420.8

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
105	3821.2	2	4232.3	4343.3	522.1	411.2
106	3930.1	3	4316.5	4434.9	504.8	386.4
107	3934.8	1	4367.9	4444.4	509.6	433.1
108	4110.3	1	4444.4	4583.0	472.8	334.2
109	4147.2	2	4343.3	4515.0	367.8	196.1
110	4163.0	3	4434.9	4626.4	463.4	271.9
111	4221.7	1	4583.0	4779.2	557.5	361.4
112	4373.8	2	4515.0	4586.0	212.1	141.2
113	4393.8	2	4586.0	4685.4	291.7	192.2
114	4420.8	3	4626.4	4736.6	315.8	205.6
115	4504.7	2	4685.4	4766.8	262.1	180.7
116	4580.8	3	4736.6	4889.1	308.3	155.7
117	4644.9	2	4766.8	4890.4	245.4	121.9
118	4839.6	1	4839.6	4994.9	155.3	.0
119	4856.6	3	4889.1	5023.0	166.5	32.6
120	4978.3	2	4978.3	5058.5	80.2	.0
121	4985.5	1	4994.9	5097.6	112.1	9.4
122	5019.3	3	5023.0	5108.5	89.2	3.7
123	5022.4	2	5058.5	5248.4	226.0	36.1
124	5041.4	1	5097.6	5222.9	181.5	56.3
125	5087.2	3	5108.5	5184.5	97.3	21.3
126	5284.7	1	5284.7	5476.1	191.5	.0
127	5321.0	3	5321.0	5464.4	143.5	.0
128	5337.0	2	5337.0	5472.2	135.2	.0
129	5411.5	3	5464.4	5643.5	232.0	53.0
130	5437.5	2	5472.2	5560.8	123.2	34.6
131	5501.0	1	5501.0	5606.5	105.4	.0
132	5524.2	2	5560.8	5645.8	121.6	36.5
133	5557.4	1	5606.5	5728.7	171.2	49.0
134	5588.9	3	5643.5	5811.1	222.1	54.6
135	5641.7	2	5645.8	5803.8	162.2	4.1
136	5681.1	1	5728.7	5870.9	189.8	47.6
137	5689.6	2	5803.8	5966.3	276.7	114.2
138	5813.2	3	5813.2	6026.5	213.2	.0
139	5826.5	1	5870.9	6046.7	220.1	44.3
140	5857.9	1	6046.7	6220.2	362.4	188.8
141	5901.8	2	5966.3	6078.3	176.5	64.6
142	5939.9	3	6026.5	6238.5	298.6	86.6
143	6013.6	1	6220.2	6387.4	373.8	206.6
144	6051.8	2	6078.3	6254.7	202.9	26.4
145	6085.7	1	6387.4	6504.8	419.1	301.7
146	6114.1	3	6238.5	6434.5	320.4	124.4
147	6137.7	2	6254.7	6367.8	230.1	117.0
148	6222.3	2	6367.8	6457.4	235.0	145.5
149	6271.4	1	6504.8	6613.2	341.8	233.4
150	6277.9	3	6434.5	6548.0	270.1	156.6
151	6294.3	2	6457.4	6568.8	274.4	163.0
152	6374.3	3	6548.0	6655.0	280.7	173.7
153	6439.5	2	6568.8	6636.8	197.3	129.2
154	6524.5	1	6613.2	6713.6	189.1	88.7
155	6605.0	2	6636.8	6816.1	211.1	31.8
156	6628.3	3	6655.0	6827.9	199.6	26.7
157	6753.3	1	6753.3	6827.8	74.4	.0
158	6755.8	2	6816.1	6898.6	142.8	60.3

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
159	6824.3	1	6827.8	6939.1	114.8	3.5
160	6893.5	3	6893.5	7102.1	208.6	.0
161	7031.1	4	7031.1	7148.3	117.2	.0
162	7046.8	2	7046.8	7207.5	160.7	.0
163	7128.1	1	7128.1	7241.4	113.2	.0
164	7182.4	3	7182.4	7368.1	185.6	.0
165	7274.2	4	7274.2	7515.4	241.2	.0
166	7403.3	2	7403.3	7496.5	93.1	.0
167	7452.7	1	7452.7	7572.6	119.9	.0
168	7505.6	3	7505.6	7570.6	65.0	.0
169	7517.9	2	7517.9	7692.3	174.4	.0
170	7546.9	3	7570.6	7674.8	127.9	23.7
171	7552.7	1	7572.6	7661.8	109.1	19.9
172	7581.1	1	7661.8	7760.9	179.7	80.7
173	7741.5	3	7741.5	7889.5	148.0	.0
174	7798.5	2	7798.5	7865.3	66.8	.0
175	7801.9	1	7801.9	7950.5	148.6	.0
176	7827.3	2	7865.3	7993.3	166.0	38.0
177	7894.7	3	7894.7	7981.9	87.3	.0
178	7941.8	4	7941.8	8000.1	58.2	.0
179	7966.9	1	7966.9	8089.2	122.4	.0
180	8014.5	3	8014.5	8118.3	103.7	.0
181	8077.6	2	8077.6	8143.0	65.4	.0
182	8130.8	1	8130.8	8333.4	202.7	.0
183	8141.6	3	8141.6	8234.2	92.6	.0
184	8255.3	1	8333.4	8429.4	174.2	78.2
185	8304.5	2	8304.5	8443.7	139.2	.0
186	8384.3	3	8384.3	8579.5	195.2	.0
187	8384.3	4	8384.3	8710.3	325.9	.0
188	8487.8	1	8487.8	8646.6	158.8	.0
189	8549.2	1	8646.6	8722.7	173.5	97.5
190	8608.2	1	8722.7	8827.5	219.3	114.4
191	8678.1	1	8827.5	8984.3	306.1	149.4

waiting time in the queue(wt2(i)).[1] For instance, the first ship arrives in the port at zero hours (because the simulation starts from zero hours) and directly berths in the smallest berth (S4) at zero hours since the berth is idle.

As soon as the ship finishes discharging, she departs at 200.4 hours resulting in a 200.4 hours'turnaround time and no waiting time in the queue. In the table, the third ship has to wait for 167.1 hours in the queue because the berth (S4) is already occupied by the first ship when she arrives at 33.3 hours. This process is continued until the last ship (191st ship) for the year finishes discharging. The main objective of the simulation model is the estimation of waiting time in the system or turn-

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[1] A(i), b(i,j) and d(i,j) represent clock times whereas wt(i) and wt2(i) represent time intervals.

around time in the port and waiting time in the queue as can be seen in the columns, wt(i) and wt2(i), respectively. The average waiting time in the system is estimated to be about 318.2 hours with 196.4 hours standard deviation and the average waiting time in the queue, 189.43 hours with 196.05 hours standard deviation. The maximum waiting time in the queue is estimated to be 766.7 hours from the 58th ship.

The simulation model in the old system was run over forty years because the period should be matched with the economic life span of the infrastructure such as quay wall and breakwater in order to be used in the cost-benefit analysis later. Every year the same procedure as the first year was conducted. The results of a 40 year simulation run can be seen in table 4.2.

The table shows waiting time as a summation of all individual ships in the system and in the queue and berth occupancy rate in each berth. The waiting time in the system has a range from 28,735.75 hours in year 24 to 68,238.75 in year 38 whilst the waiting time in the queue is from 4,993.59 hours in year 40 to 44,972.72 hours in year 38. The higher values in waiting time can be explained from the berth occupancy rate columns. The busiest berth is the biggest berth (S1) whilst the smallest berth (S4) seems to be rather idle. This figure implies that the expansion program is more likely to be necessary in order to reduce the waiting time cost.

Table 4.2 Results of the Simulation Model - Old System -

year	waiting time in the system (hour)	waiting time in the queue (hour)	Berth Occupancy Rate (%) S1	S2	S3	S4
1	60760.11	36181.28	92.	83.	86.	19.
2	39478.88	15128.35	81.	75.	79.	44.
3	36830.23	12628.93	85.	74.	75.	43.
4	36456.58	12570.50	89.	77.	77.	29.
5	38442.64	14750.45	89.	79.	82.	21.
6	56083.38	32655.77	86.	80.	78.	23.
7	36089.36	12216.48	86.	77.	78.	32.
8	39457.68	15258.95	88.	80.	80.	28.
9	43138.66	18703.23	90.	76.	79.	34.
10	37209.13	13489.13	88.	77.	77.	29.
11	34979.95	11164.15	89.	81.	82.	20.
12	64176.21	40611.30	87.	74.	77.	32.
13	38391.82	15626.97	83.	76.	76.	25.
14	38352.55	13162.52	98.	78.	81.	30.
15	47092.65	23666.63	89.	77.	82.	20.
16	51044.12	26008.04	91.	81.	82.	32.
17	36363.28	12235.81	89.	74.	79.	34.
18	38245.06	14371.33	94.	82.	83.	14.
19	46167.00	22541.41	87.	79.	79.	24.
20	36378.98	13203.63	98.	74.	78.	13.
21	53299.56	30131.39	90.	82.	82.	11.
22	36720.16	12264.66	93.	77.	81.	29.
23	41267.63	18091.83	88.	78.	83.	15.
24	28735.75	5867.78	91.	77.	76.	17.
25	56754.02	33616.98	87.	78.	81.	18.
26	38300.52	14247.61	99.	81.	88.	7.
27	35236.08	11492.59	90.	78.	84.	19.
28	46868.97	22923.14	90.	87.	85.	12.
29	55967.22	32023.28	88.	86.	87.	12.
30	68136.84	43194.33	90.	85.	86.	24.
31	45614.59	21147.59	92.	81.	80.	27.
32	40591.81	17280.38	88.	83.	82.	13.
33	55769.38	31445.59	97.	86.	86.	9.
34	32274.63	7876.19	93.	82.	77.	26.
35	46281.91	21676.34	88.	80.	85.	28.
36	41732.91	17424.78	91.	83.	82.	22.
37	31259.41	7879.84	87.	74.	76.	30.
38	68238.75	44972.72	87.	75.	77.	26.
39	42768.81	18953.69	96.	78.	78.	21.
40	28815.13	4993.59	92.	68.	71.	42.

