COST-BENEFIT ANALYSIS ON A PORT DEVELOPMENT PROJECT USING A SIMULATION PROGRAM

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INTRODUCTION

This paper intends to present an investment appraisal approach of port development project using simulation model as its objective showing that how a port development project in a case study should incorporate a simulation technique into the cost-benefit analysis.

There can be another method for the solution, for instance, queuing theory model. However, the queuing model appears to have at least three problems with its applicability to the cost-benefit analysis particularly in maritime context.[1]

First, 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. Second, in the case of a multi-server queuing model with different size for example, two berths with the sizes of which being different, 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. Third, when the distribution of vessel 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.[2] Furthermore, when it is known by some statistical tests 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.

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 employs a simulation approach as its methodology.

As for the scope of this study, it will be confined to economic analysis, 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.[3]

1.SIMULATION MODEL

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.

1.1.System Analysis

1.1.1.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 four berths to import raw materials such as iron ore and coal for processing and to export the finished product, steel.

The port has one 150,000 dwt berth, two 100,000 dwt berths and one 50,000 dwt berth totaling four. The system can be said to be a four channelled - single phase waiting line system[4]. In other words, a ship is served in 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).

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.

1.1.2.System parameter estimation

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 represent empirical distribution in a real system.[5] 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 can be used for random number generation. If not, the empirical distribution should be generated in the computer.

The system parameter estimation is 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 the biggest berth (henceafter S1), 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 1.

Table 1 Mean and standard deviation of empirical distribution (unit:hour)

	interarrival	service (S1)	service (S2)	service (S3)	service (S4)
mean	47.077	134.89	112.64	130.675	153.38
s.d.	40.514	35.89	35.95	58.9	92.18

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.[6]

From table 1 and equation 1 and 2 (see note 6), 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 equation 1,

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

$\beta = \alpha \cdot \mu = 1.35020798 \approx 1$[7]

In the same manner, the other parameters of service time distributions were estimated. The results are shown in table 2.

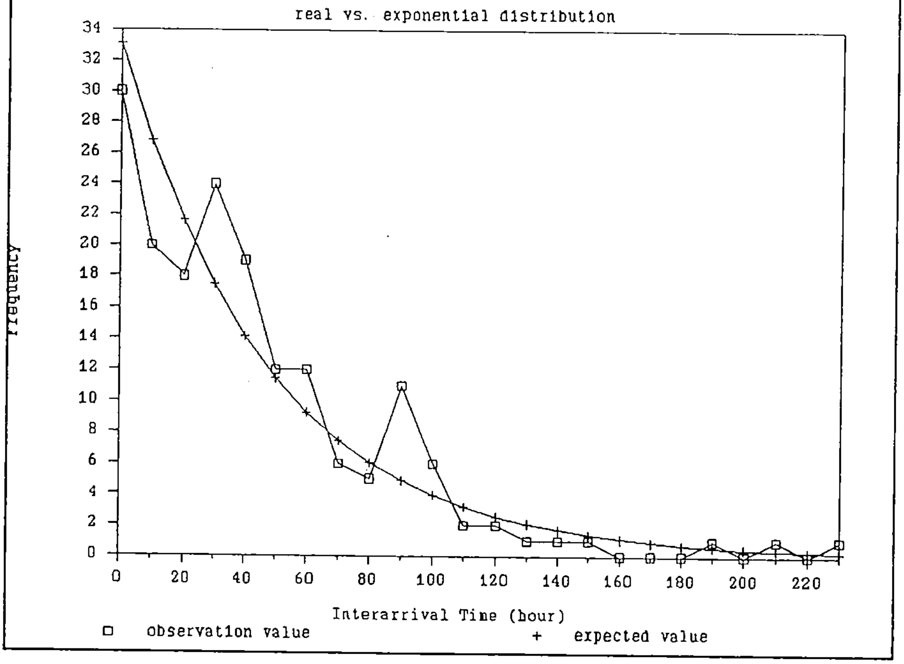
Table 2 Estimated parameters

	interarrival	service (S1)	service (S2)	service (S3)	service (S4)
α ß	0.02868 1	0.105 14	0.0287 10	0.0377 5	0.018 3

From the table, it can be hypothesized that the interarrival time distribution can be represented by exponential distribution with α=0.02868 and service time distribution in berth S1, gamma distribution with α=0.105 and ß=14 and so on.