1.2. Result with the new system

As mentioned in the previous chapter, the port is considering building up one new big berth which can handle a 250,000 DWT ship. If the new berth is constructed, the smallest berth (S4) is scheduled not to be used for iron ore and coal ships any more. Thus, the new port system will use one new berth and three existing berths (S1, S2 & S3) for discharging iron ore and coal. Obviously the new system will be the same multi-channelled single phase system as the existing system.

In the new system, the symbol for berth numbers such as S1, S2, S3 and S4 will be referred to differently from the previous one. S1 will refer to new biggest berth, S2 will refer to S1 in the old system, S3 to S2 in the old system and S4 to S3 in the old system.

If the new berth is constructed, the people of the company, POSCO, expect that they can charter larger vessels replacing smaller vessels and reduce ship calling frequencies from <u>191 ship callings</u> in the old system to <u>132 ship callings</u> in the new system annually. In the same manner, the distribution of DWT in the new system is expected to have the following composition.

* 60,000 DWT - 100,000 DWT : 20 %
* 100,000 DWT - 150,000 DWT : 35 %
* Over 150,000 : the same distribution as in the old system : 45 %

In addition to the above-mentioned information, some more information is required to run the simulation model in the new system as to the random number distributions. In other words, the new interarrival time distribution and service time distribution in the new berth should be estimated. However, due to the lack of historical data for the distributions in the new system, the distributions should be estimated either analytically or from referring to the literature or the experience experts have had from similar ports. Furthermore the berth allocation policy should be decided again as to which size vessel will be allocated to a specific berth as done in the old system.

As far as the new interarrival time distribution is concerned, it is more likely to have exponential distribution because in many waiting-line problems the probability of random arrival between times x and $x + \delta x$ is indeed proportional to the time interval δx, as implied by the exponential distribution from the literature.[2] So, if the distribution is exponential, the only thing to be done is the estimation of the parameter. As explained in the expression 3.7, exponential distribution has only one parameter, α where $\mu=1/\alpha$. Once the mean value is

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[2] See Gottfried, op. cit. pp. 85 - 86.

estimated, the parameter, α, can be straightforward to calculate. The easiest way to calculate the mean value of the interarrival time distribution would be to divide total annual hours (365 days · 24 hours = 8760 hours) by the number of ships calling (132 callings) minus one. Thus, the mean value would be $8760 \div 131 = 66.870229$ hours and the parameter, α would be $1/\mu = 0.014954$ following the formula. This value for α will be used in the new system simulation.

As far as the estimation of the service time distribution in the new berth is concerned, it is likely to be more uncertain. Although service time distribution is very often represented by gamma distribution, it seems to be rather difficult to estimate the parameters because it has two parameters, α and β requiring estimation of the mean value and the standard deviation.[3]

During the simulation study, the most intractable part was the estimation of this service time distribution in the new system. After several discussions with a number of experts, the author was conclusively advised to use the same distribution as the biggest berth distribution (S1) in the existing system and afterwards to test the impact of variation from that one by changing the mean value with the same standard deviation as S1 of the old system in the sensitivity analysis.[4]

Consequently, the service time distribution in the new berth (S1) is assumed to have the same distribution as the biggest berth in the existing system and variation will be tested in the sensitivity analysis.

The simulation model in the new system will be run based on six random number distributions in the same manner as in the old system, namely one new DWT, one new interarrival time, one new service time and three other service time distributions from the existing system. The distributions are as follows;

* DWT distribution - empirical distribution
* Interarrival time - exponential (α=0.014954)
* S1 service time (new berth) - gamma (α=0.105, β=14)
* S2 service (S1 in old system) - gamma (α=0.105, β=14)
* S3 service (S2 in old system) - empirical
* S4 service (S3 in old system) - empirical

The new DWT distribution was tabulated in accordance with the principle of the new composition as explained before. The result can be seen in table 4.3.

Berth allocation policy in the new system was concluded after discussions with the company people in charge of berth

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[3] See expression 3.8.

[4] For instance, Dr. J. Lüsch from E. Germany conducted some research about the change of service time distribution pattern after expansion investment over three different periods and found that even after investment, the distributions were the same types as preinvestment ones.

allocation in such a manner that ships larger than 165,000 DWT should be allocated either in the new berth, S1 or S2 and ships smaller than 115,000 DWT either in S3 or S4 and ships inbetween in the earliest available berth.

Table 4.3 Estimated Distribution of DWT
- New System -

boundary	relative	cumulative
65000 - 100000	.200	.200
- 150000.000	.350	.550
- 155000.000	.146	.696
- 160000.000	.120	.817
- 165000.000	.042	.859
- 170000.000	.005	.864
- 175000.000	.000	.864
- 180000.000	.021	.885
- 185000.000	.042	.927
- 190000.000	.000	.927
- 195000.000	.000	.927
- 200000.000	.000	.927
- 205000.000	.000	.927
- 210000.000	.005	.932
- 215000.000	.000	.932
- 220000.000	.016	.948
- 225000.000	.026	.974
- 230000.000	.005	.979
- 235000.000	.000	.979
- 240000.000	.000	.979
- 245000.000	.000	.979
- 250000.000	.000	.979
- 255000.000	.021	1.000

The simulation model was run in the new system for 40 years in the same way as the old system. The results of the first year are presented in table 4.4 and whole period results in table 4.5.

Table 4.4 Results of The First Year Simulation
- New System -

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
1	.0	3	.0	67.1	67.1	.0
2	57.2	1	57.2	157.9	100.8	.0
3	84.6	2	84.6	213.2	128.6	.0
4	241.5	4	241.5	312.3	70.8	.0
5	279.5	3	279.5	382.4	102.9	.0
6	298.1	1	298.1	436.2	138.1	.0
7	393.1	2	393.1	567.5	174.3	.0
8	394.2	1	436.2	572.0	177.7	42.0
9	557.2	4	557.2	674.0	116.8	.0
10	559.3	3	559.3	653.3	94.0	.0
11	587.7	2	587.7	669.1	81.4	.0
12	680.3	1	680.3	795.1	114.9	.0
13	697.3	3	697.3	830.4	133.1	.0
14	714.0	2	714.0	816.2	102.2	.0
15	737.8	4	737.8	827.8	90.0	.0
16	756.3	1	795.1	949.1	192.8	38.8
17	873.4	2	873.4	937.9	64.5	.0
18	879.9	4	879.9	1018.4	138.5	.0
19	885.4	3	885.4	1031.2	145.8	.0
20	999.9	2	999.9	1160.0	160.1	.0
21	1052.1	1	1052.1	1199.3	147.2	.0
22	1106.1	4	1106.1	1220.6	114.5	.0
23	1152.0	2	1160.0	1304.2	152.2	8.1
24	1222.2	3	1222.2	1311.8	89.7	.0
25	1287.1	1	1287.1	1441.2	154.1	.0
26	1309.9	4	1309.9	1443.6	133.7	.0
27	1375.0	2	1375.0	1519.5	144.5	.0
28	1407.5	3	1407.5	1590.5	183.0	.0
29	1419.4	1	1441.2	1551.2	131.8	21.9
30	1450.8	4	1450.8	1598.3	147.5	.0
31	1467.4	2	1519.5	1619.8	152.4	52.0
32	1503.9	1	1551.2	1670.0	166.1	47.3
33	1544.7	3	1590.5	1723.2	178.5	45.8
34	1604.4	4	1604.4	1690.8	86.5	.0
35	1647.0	4	1690.8	1808.4	161.4	43.8
36	1686.0	2	1686.0	1882.2	196.2	.0
37	1737.2	1	1737.2	1850.2	113.0	.0
38	1836.3	3	1836.3	1953.4	117.1	.0
39	2005.6	4	2005.6	2105.3	99.7	.0
40	2049.4	1	2049.4	2184.7	135.3	.0
41	2060.1	2	2060.1	2220.5	160.4	.0
42	2199.4	3	2199.4	2276.1	76.7	.0
43	2294.2	4	2294.2	2411.3	117.1	.0
44	2356.2	3	2356.2	2481.7	125.5	.0
45	2381.5	4	2411.3	2485.3	103.8	29.8
46	2466.7	1	2466.7	2575.5	108.8	.0
47	2475.3	2	2475.3	2579.6	104.2	.0
48	2509.1	3	2509.1	2571.8	62.7	.0
49	2730.8	1	2730.8	2827.5	96.7	.0
50	2832.2	4	2832.2	2930.5	98.3	.0
51	2869.3	3	2869.3	2932.1	62.8	.0

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
52	2873.4	2	2873.4	3066.2	192.8	.0
53	2873.9	1	2873.9	2965.7	91.8	.0
54	2980.7	4	2980.7	3095.6	114.9	.0
55	2994.5	3	2994.5	3091.6	97.1	.0
56	3064.0	1	3064.0	3172.6	108.7	.0
57	3096.1	2	3096.1	3184.4	88.3	.0
58	3148.5	1	3172.6	3301.7	153.1	24.1
59	3208.2	2	3208.2	3368.5	160.3	.0
60	3224.1	3	3224.1	3309.8	85.7	.0
61	3252.5	4	3252.5	3325.0	72.6	.0
62	3285.4	1	3301.7	3433.7	148.3	16.2
63	3395.7	3	3395.7	3496.2	100.5	.0
64	3469.6	4	3469.6	3638.6	169.0	.0
65	3485.6	2	3485.6	3632.2	146.6	.0
66	3487.5	1	3487.5	3639.7	152.2	.0
67	3506.9	3	3506.9	3623.5	116.6	.0
68	3551.1	2	3632.2	3744.5	193.3	81.0
69	3567.4	3	3623.5	3781.9	214.4	56.0
70	3592.0	4	3638.6	3750.3	158.3	46.6
71	3906.6	1	3906.6	4086.7	180.2	.0
72	3929.9	2	3929.9	4050.2	120.3	.0
73	3957.7	4	3957.7	4057.6	100.0	.0
74	4066.5	2	4066.5	4174.2	107.7	.0
75	4080.3	3	4080.3	4226.4	146.1	.0
76	4110.0	4	4110.0	4279.2	169.1	.0
77	4143.3	1	4143.3	4320.2	176.9	.0
78	4222.0	2	4222.0	4314.7	92.7	.0
79	4224.0	3	4226.4	4295.3	71.3	2.4
80	4224.0	4	4279.2	4435.7	211.6	55.1
81	4266.0	3	4295.3	4357.0	91.0	29.4
82	4273.1	2	4314.7	4444.0	170.9	41.6
83	4395.5	1	4395.5	4504.8	109.3	.0
84	4736.3	3	4736.3	4846.9	110.6	.0
85	4915.5	4	4915.5	4981.1	65.6	.0
86	5007.8	2	5007.8	5132.5	124.7	.0
87	5035.5	3	5035.5	5105.5	70.0	.0
88	5055.1	1	5055.1	5199.7	144.7	.0
89	5094.7	4	5094.7	5211.6	116.9	.0
90	5204.3	2	5204.3	5307.3	103.0	.0
91	5264.5	3	5264.5	5349.1	84.6	.0
92	5363.3	1	5363.3	5456.8	93.5	.0
93	5472.7	4	5472.7	5607.9	135.1	.0
94	5479.2	2	5479.2	5685.7	206.6	.0
95	5715.8	3	5715.8	5778.8	63.0	.0
96	5729.8	1	5729.8	5818.7	89.0	.0
97	5742.3	4	5742.3	5852.4	110.1	.0
98	5778.2	2	5778.2	5895.1	116.9	.0
99	5914.9	3	5914.9	6097.1	182.2	.0
100	5924.1	1	5924.1	6050.5	126.4	.0
101	5980.1	2	5980.1	6122.3	142.2	.0
102	5992.2	4	5992.2	6212.0	219.8	.0

ship no	a(i)	berth no	b(i,j)	d(i,j)	wt(i)	wt2(i)
103	6167.8	1	6167.8	6346.7	178.9	.0
104	6202.2	3	6202.2	6291.6	89.4	.0
105	6246.7	2	6246.7	6420.3	173.6	.0
106	6309.1	4	6309.1	6427.8	118.7	.0
107	6363.3	3	6363.3	6549.3	186.1	.0
108	6468.0	1	6468.0	6635.2	167.2	.0
109	6522.3	2	6522.3	6614.5	92.2	.0
110	6571.7	4	6571.7	6645.2	73.5	.0
111	6612.1	3	6612.1	6788.7	176.6	.0
112	6645.6	2	6645.6	6758.1	112.5	.0
113	6721.6	1	6721.6	6836.9	115.2	.0
114	6907.7	4	6907.7	6986.4	78.7	.0
115	6914.4	2	6914.4	7030.6	116.2	.0
116	6972.2	1	6972.2	7055.6	83.4	.0
117	7006.0	2	7030.6	7178.7	172.6	24.6
118	7069.6	1	7069.6	7224.4	154.8	.0
119	7092.0	3	7092.0	7252.7	160.7	.0
120	7207.5	4	7207.5	7360.1	152.6	.0
121	7425.2	2	7425.2	7527.7	102.5	.0
122	7555.5	3	7555.5	7617.0	61.5	.0
123	7581.7	1	7581.7	7687.8	106.1	.0
124	7665.9	4	7665.9	7740.1	74.2	.0
125	7690.8	2	7690.8	7827.3	136.5	.0
126	7699.5	3	7699.5	7810.4	110.9	.0
127	7773.1	1	7773.1	7855.6	82.5	.0
128	7845.1	4	7845.1	7994.9	149.8	.0
129	7935.4	2	7935.4	8111.8	176.4	.0
130	8042.9	3	8042.9	8154.9	112.0	.0
131	8082.5	1	8082.5	8226.3	143.8	.0
132	8100.7	4	8100.7	8325.2	224.6	.0

Table 4.5 Results of Simulation - New System -

year	waiting time in the system (hour)	waiting time in the queue (hour)	Berth Occupancy Rate (%) S1	S2	S3	S4
1	16815.68	706.48	48.	51.	42.	44.
2	17549.13	1001.85	49.	49.	42.	48.
3	16177.33	403.80	49.	50.	40.	42.
4	16774.37	234.68	52.	50.	41.	45.
5	17562.02	789.02	52.	52.	46.	42.
6	18071.86	1487.98	48.	50.	42.	49.
7	16327.42	447.66	50.	46.	42.	43.
8	16793.19	393.23	49.	51.	42.	46.
9	17990.80	873.80	51.	54.	44.	46.
10	17276.65	714.33	51.	54.	41.	43.
11	18801.82	1910.36	53.	51.	42.	47.
12	18151.59	913.20	54.	49.	48.	46.
13	18771.95	2713.80	49.	47.	44.	43.
14	16486.09	534.88	47.	48.	38.	48.
15	17793.45	1184.18	53.	51.	40.	45.
16	16534.70	1017.74	46.	48.	42.	41.
17	16882.89	316.72	52.	50.	42.	45.
18	17614.50	695.28	54.	52.	43.	44.
19	17098.84	1080.58	47.	48.	43.	45.
20	18149.70	1500.69	50.	49.	44.	48.
21	17459.42	797.02	51.	46.	45.	48.
22	16953.09	596.22	50.	49.	42.	46.
23	16607.69	384.80	48.	48.	39.	51.
24	17151.97	995.47	52.	50.	40.	42.
25	16822.20	927.20	48.	52.	39.	43.
26	17028.19	186.61	54.	51.	41.	46.
27	18361.61	1332.41	53.	52.	44.	46.
28	18023.30	762.30	50.	55.	43.	49.
29	18655.59	1637.53	52.	49.	45.	49.
30	17794.03	1158.72	51.	50.	44.	44.
31	17026.16	536.78	52.	52.	43.	42.
32	17546.38	1182.47	52.	49.	40.	46.
33	18162.03	1463.09	46.	48.	47.	49.
34	16951.06	641.50	51.	46.	45.	45.
35	17896.59	1672.22	50.	49.	40.	46.
36	17582.38	801.31	50.	52.	44.	46.
37	19679.88	2044.25	53.	52.	48.	48.
38	17106.53	908.56	48.	48.	44.	45.
39	16448.56	147.22	50.	52.	42.	42.
40	17696.66	952.69	52.	48.	44.	47.

The average waiting time for the first year in the new system is estimated to be about 127.39 hours with 39.49 hours standard deviation and the average waiting time in the queue, 5.35 hours with 14.78 hours standard deviation. The maximum waiting time in the queue is estimated to be 81 hours from the 68th ship. In table 4.4, only 19 ships among 132 ships have to wait in the queue whilst in table 4.1, 139 ships of 191 ships have to wait in the queue. The reduction in the waiting time in the new system does, to a great extent, obviously result from the construction of the new berth.

Table 4.5 shows us that the waiting time in the system has ranged from 16,177.33 hours in year 3 to 19,679.88 hours in year 37 whereas the waiting time in the queue is from 147.22 hours in year 39 to 2,713.8 hours in year 13. The great improvement in the waiting times can be better explained from the berth occupancy rate columns. All the berths seem to have almost equally balanced occupancy rates as a consequence of new berth construction. In the old system, the berth occupancy rate in S1 was considerably higher, sometimes reaching theoretically possible occupancy rate whilst S4 was rather idle as can be seen in table 4.2. It implies that the construction of the new berth would be beneficial to the national economy as well as to the company. The economic implications will be examined in the next section, the cost-benefit analysis.

2. The Cost-Benefit Analysis

This section will deal with the cost -benefit analysis of the expansion project from the perspective of the national economy. In other words, it will be examined whether the nation, South Korea, will be better off or worse off as a consequence of the construction.

As explained in chapter II, theory part, the economic analysis should be conducted in the context of social cost and social benefit. The orthodox way to do that would be the employment of opportunity cost calculation reflecting shadow price in each cost and benefit item. When a market is in a competitive situation, to a great extent, it is assumed that the market price reflects the shadow price.

Since the Korean economy has been developed in a rather competitive market situation, it can be assumed that the market price can represent the shadow price. So, the quantification of the cost and the benefit will be based on the market price.

The cost-benefit analysis will be conducted under the following premises.

* The period of the analysis will be forty years in order that the analysis should be matched with the estimated economic life span of the main construction structure, namely the quay wall structure.

* The main benefit will be realized from the reduction in ship turnaround time costs from the old system to the new system. Despite that there might exist some indirect benefits which are difficult to be quantified or impossible such as the externality effect, it is assumed that the indirect benefit can be cancelled out by the indirect cost.