This hypothesis was tested by employing chi-square goodness-of-fit test for each distribution. For instance, the chi-square value of the interarrival time distribution showed that the hypothesis cannot be rejected at the 5 % significance level as can be seen in graph 1.[8]

Fig. 1. Interarrival Time Distribution



The consequence of the chi-square test showed 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.

1.2.Model Description

Among various types of simulation model, 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. And it is more likely to be a dynamic and stochastic system since it evolves over time and also contains one or more random variables such as arrival time and service time.[9]

1.2.1.Random number generator

The key to simulating discrete, random events is the ability to generate random numbers on a computer. 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) was used in the simulation model because the method could easily be implemented in a high-level programming language, such as FORTRAN.[10]

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

Based on these findings, the generation of non-uniform random variates, such as in our distributions, was conducted from uniform random variates by either the analytical integration method, known as inverse transformation method, or direct simulation techniques.[11] For instance, the exponential and empirical distributions were generated by the inverse transformation method whilst the gamma distribution was generated by the direct simulation technique.

1.2.2.Algorism for calculating waiting times

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

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a(i) = a(i-1) + AT
d(i,j) = b(i,j) + ST
aq(i,j) = a(i)
If aq(i,j) >= blast(j), then b(i,j) = aq(i,j)
if not, b(i,j) = blast(j)
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wt(i) = d(i,j) - a(i,j)
wt2(i) = b(i,j) - a(i,j)
where,
i : serial number of ship
j : berth number (1=S1, 2=S2, 3=S3, 4=S4)
AT : interarrival time (random variable)
ST : service time (random variable)
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
wt(i) : waiting time in system
wt2(i) : waiting time in queue

In the above formulae, consecutive arrival time can be calculated by adding the interarrival time up to a previous ship's arrival time. And the consecutive departure time is a summation of berthing time and service time. Depending upon ship size and berth availability, the berth is allocated. As to 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. Waiting time in the system and in the queue is a difference between arrival time and departure time, and berthing time, respectively. Assessing these waiting time distributions would be the main objective of the simulation model.

Interarrival time and service time should be generated by the computer itself. Once the two random variables are generated by computer, all the other values are fixed by the formulae.

2.SIMULATION RESULT

The simulation model result showed 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 were compared in cost-benefit analysis in terms of required costs such as construction cost for infrastructure and superstructure and maintenance and operating cost and expected benefits, mainly resulting from reduction in ship turnaround time cost from old system to the new system. Finally, the riskiness in the project was 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 change of discount rate in the cost-benefit analysis.

2.1. The Simulation Model Result

2.1.1. 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[12]
* 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, waiting time in the system and in the queue and berth occupancy rate in each berth were calculated.

The simulation model in the old system was run over forty years because the period should be matched with the economic life span of infrastructure such as quay wall and breakwater in order to be used in cost-benefit analysis later.

The result showed that 139 ships out of 191 ships on average had to wait in the queue in the old system. The higher values in waiting time could be explained from berth occupancy rate. The busiest berth was the biggest berth (S1) whilst the smallest berth (S4) seemed to be rather idle. This implies that expansion program is more likely to be necessary in order to reduce the waiting time cost.

2.1.2. Result with the new system

If the new berth (250,000 dwt) is constructed, the smallest berth (S4) is scheduled not to be used for iron ore and coal ships any more. So, 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 same multi-channel single phase system as the existing system.

Consequently, the simulation model in the new system was 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[13] and three other service time distribution 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 simulation model was run in the new system for 40 years in the same way as in the old system. Out of 132 ships, only 19 ships on average were to wait in the queue. The great improvement in the waiting times could be better explained from the berth occupancy rates. All the berths seemed to have almost equally balanced occupancy rates as a consequence of new berth construction whilst in the old system, the berth occupancy rate in S1 was considerably high and that in S4 rather idle. The reduction of waiting time in the new system obviously resulted from the construction of the new berth.

2.2.The Cost-Benefit Analysis

The cost-benefit analysis examined whether the nation, South Korea, would be better off or worse off as a consequence of the construction. 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 benefit was based on the market price.