* The main cost items will be the construction cost of the infrastructure, all of the handling equipment cost, the maintenance and operating cost which are directly connected to the new berth operation.

* The social discount rate will be 10% recommended by the Economic Planning Board of S. Korea.

2.1. The cost estimation

The expansion program is scheduled to construct 390 m quay wall for the beginning three years of the investment and install two unloaders with 2,000 ton/hour capacity. It is expected by some engineering consulting companies that the expansion plan would require 54.6 million cubic meter dredging over the first 6 years.

After consultation with the engineering company the construction cost was estimated, as can be seen in table 4.6.

Table 4.6 The Construction plan[5]

cost unit : million US $

item	dimension	total over the period		1989 - 1991		1992 -1994	
		no	cost	no	cost	no	cost
quay wall	250,000 DWT	390 (m)	23.967	390 (m)	23.967		
dredging		6 mn m^3	78	4.1mn m^3	52	1.9 m^3	26
unloader	2,000 t/h	2 e.a.	17.827	2	17.827		

The maintenance and the operating cost for the new assets were calculated based on the recommended ratio of UNCTAD.[6] In other words, the annual maintenance and operating cost were calculated as a product of economic value of asset and the ratio. For instance, the price of two unloaders is $ 17.8 million, the maintenance ratio is 5 % and the annual maintenance cost would be $ 17.8 million · 5% = $ 0.89 million.

From the construction costs and the maintenance and operating costs, the annual cost over the investment period was estimated. The results can be seen in table 4.7.

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[5] The price with base year, 1989, was calculated using 700 for the exchange rate of the Korean currency, Won, vs. $ US.

[6] See UNCTAD, Port Development, 1985, pp. 112 - 116, where the following ratio is recommended.

item	economic life span (year)	maintenance ratio	operating ratio
quay	40	0.75 %	
handling equip.	20	5 %	5 %
dredging		1 %	

Table 4.7 Annual cost estimation

unit:000$

year	capital	maint.	operating	total
1989	25322.3			25,322.3
1990	25322.3			25,322.3
1991	43149.3	1071.1	891.4	45,111.8
1992	8666.7	1071.1	891.4	10,629.2
1993	8666.7	1071.1	891.4	10,629.2
1994	8666.7	1071.1	891.4	10,629.2
1995		1851.1	891.4	2,742.5
1996		1851.1	891.4	2,742.5
1997		1851.1	891.4	2,742.5
1998		1851.1	891.4	2,742.5
1999		1851.1	891.4	2,742.5
2000		1851.1	891.4	2,742.5
2001		1851.1	891.4	2,742.5
2002		1851.1	891.4	2,742.5
2003		1851.1	891.4	2,742.5
2004		1851.1	891.4	2,742.5
2005		1851.1	891.4	2,742.5
2006		1851.1	891.4	2,742.5
2007		1851.1	891.4	2,742.5
2008		1851.1	891.4	2,742.5
2009		1851.1	891.4	2,742.5
2010		1851.1	891.4	2,742.5
2011	17827.0	1851.1	891.4	20,569.5
2012		1851.1	891.4	2,742.5
2013		1851.1	891.4	2,742.5
2014		1851.1	891.4	2,742.5
2015		1851.1	891.4	2,742.5
2016		1851.1	891.4	2,742.5
2017		1851.1	891.4	2,742.5
2018		1851.1	891.4	2,742.5
2019		1851.1	891.4	2,742.5
2020		1851.1	891.4	2,742.5
2021		1851.1	891.4	2,742.5
2022		1851.1	891.4	2,742.5
2023		1851.1	891.4	2,742.5
2024		1851.1	891.4	2,742.5
2025		1851.1	891.4	2,742.5
2026		1851.1	891.4	2,742.5
2027		1851.1	891.4	2,742.5
2028		1851.1	891.4	2,742.5
2029		1851.1	891.4	2,742.5
2030		1851.1	891.4	2,742.5

2.2. The benefit estimation

The benefit of the project should be the amount of reduced ship turnaround time cost from the old system to the new system. In other words, the benefit will result from ship time cost saving due to the expansion program. Thus, annual benefit will be the difference between the summation of individual ship's time cost in the old system and summation in the new system per annum.

The annual benefit can be expressed by the formula (4.1).

$$Benefit_i = \sum_{j=1}^{n} WT(j) \cdot WTC(j) - \sum_{j=1}^{m} WT^*(j) \cdot WTC^*(j) \qquad (4.1)$$

where, i : year
j : serial no. of ship
n : total no. of ships entering the old system=191 ships
m : " entering the new system=132 ships
WT(j) : waiting time in the system of jth ship in the old system
$WT^*(j)$: " in the new system
WTC(j) : waiting time cost of jth ship in the old system
$WTC^*(j)$: " in the new system

In the formula, the waiting times in both system have already been calculated, as can be seen in tables 4.1, 4.2, 4.4 and 4.5. The only thing that has to be estimated is the cost of the waiting time or the cost of ship time in the port in order to calculate the annual benefit.

There appear, at least in theory, to be three principal methods by which the cost of ships' time might be evaluated. First one might identify a series of specific reductions (or increases) in delays to ships and then examine the relationship between these and the market prices for their services. Secondly, there is the rather theoretical possibility of conducting a series of observed experiments in which ship operators were presented with a large number of choices between avoiding delays in exchange for some extra payment (for example, of port dues) and accepting the existing situation. Thirdly, it is possible to use the concept of long-run opportunity cost. The opportunity cost of a ship's time is what it could have earned in that time had it not been delayed, minus the extra cost involved. Obviously, the gross earnings will depend, inter alia, on the state of the relevant shipping market but it is possible to assume that in the long run this will reflect the opportunity cost of capital; this assumption may not, necessarily, be correct, but the opportunity cost of capital is still, for most public sector purposes involving the assessment of social cost, the relevant measure.[7]

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[7] R. O. Goss and M. C. Mann, the cost of ships' time : In Advances in Maritime Economics Edited by R. O. Goss, 1982, re-published by the Univ. of Wales Institute of Science and Technology, U.K., pp. 139-142.

The third method is adopted here because the approach is in line with the purpose of this study, the economic analysis.[8]

In this context a shadow price can be defined formally as that level of price at which the discounted revenue, for a given level of output, is exactly equal to the discounted cash operating costs plus the capital costs. In other words, this represents a long-term equilibrium revenue level which yields a net present value of zero or an internal (d.c.f.) rate of return precisely equal to the opportunity cost of capital.[9]

Goss and Mann conducted this research based on the standardized price using the base year 1970 and provided costs of a ship's time by size and by ship type.[10]

This study will employ the same approach, update the data and evaluate the cost of ship time per day and per hour mainly focused on bulk carriers which will be used for the estimation of the benefit.

The data for updating the evaluation are referred to from a published book of Drewry Shipping Consultants Ltd.[11], where the capital cost per DWT and operating cost and bunker price are presented. The book provides new building ship costs per DWT in 3 categories, the operating costs for 3 model ships and the bunker price per ton. The data can be seen below in tables 4.8 and 4.9.

Table 4.8 Capital cost of newbuilding ship

vessel size (1,000 DWT)	cost ($/DWT)
10 - 50	733
50 - 100	400
100 - 150	325

Source : Drewry, op. cit., p. 4.

[8] It is generally known as 'shadow-pricing' though in this paper the results are shown in terms of ship/days and /hours rather than as prices of specific services obtainable in any actual market. See Goss and Mann, ibid.

[9] Goss and Mann, ibid.

[10] Goss and Mann, op. cit. pp. 138-177.

[11] Drewry Shipping Consultants Ltd., Financing Ships; the challenge of the 1990's, 1989, London, pp. 4, 67, 125.

Table 4.9 Operating cost of dry bulk carrier [12]

DWT	1989	1990	1991	1992	growth rate
25000	1175	1220	1280	1350	4.7 %
65000	1390	1445	1515	1590	4.6 %
120000	1705	1770	1860	1950	4.6 %

Source : Drewry, op. cit., p. 125.

* Bunker price : 145 $/ton in 1988 for Marine Diesel Oil (MDO)[13]

From the given data, the cost of a ship's time was calculated for 3 model ships, of namely 25,000 DWT, 65,000 DWT and 120,000 DWT, according to the approach of Goss and Mann resulting in 3 ship time costs per day and hour for the 3 model ships. Based on these costs, the other ship costs in other size categories were estimated by interpolation and extrapolation techniques. The detailed process can be illustrated as follows;

(a). Capital charge

To begin with, capital charges are expressed as a constant annuity equivalent to the capital cost of the ship and extending over its life. The ship life assumed for this study is 20 years in the same manner as Goss and Mann's. The annual capital charge can be calculated using the annuity formula which converts the capital cost into a constant annual equivalent as can be seen by the formula (4.2).

$$CC = \frac{Co}{\dfrac{1 - (1 + r)^{-n}}{r}} \qquad (4.2)^{14}$$

where, CC : capital charge
Co : capital cost
r : discount rate
n : ship life

[12] Geometric growth rate from 1989 to 1992. This growth rate will be used for the calculation of ship time cost later.

[13] Average of Rotterdam, Genoa, Houston, Singapore and Los Angeles. MDO is used in the ancillary engines for diesel engined vessel. It is assumed that 1989 price would be the same as 1988. See Drewry, op. cit., p. 67.

[14] Goss and Mann, op. cit., p. 174.

For instance, in the case of the 65,000 DWT model ship, the capital cost[15] was 400 $/DWT from table 4.8 times 65,000 = $ 26 million. Thus, the annual capital charge was $ 3.05 million using the expression (4.2), where 10 % discount rate and a 20 year ship life were used.

(b). Operating cost

The operating cost is calculated under the assumption that it increases by 4.6 % per year as can be seen in the table 4.9. The present value of such a geometrically growing time series can be expressed by the expression (4.3).

$$PV = Ca \cdot \left[\frac{1 - \left(\frac{1+g}{1+r}\right)^{n}}{r - g} \right] \qquad (4.3)^{16}$$

where, Ca : operating cost of factors of production
g : growth rate

This present value can then be divided by the appropriate annuity factor to give the long-term opportunity cost of operating costs spread over the entire life of the ship. The formula is expressed in the expression (4.4) from the expression (4.2) and expression (4.3).

$$OC = \frac{PV}{\frac{1 - (1+r)^{-n}}{r}} = \frac{Ca \cdot \left[r - r \cdot (1+g)^{n}/(1+r)^{n} \right]}{(r-g) \cdot [\, 1 - (1+r)^{-n} \,]} \qquad (4.4)^{17}$$

where, OC : operating cost

Again in the case of the 65,000 DWT model ship, the operating cost was $ 1.9 million using the expression (4.4), where $ 1.39 million for Ca and 4.6 % for g from table 4.9 were used.

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[15] Although the existing ships calling at the port are aged, the newbuilding price is employed not only because replacement by new building is expected in such a long period of project time as 40 year, but because the standardizing process of the capital cost for different aged ships into the base year price seems to be difficult due to lack of a consistent price index for reflation during the study.

[16] See Goss and Mann, op. cit., p. 175.

[17] See Goss and Mann, ibid.

(c). Fuel cost

Fuel cost is taken as in port (hotel load) consumptions at relevant prices. This represents the cost per day when the ship is idle.[18] It seems to be common sense that a ship can be assumed to consume two tons of Marine Diesel Oil per day in port regardless of the size. Thus, the model ship is assumed to consume 2 tons per day and the daily fuel cost is 2 tons · $ 145 /day = $ 290 .

Finally, if the summation of the annual capital charge and the operating cost is divided by annual working days and the daily fuel cost is added up, the cost of a ship's time per day can be calculated. Usually, 350 is taken as the number of annual working days, not because these costs do not carry on during a repair period, but because we are calculating the opportunity cost of a ship's time, which must be derived from its earning rate. So, the cost of a ship's time per day can be expressed by the expression (4.5).

$$WTC = (CC + OC)/350 + FC \qquad (4.5)$$ [19]

where, WTC : cost of ships' time per day
CC : capital charge
OC : operating cost
FC : daily fuel cost

The cost of the 65,000 DWT model ship's time per day was calculated using the expression (4.5) and resulted in approximately $ 14,498 per day. In the same manner, the other two model ship time costs were calculated and resulted in $ 11,074 for the 25,000 DWT ship and $ 20,102 for the 120,000 DWT ship. The calculation is tabulated in table 4.10.

Table 4.10 Daily time cost of the model ships

Size	25,000	65,000	120,000
(1) Co	18,325,000	26,000,000	39,000,000
(2) Ca	1,175,000	1,390,000	1,705,000
(3) CC	2,152,447	3,053,950	4,580,925
(4) OC	1,621,907	1,918,682	2,353,491
(5) (CC+OC) ÷350	10,783.87	14,207.52	19,812.62
(6) FC	290	290	290
(7) WTC	11,073.87	14,497.52	20,102.62

Based on the result of table 4.10, other costs in other categories of size, for instance, from 10,000 DWT to 250,000 DWT were estimated by interpolation and extrapolation techniques.

[18] Goss and Mann, ibid.

[19] Goss and Mann, op. cit., p. 176.

The results are presented in table 4.11.

Table 4.11 Estimated cost of ship time[20]

DWT	Cost per ship/day			Cost per ship/hour ($)		
	8%	10%	12%	8%	10%	12%
10000	6254	6615	6999	260.6	275.6	291.6
20000	9210	9804	10443	383.8	408.5	435.1
30000	10763	11502	12296	448.5	479.2	512.3
40000	11539	12358	13237	480.8	514.9	551.5
50000	12315	13214	14178	513.1	550.6	590.7
75000	14398	15517	16714	599.9	646.5	696.4
100000	16697	18064	19526	695.7	752.7	813.6
125000	18980	20592	22314	790.8	858.0	929.8
150000	21004	22839	24748	875.2	951.6	1031.2
200000	24676	26901	29285	1028.2	1120.9	1220.2
250000	27942	30531	33313	1164.2	1272.1	1388.0

In the table, the extrapolation technique was applied to the size category larger than the biggest model ship, 120,000 DWT and smaller than the smallest model ship, 25,000 DWT and the interpolation was applied inbetween.

The extrapolation was conducted to reflect the same cost structure as Goss and Mann's, depending on the different size class, in the following manner. Firstly, the cost of the same model ship size, namely 25,000, 65,000 and 120,000 DWT was calculated in Goss and Mann's result by interpolation[21] for later comparison with the result of this study. Then, the cost in extrapolation size category, for instance 10,000 DWT, resulted from multiplying the cost of the model ship size from table 4.10, by the ratio of the cost of concerned size vs. the cost of the model ship size from Goss and Mann's result. In the case of 10,000 DWT, for instance, the cost of 25,000 DWT in Goss and Mann's result (10 % discount rate) was estimated to be about £ 1312.5 and the cost of 10,000 DWT was £ 784. Thus, the ratio between them was £ 784/£ 1312.5 = 0.5973. In table 4.10, the cost of 25,000 DWT ship is $ 11,073.87. Accordingly, the cost of

[20] Three discount rates, namely 8 %, 10 % and 12 % were applied in the same manner as Goss and Mann's. These discount rates will be used later in the sensitivity analysis.

[21] Because Goss and Mann's result does not provide the cost of our model ship size, it should be necessary to interpolate the figures. For instance, a 25,000 cost resulted from the interpolation between 20,000 and 30,000 from Goss and Mann's results.

a 10,000 DWT ship/day would be $ 11,073.87 · 0.5973(ratio) = $ 6,614.79 as can be seen in table 4.11.

The interpolation was conducted by size criterion[22] based on the costs of the three model ships. For instance, the cost of 40,000 DWT was interpolated between 25,000 DWT and 65,000 DWT by size difference.

After inserting the calculation process of the cost of ship time from table 4.11 into the computer program, the simulation model was run again, not only in the old system but also in the new system, resulting in an annual benefit, derived from the expression (4.1). The result is presented in table 4.12.

This benefit will be compared with the annual cost in terms of discounted present value in the next section.

2.3 The NPV and the IRR

The annual cost and benefit will be discounted at the social discount rate, 10 %, expressed in 1989 money terms. The present value of the annual cost and benefit will be summed up resulting in the NPV and the IRR will also be calculated. The result of the calculation is presented in table 4.13.

The table shows the annual cost from table 4.7, the annual benefit from table 4.12, the annual net benefit, the discounted factor at 10 % and the present value of the annual net benefit. The net present value of the project is the summation of the present value of the annual benefit (the last column in the table) resulting in approximately 56 million dollars. This implies that the country will be better off from the project by the amount of the net present value. The implication is confirmed once again in the result of the internal rate of return, 16.86 %, since the IRR is higher than the discount rate, 10 %.

The calculation of the IRR is graphically presented in figure 4.1, where the IRR, which makes the NPV equal to zero, is located at a discount rate of between 16 % and 17 %.

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[22]The same methods as for the ratio multiplication in the extrapolation could not be applied because it seemed to be ambiguous which figure between 2 figures of interpolation should be applied as a base of the technique. Furthermore, even if one figure was chosen as a criterion, it was found that some costs in smaller size vessel were larger than the costs in bigger vessel size.

Table 4.12 Estimation of annual benefit[23]

year	(1) cost of ship time in old system	(2) cost of ship time in new system	(3) benefit = (1) - (2)
1991	$51,297,710	$15,662,780	$35,634,930
1992	$32,545,130	$16,340,650	$16,204,480
1993	$29,992,070	$14,999,980	$14,992,090
1994	$30,630,560	$15,609,230	$15,021,330
1995	$33,180,410	$16,394,720	$16,785,690
1996	$47,583,760	$16,881,330	$30,702,430
1997	$30,083,820	$15,194,100	$14,889,720
1998	$32,524,610	$15,527,760	$16,996,850
1999	$35,794,870	$16,891,370	$18,903,500
2000	$30,819,780	$16,024,770	$14,795,010
2001	$29,518,710	$17,576,080	$11,942,630
2002	$55,054,650	$16,770,000	$38,284,650
2003	$31,845,420	$17,302,010	$14,543,410
2004	$32,713,920	$15,111,070	$17,602,850
2005	$39,210,420	$16,654,450	$22,555,970
2006	$42,569,960	$15,255,980	$27,313,980
2007	$30,661,470	$15,884,060	$14,777,410
2008	$33,066,840	$16,423,750	$16,643,090
2009	$39,256,250	$16,026,710	$23,229,540
2010	$31,502,310	$16,799,750	$14,702,560
2011	$46,497,010	$16,331,710	$30,165,300
2012	$31,337,910	$15,588,250	$15,749,660
2013	$35,086,940	$15,360,370	$19,726,570
2014	$24,359,660	$15,921,250	$8,438,410
2015	$48,065,060	$15,584,880	$32,480,180
2016	$33,586,940	$15,938,220	$17,648,720
2017	$30,217,770	$16,989,550	$13,228,220
2018	$40,100,340	$16,851,020	$23,249,320
2019	$48,083,180	$17,286,170	$30,797,010
2020	$58,231,620	$16,592,740	$41,638,880
2021	$37,660,400	$15,864,430	$21,795,970
2022	$33,749,490	$16,480,130	$17,269,360
2023	$47,884,750	$16,622,410	$31,262,340
2024	$27,036,000	$15,742,840	$11,293,160
2025	$38,755,660	$16,691,320	$22,064,340
2026	$35,153,610	$16,349,360	$18,804,250
2027	$25,638,070	$18,234,110	$7,403,960
2028	$58,235,210	$15,840,100	$42,395,110
2029	$35,997,030	$15,286,940	$20,710,090
2030	$23,306,790	$16,359,300	$6,947,490