The cost-benefit analysis was conducted under the following premises. First, the period of the analysis was forty years in line with the estimated economic life span of main construction structure, namely quay wall structure. Second, the main benefit was realized from the reduction in ship turnaround time cost from the old system to the new system.[14] Third, the main cost items was the construction cost of the infrastructure, handling equipment cost, the maintenance and operating cost which were directly connected to the new berth operation. Fourth, the social discount rate was 10 % recommended by the Economic Planning Board of S. Korea.

2.2.1.The cost estimation

The expansion program was 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 was expected by some engineering consulting company that the expansion plan would require 54.6 million cubic meter dredging over the beginning 6 years. After consultation with the engineering company, the construction cost was estimated.

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

From the construction cost and maintenance and operating cost, annual cost over the investment period was estimated.

2.2.2.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. Since the waiting time of each vessel was already calculated in the simulation model, the only thing that had to be estimated was the cost of the waiting time or cost of ship time in the port in order to calculate the annual benefit.

For the ship time cost, the concept of long-run opportunity cost was used. It consisted of capital charge, operating and fuel (in the port area) costs.[15] Using a number of published data, for instance, Drewry data[16] for capital cost, the ship time cost was calculated by ship size and hour. This ship time cost was fed back to the simulation model and the annual benefit was estimated as the difference between the summation of individual ship's time cost in the old system and summation in the new system per annum.

2.2.3.The NPV and IRR

The annual cost and benefit were discounted at the social discount rate, 10%, expressed in 1989 money terms. The present value of the annual cost and benefit were summed up resulting in the NPV of about 56 million dollars and the IRR of 16.89%. Thus, the investment plan proved to be beneficial to the country by the amount of the NPV.

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.

CONCLUSION

An attempt has been made in this paper to present an investment appraisal approach of a port development project using a simulation model by employing a case study.

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 and feed back to the simulation model.

NOTES

1. For further discussions, see Chang, Y. T., Cost-benefit analysis in a port development project using a simulation model. Malmo, Sweden:World Maritime University (master's thesis), 1989. pp. II-12 - II-17.

2. See Page, E., Queuing theory in OR. London:Butterworths, 1972. pp. 67-87.

3. See Frankel, Ernst G., Port planning and development. USA:John Wiley & Sons Inc., 1987. pp. 249 - 250.

4. See Evans, J. J. and Marlow, P. B., Quantitative methods in maritime economics. London:Fairplay Publications Ltd., 1986. p. 126.

5. See Gottfried, Elements of stochastic process simulation. Englewood Cliffs, New Jersey:Prentice-Hall Inc., 1984. pp. 8-9.

6. The probability density functions are represented by the following formulae.

Exponential distribution:

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

Gamma distribution:

$$f(x) = \frac{\alpha^{\beta} \cdot x^{(\beta-1)} \cdot e^{-\alpha x}}{(\beta-1)!} \quad (2)$$

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 $\beta=1$)

7. The value of β must be an integer of the Erlang distribution, however, there is no guarantee that the value derived by equation 1 and 2 will be an integer. In such

cases, the integers above and below the value given by the equation should be used, to give bounds on the actual distribution. For more details, see Page, ibid.

8. The chi-square value was 25.26, which is less than the critical point at 5 percent significance level with 23 degree of freedom.

9. For the details, see Law, A. M. and Kelton, W. D., Simulation modeling and analysis. USA:McGraw-Hill, 1982. pp. 2-4.

10. See Gottfried, op. cit., pp. 19-38.

11. See Gottfried, op. cit. pp. 76-111

12. The size of ship (dwt) was collected from the raw data set. And the distribution was tested by the chi-square test resulting in recommending empirical distribution. That is the raw data distribution itself should be generated by computer.

13. These new distributions were estimated based on the information from the people of the company, POSCO, and a number of experts in this field on the size and number of vessels to call in the new system. For more details, see Chang, op. cit., pp. IV-8 - IV-10.

14. Despite that there might exist some indirect benefits which were difficult to be quantified or impossible such as the externality effect, it was assumed that the indirect benefit could be canceled out by indirect cost.

15. See Goss, R. O. and Mann, M. C., The cost of ships' time : In advances in maritime economics, Edited by R. O. Goss. Cardiff, U.K.:republished by the Univ. of Wales Institute of Science and Technology, 1982. pp. 139-142.

16. See Drewry Shipping Consultants Ltd., Financing ships; the challenge of the 1990's. London:1989. pp. 4,67,125.

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