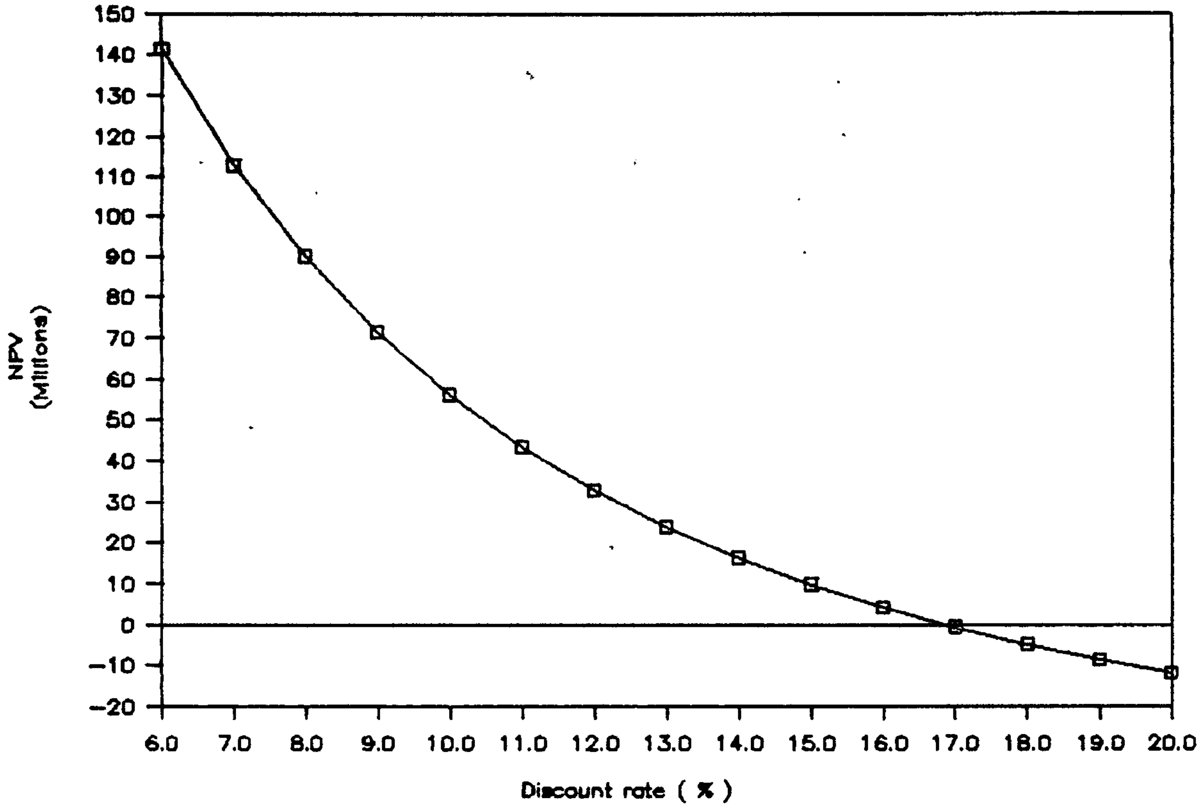
[23] The benefit is realized from 1991 when the new berth starts to operate.

Table 4.13 Results of NPV and IRR

unit : 1000 US $

year	cost (1)	benefit (2)	net benefit (3)=(2)-(1)	dc factor (4)	pv of nb (5)=(3)*(4)
1989	25,322.3		($25,322)	1.000	($25,322)
1990	25,322.3		($25,322)	0.909	($23,020)
1991	45,111.8	$35,635	($9,477)	0.826	($7,832)
1992	10,629.2	$16,204	$5,575	0.751	$4,189
1993	10,629.2	$14,992	$4,363	0.683	$2,980
1994	10,629.2	$15,021	$4,392	0.621	$2,727
1995	2,742.5	$16,786	$14,043	0.564	$7,927
1996	2,742.5	$30,702	$27,960	0.513	$14,348
1997	2,742.5	$14,890	$12,147	0.467	$5,667
1998	2,742.5	$16,997	$14,254	0.424	$6,045
1999	2,742.5	$18,904	$16,161	0.386	$6,231
2000	2,742.5	$14,795	$12,053	0.350	$4,224
2001	2,742.5	$11,943	$9,200	0.319	$2,931
2002	2,742.5	$38,285	$35,542	0.290	$10,295
2003	2,742.5	$14,543	$11,801	0.263	$3,108
2004	2,742.5	$17,603	$14,860	0.239	$3,557
2005	2,742.5	$22,556	$19,814	0.218	$4,312
2006	2,742.5	$27,314	$24,572	0.198	$4,861
2007	2,742.5	$14,777	$12,035	0.180	$2,165
2008	2,742.5	$16,643	$13,901	0.164	$2,273
2009	2,742.5	$23,230	$20,487	0.149	$3,045
2010	2,742.5	$14,703	$11,960	0.135	$1,616
2011	20,569.5	$30,165	$9,596	0.123	$1,179
2012	2,742.5	$15,750	$13,007	0.112	$1,453
2013	2,742.5	$19,727	$16,984	0.102	$1,724
2014	2,742.5	$8,438	$5,696	0.092	$526
2015	2,742.5	$32,480	$29,738	0.084	$2,495
2016	2,742.5	$17,649	$14,906	0.076	$1,137
2017	2,742.5	$13,228	$10,486	0.069	$727
2018	2,742.5	$23,249	$20,507	0.063	$1,293
2019	2,742.5	$30,797	$28,055	0.057	$1,608
2020	2,742.5	$41,639	$38,896	0.052	$2,026
2021	2,742.5	$21,796	$19,054	0.047	$902
2022	2,742.5	$17,269	$14,527	0.043	$625
2023	2,742.5	$31,262	$28,520	0.039	$1,116
2024	2,742.5	$11,293	$8,551	0.036	$304
2025	2,742.5	$22,064	$19,322	0.032	$625
2026	2,742.5	$18,804	$16,062	0.029	$472
2027	2,742.5	$7,404	$4,662	0.027	$125
2028	2,742.5	$42,395	$39,653	0.024	$964
2029	2,742.5	$20,710	$17,968	0.022	$397
2030	2,742.5	$6,947	$4,205	0.020	$84
$NPV = \sum_{1}^{42}$ pv of nb (5) =					$56,111
IRR = 16.86 %					

Figure 4.1 NPV vs. discount rate



3. The Sensitivity Analysis

A sensitivity analysis will be conducted as to the changed parameters of the service time distribution in the new berth (S1), the change of the DWT distribution, the change of the berth allocation criteria and the change of the discount rate. The impact of the changes will be assessed in terms of the annual waiting time in the system, the NPV and the IRR.

To begin with, the parameters (α and β) of the service time distribution in the new berth (S1) are changed. As mentioned before, the sensitivity test on the service time distribution is conducted as to the mean value of service time without changing the standard deviation. As far as the service time distribution in the new berth is concerned, the simulation model in the new system was previously run based on the gamma distribution with α=0.105 and β=14. The sensitivity will be examined by shifting the value of β from 14 to 13, 12 and 11 stepwise[24].

From the expression (3.8), the following relationship can be derived.

$$\alpha = \sqrt{\beta}/\sigma \quad , \quad \mu = \beta/\alpha$$

In the formula, α can be calculated because β and the standard deviation (σ) are known. For instance, when β is equal to 13, α is equal to $\sqrt{\beta}/\sigma$ = $\sqrt{13} \div 35.89293$ = 0.100453 and the mean value (μ) is β/α = 13 $\div$ 0.100453 = 129.41 hours. This shows that the average of service time in S1 is reduced from 134.89 hours to 129.41 hours. In the same manner, the other values of α for β = 12 and β = 11 were calculated resulting in the following.

* β = 13 : α = 0.100453, μ = 129.41 hours
* β = 12 : α = 0.096512, μ = 124.34 hours
* β = 11 : α = 0.092403, μ = 119.04 hours

As to the DWT distribution, the sensitivity is conducted by increasing the portion of the vessels larger than or equal to 200,000 DWT by 10 % from table 4.3, where the cumulative probability in 200,000 DWT class is 0.927.

Regarding the berth allocation criteria, the criteria are changed from 165,000 DWT to 155,000 DWT for larger berths (S1 & S2) and from 115,000 DWT to 100,000 DWT for smaller berths (S3 & S4). In other words, the vessels larger than 155,000 DWT are allocated in either S1 or S2, the vessels smaller than 100,000 DWT in either S3 or S4 and the vessels inbetween in the earliest available berth.

The simulation model was run in each case of the above mentioned

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[24] Changing the value of β a into lower value implies that the average of the service time is reduced. This seems to be a plausible assumption since the new berth will operate two bigger unloaders (2,000 t/h) than the existing unloaders (1,800 t/h and 1,500 t/h) in the biggest berth in the existing system.

cases, calculating the annual waiting time in the system. The NPV and the IRR were again calculated in each case. The results can be seen in table 4.14.

Table 4.14 Results of sensitivity analysis

unit : hour

year	wt	wtp1	wtp2	wtp3	wtd	wtb
1	16816	17196	16509	16360	18019	17964
2	17549	17618	18844	16487	20854	18746
3	16177	15813	16976	15488	17631	19232
4	16774	18312	15978	17041	16828	19891
5	17562	17284	18409	16392	17351	19328
6	18072	17823	17082	18152	18519	19472
7	16327	17216	16801	17028	17867	18664
8	16793	17272	17939	17858	18502	17783
9	17991	18979	17009	16516	18506	19199
10	17277	18199	17269	17211	19489	18450
11	18802	17699	16669	16437	16542	17782
12	18152	16993	16740	15947	19736	18872
13	18772	17184	17824	16198	17032	19403
14	16486	16815	17077	18296	18522	19472
15	17793	18163	17557	17795	18169	18982
16	16535	18150	16860	18935	20013	18291
17	16883	17911	17431	17880	17930	19281
18	17615	17501	16497	17623	16664	18123
19	17099	17462	16360	16314	17382	19675
20	18150	16704	16838	17170	17579	18488
21	17459	16453	17116	16841	18689	19414
22	16953	18090	17178	17568	17850	18286
23	16608	17845	18939	16397	18384	19050
24	17152	16225	17121	16755	17694	18080
25	16822	16285	17475	16418	17479	17307
26	17028	17394	15949	16688	17110	18428
27	18362	16394	16880	16478	16996	21522
28	18023	17523	16675	16740	17565	20392
29	18656	16764	16579	16410	16828	18442
30	17794	15955	18567	16433	18654	17641
31	17026	17295	17913	16557	16799	19418
32	17546	18324	17116	17340	16022	17843
33	18162	.17819	17760	16743	17657	21745
34	16951	17581	17981	15793	17381	17285
35	17897	17436	17151	18444	19178	17639
36	17582	16471	17134	17083	16956	17225
37	19680	17582	16969	16466	17162	19222
38	17107	17313	16530	16577	17507	21530
39	16449	17632	17528	17922	17791	19464
40	17697	16305	17874	16499	17610	19154
mean	17464	17324	17228	16932	17861	18905
s.d.	766	708	694	758	992	1081
max	19680	18979	18939	18935	20854	21745
min	16177	15813	15949	15488	16022	17225
NPV	$56,111	$55,310	$57,118	$59,867	$51,544	$42,855
IRR	16.86%	16.69%	16.89%	17.35%	16.16%	15.16%

The symbols in the table mean the following cases;

wt : waiting time in the original case (no sensitivity case)
wtp1 : " " in the case of $\beta=13$
wtp2 : waiting time in the case of $\beta=12$
wtp3 : " " in the case of $\beta=11$
wtd : " " in the case of changed DWT distribution
wtb : " " in the case of changed berth allocation policy.

The table shows the annual waiting time in the system, the mean, the maximum and the minimum values with the standard deviation, the NPV and the IRR in each case. In all cases, the project is recommended as can be seen in the NPV and the IRR rows.

Finally, the sensitivity to the discount rate was tested. As explained in the benefit estimation section, the discount rate should be reflected in calculating the cost of ship time[25] before calculating the NPV. Then, the discount rate is applicable to the calculation of the NPV. In other words, the discount rate is reflected both in the numerator and denominator of the NPV formula since the benefit is calculated based on the opportunity cost of ship time which also uses the discount rate (see table 4.11). Thus, 8 % and 12 % discount rates were applied for the NPV calculation as well as the benefit estimation.

The NPV at an 8 % discount rate was approximately 72.7 million dollars with a 15.12 % IRR and the NPV at a 12 % discount rate approximately 45 million dollars with an 18.74 % IRR. Once again, the project is recommended.

[25] See expressions (4.2), (4.3) and (4.4).

Chapter V. Conclusion

An attempt has been made in this study as to presenting an investment appraisal approach, with particular reference to the economic analysis, of a port development project using a simulation model by employing a case study. The results found during the study can be summarized as in the following words.

As a consequence of the system analysis, it was found that as far as ship arrival and departure in the port are concerned, the port system can be represented by one exponential distribution as its interarrival time distribution and two gamma distributions and two empirical distributions as its service time distributions. Based on these findings, a simulation model was run over the period of forty years, which appear to be the economic life span of the quay wall structure. The results showed us that big congestion would occur especially in the biggest berth if the present port system continues. This implies that an expansion program is more likely to be necessary in order to solve the congestion problem. Then, an expansion program which is the construction of a new berth was incorporated into the simulation model. The simulation model under the expansion conditions resulted in a great deal of improvements in ship waiting times.

The economic soundness of the port project was assessed by the economic appraisal, in terms of the cost-benefit analysis, reflecting the opportunity cost to the nation concerned as to whether the project would be economically justified or not. The results of the cost-benefit analysis led to a conclusion that the country, South Korea, would be likely to be better off by the amount of the net present value, approximately US $ 56 million. Thus, it can be said that the project should be accepted.

As regards the uncertainties and risk that might be involved in the project, several sensitivity analyses were conducted mainly focused on some major factors, such as the service time distribution in the new berth, DWT distribution, berth allocation policy and discount rates, which probably could affect the results of the cost-benefit analysis. In all cases, it was found that the results of the cost-benefit analysis would not seem to be sensitive to the changes of the major factors. Accordingly, the viability of the project was confirmed once again by the sensitivity analyses.

However, some caution should be taken in the interpretation of the results. Although the uncertainties and risk were examined by the sensitivity analyses, one cannot say that the results of this analysis will absolutely happen in the future as they were presented in this study. For instance, there can be a difference between the actual distribution of the service time distribution in the new berth in the future and the assumed one in the simulation model. Due to the lack of the historical data, there appear to exist no better alternatives in the estimation of the future distribution than one employed in this study.

This problem can be, however, overcome when the new berth is operated enabling the analyst to collect the historical data. Obviously these data can be fed back to the simulation model and incorporated into the cost-benefit analysis.

Finally as to the simulation model, it can be generalized, to some extent, and applied to other ports. Although the model was built up based on the port in the case study, basic principles or general working procedures in other ports, such as ship arrival, berth allocation, loading or discharging and departure, would be same as in the port of the case study regardless of the size, numbers, structure of berth and so on.

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Appendix Computer Simuation Program

```
c=====================================================
c=                                                   =
c=           Simulation  Main  Program              =
c=                                                   =
c=              in the Old System                   =
c=                                                   =
c=====================================================

c                  --------------
c                  Flow Chart  A
c                  --------------
      dimension a(300),b(200,4),d(200,4)
      dimension wt(300),wt2(300),wtc(20,10)
      dimension aq(300,4)
      dimension bo(50),bo2(50),cu(50),cu2(50)
      dimension bod(50),cud(50)
      dimension bwt(50),bwf(50),bwy(50),kbw(50)
      dimension bwt2(50),bwf2(50),bwy2(50),kbw2(50)
      dimension blast(4),kberth(4),sumst(4)
      double precision alpa,alpa2
      open(1,file='dwt.grp',status='old')
      open(2,file='st2.grp',status='old')
      open(3,file='st3.grp',status='old')
      open(6,file='table.out',status='new')
      open(7,file='final.out',status='new')
      open(8,file='wout.res',status='new')
      open(9,file='wtc.grp',status='old')
      open(10,file='wtc.out',status='new')
      write(6,600)
600   format(///64('=')/t2,'ship no',t11,'a(i)',t18,'berth no',t31,
     +       'b(i,j)',t42,'d(i,j)',t51,'wt(i)',t58,'wt2(i)',/64('-'))

610   format(t2,i4,t8,f8.1,t22,i2,t28,f8.1,t39,f8.1,t50,f5.1,
     +       t58,f5.1)
      n=191
      do 3 i=1,n
      a(i)=0.
      wt(i)=0.
      wt2(i)=0.
      do 3 j=1,4
      aq(i,j)=0.
      b(i,j)=0.
      d(i,j)=0.
      blast(j)=0.
      kberth(J)=0
      sumst(j)=0.
3     continue
      sumwt=0.
      sumwtq=0.
      sumwtc=0.
      kx=129
      dummy=rand(kx)
      read(1,100)
      ii=1
```

```
1       read(1,*,end=2) bod(ii),re,cud(ii),ob
        ii=ii+1
        goto 1
2       m3=ii-1
        call empi(bod,cud,m3,dwt)
c------------------- read shipcost(i) ---------------
        write(*,*)'How much percentage is the discount rate (8,10,12 %)?'
        read(*,*) dc
        do 10 is=1,20
        do 10 is2=1,10
        wtc(is,is2)=0.
10      continue
        read(9,900)
900     format(/)
        do 11 i=1,11
        read(9,*,end=920) (wtc(i,j),j=1,7)
11      continue
920     call timecost(dwt,dc,wtc,shipcost)
c-------------------------------------------------------
        if     (dwt.ge.110000) then
        j=1
        else if(dwt.le.60000) then
        j=4
        else
        j=2
        end if
        read(2,100)
        read(3,100)
100     format(////)
        i1=1
        i2=1
4       read(2,*,end=5) bo(i1),re,cu(i1),ob
        i1=i1+1
        goto 4
5       read(3,*,end=6) bo2(i2),re,cu2(i2),ob
        i2=i2+1
        goto 5
6       m1=i1-1
        m2=i2-1
        alpa=0.1047039
        alpa2=0.018052608
        if(j.eq.1) call gamma(14,alpa,1,st)
        if(j.eq.2) call empi(bo,cu,m1,st)
        if(j.eq.3) call empi(bo2,cu2,m2,st)
        if(j.eq.4) call gamma(3,alpa2,1,st)
        d(1,j)=st
        sumst(j)=sumst(j)+st
        blast(j)=d(1,j)
        wt(1)=d(1,j)
        kberth(j)=1
        cwt=wt(1)*shipcost
        sumwt=wt(1)
c-------------------- wtc(i)  calculation ----
        sumwtc=cwt
        write(6,610) 1,a(1),j,b(1,j),d(1,j),wt(1),wt2(1)
        cut=165000
        cut1=65000
c-----------------------------------------------------------------
```

```
c                                                                    -
c                 PERIOD  OF  SIMULATION                             -
c                                                                    -
c--------------------------------------------------------------------
      write(*,*) ' How many years do you want to simulate ? (00 yrs)'
      read(*,*) iperiod
      do 9 ip=1,iperiod
      if (ip.eq.1) then
      ifirst=2
      else
      ifirst=1
      end if
      do 7 i=ifirst,n
c                 ---------------
c                 Flow Chart  B
c                 ---------------
      avg=47.07707
      call expon(avg,0.0,at)
      a(i)=a(i-1)+at
c                 ---------------
c                 Flow Chart  C
c                 ---------------
      call empi(bod,cud,m3,dwt)
c                 ---------------
c                 Flow Chart  D
c                 ---------------
c-----------------------------------------------------
c           Berth  Allocation  Process                -
c-----------------------------------------------------
      if(dwt.le.cut1) j=4
      if(dwt.gt.cut1.and.dwt.lt.cut) then
      if(blast(1).le.blast(2).and.blast(1).le.blast(3)) then
          j=1
      else if(blast(2).le.blast(1).and.blast(2).le.blast(3)) then
          j=2
      else
          j=3
      end if
      else if(dwt.ge.cut) then
         j=1
      else
      end if
      aq(i,j)=a(i)
      if(aq(i,j).ge.blast(j)) then
      b(i,j)=aq(i,j)
      else
      b(i,j)=blast(j)
      end if
      kberth(j)=kberth(j)+1
c                 ---------------
c                 Flow Chart  E
c                 ---------------
      if(j.eq.1) call gamma(14,alpa,1,st)
      if(j.eq.2) call empi(bo,cu,m1,st)
      if(j.eq.3) call empi(bo2,cu2,m2,st)
      if(j.eq.4) call gamma(3,alpa2,1,st)
      d(i,j)=b(i,j)+st
      sumst(j)=sumst(j)+st
```

```
      blast(j)=d(i,j)
c                ---------------
c                Flow Chart   F
c                ---------------
      wt(i)=d(i,j)-aq(i,j)
      wt2(i)=b(i,j)-aq(i,j)
c ------------- wtc & sumwtc calculation  -----
      call timecost(dwt,dc,wtc,shipcost)
      cwt=wt(i)*shipcost
      sumwtc=sumwtc+cwt
c ---------------------------------------------
      sumwt=sumwt+wt(i)
      sumwtq=sumwtq+wt2(i)
      if(ip.eq.1) then
      write(6,610) i,a(i),j,b(i,j),d(i,j),wt(i),wt2(i)
      else
      end if
      j=0
7     if(i.lt.n) continue
      rho1=sumst(1)/8760
      rho2=sumst(2)/8760
      rho3=sumst(3)/8760
      rho4=sumst(4)/8760
      write(*,*) ip,' year'
      write(*,*) ' waiting time in system =',sumwt
      write(*,*) ' waiting time in  queue =',sumwtq
      write(*,*)' berth occupancy rate( S1,S2,S3&S4)   ',rho1*100,
     +          rho2*100,rho3*100,rho4*100
      write (*,*)'                                            '
c                ---------------
c                Flow Chart   G
c                ---------------
      if (ip.eq.1) then
      write(*,*)' cases of s1, s2, s3 & s4 =',kberth(1),kberth(2),
     +                                        kberth(3),kberth(4)
c------------ Boundary Calculation  -----------
      bwt(1)=0.
      bwt2(2)=0.
      do 8 ik=2,50
      bwt(ik)=bwt(ik-1)+20.
      bwt2(ik)=bwt2(ik-1)+20.
8     continue
c-----------------------------------------------------
      call group(wt,bwt,bwf,bwy,50,n,kbw)
      call group(wt2,bwt2,bwf2,bwy2,40,n,kbw2)
      call para(wt,wtavg,wtsd,n)
      call para(wt2,wt2avg,wt2sd,n)
      write(7,700)
      call output(bwt,bwf,bwy,wtavg,wtsd,50,n)
      write(7,710)
      write(7,720)
      call output(bwt2,bwf2,bwy2,wt2avg,wt2sd,40,n)
      write(7,710)
700   format(////,t47,45('*'),/,t52,'The Distribution of Waiting Time',
     +       /,t60,' in  System',/,t47,45('*'))
710   format(120('-')///////)
720   format(////,t47,45('*'),/,t52,'The Distribution of Waiting Time',
     +       /,t60,' in  Queue',/,t47,45('*'))
```

```
      a(0)=a(n)
      write(8,800)
      write(8,810) ip,sumwt,sumwtq,rho1*100,rho2*100,rho3*100,rho4*100
      write(10,930)
      write(10,940) ip,sumwtc
930   format(/60('=')/2x,'year',10x,'wtc',/60('-'))
940   format(2x,i4,3x,f15.2)
      sumwt=0.
      sumwtq=0.
      sumst(1)=0.
      sumst(2)=0.
      sumst(3)=0.
      sumst(4)=0.
      sumwtc=0.
800   format(/////2x,60('='),/t3,'year',t11,'waiting time',t29,
     +       'waiting time',t47,'Berth Occupancy Rate (%)'/t11,
     +       'in the system',t29,'in the queue',t48,'S1',t52,'S2',
     +       t56,'S3',t60,'S4'/2x,60('-')/)
810   format(t3,i4,t11,f13.2,t29,f13.2,t47,4f4.0)
      else
      a(0)=a(n)
      write(8,810) ip,sumwt,sumwtq,rho1*100,rho2*100,rho3*100,rho4*100
      write(10,940) ip,sumwtc
      sumwt=0.
      sumwtq=0.
      sumst(1)=0.
      sumst(2)=0.
      sumst(3)=0.
      sumst(4)=0.
      sumwtc=0.
      end if
9     continue
      stop
      end
c------------- subroutine ----------
      function rand(kx)
      if(kx.gt.0) ix=kx
      iy=65539*ix
      if(iy.lt.0) iy=(iy+2147483647)+1
      rand=float(iy)/2147483647
      ix=iy
      return
      end
      subroutine empi(b,y,m,x)
      dimension b(51),y(50)
      u=rand(0)
      do 1 j=1,m
      if (u.le.y(j)) goto 2
1     continue
2     y1=0.
      if(j.gt.1) y1=y(j-1)
      x=b(j)+((u-y1)/(y(j)-y1))*(b(j+1)-b(j))
      return
      end
      subroutine gamma(ibeta,alfa,l,x)
      double precision alfa
      p=1.
      do 1 i=1,ibeta
```

```
      u=rand(0)
      p=p*u
1     continue
      x=-(1./alfa)*alog(p)
      return
      end
      subroutine expon(xavg,x0,x)
      alpha=1./(xavg-x0)
      x=x0-alog(rand(0))/alpha
      return
      end
      subroutine group(data,b,f,y,m,n,k)
      dimension data(500),b(51),f(50),y(50),k(50)
      do 1 j=1,m
1     k(j)=0
      do 3 i=1,n
      do 2 j=1,m
      if(data(i).ge.b(j+1)) goto 2
      k(j)=k(j)+1
      goto 3
2     continue
3     continue
      f(1)=float(k(1))/n
      y(1)=f(1)
      do 4 j=2,m
      f(j)=float(k(j))/n
4     y(j)=y(j-1)+f(j)
      return
      end
      subroutine para(data,avg,sd,n)
      dimension data(500)
      sum1=0.
      sum2=0.
      do 1 i=1,n
      sum1=sum1+data(i)
1     sum2=sum2+data(i)**2
      avg=sum1/n
      sd=sqrt(sum2/n-avg**2)
      return
      end
      subroutine output(b,f,y,avg,sd,m,n)
      dimension b(51),f(50),y(50)
100   format('0',10x,'mean=',e12.5,10x,'standard deviation =',e12.5,
     +  10x,'number of data points =',i4//)
200   format('0',120('='),/,14x,'interval',14x,'lower',14x,'upper',
     +  14x,'relative',
     +  14x,'cumulative',/,16x,'number',15x,'bound',14x,'bound',14x,
     +  'frequency',12x,'distribution'/120('-')/)
300   format(18x,i2,14x,f8.4,11x,f8.4,13x,f8.4,15x,f8.4)
      write(7,100) avg,sd,n
      write(7,200)
      do 1 j=1,m
      j1=j+1
1     write(7,300) j,b(j),b(j1),f(j),y(j)
      return
      end
      subroutine timecost(dwt,dc,wtc,shipcost)
      dimension wtc(20,10)
```

```
      do 1 i=1,11
      if (dwt.ge.wtc(i,1)) then
         if(i.eq.11) then
           m=11
           goto 2
         else
           goto 1
         end if
       else
         if(i.eq.1) then
           m=1
           goto 2
         else
           m=i-1
           goto 2
         end if
       end if
1      continue
2      if(dc.eq.8) shipcost=wtc(m,5)
       if(dc.eq.10) shipcost=wtc(m,6)
       if(dc.eq.12) shipcost=wtc(m,7)
       return
       end
```