항만투자분석을 위한 실험계획법 : 산물터미널에서의 사례연구

장영태*

Experimental Design for Port Investment Analysis : A Case Study in a Bulk Terminal

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Abstract

Experimental design in simulation provides an efficient way of economizing simulation runs since a considerable number of simulation runs that originally were planned can be reduced by this approach. This experimental design method is an active area of research together with the output analysis and so no single panacea seems to exist so far. Thus, selection of techniques of experimental design and output analysis more likely depends upon the objective of simulation analysis, budget constraint and sometimes the analyst's subjective judgment. This paper attempts to describe an experimental design methodology for port investment analysis using a case study in a bulk terminal in Korea. Detailed display will be focused on simulation period, warm-up period, the number of replications needed in production runs after brief explanation on the system configuration.

Key Words : experimental design, port investment, bulk terminal

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1. Introduction

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[1]. 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.[2]

One way to overcome these problems of overcapacity and undercapacity within constrained resources is to match the provision of port capacity for the demand. In an economic sense, this is an attempt to find a solution having the maximum benefit-cost ratio. The costs are composed of the capital cost, the maintenance cost and the operating cost of the infrastructure and the superstructure which would be installed as the investment program to meet the demand for cargo. The benefits can be considered as cost savings accruing to societies or nations concerned thanks 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.[3] Whereas the estimation of the costs is rather straightforward, usually provided by engineering companies, the estimation of the benefits, chiefly the reduction of the ship turnaround times, is somewhat complex and the most crucial factor of the cost-benefit analysis.

Simulation models have been applied for various purposes in the maritime context such as an installation plan of cargo handling equipment, changes of port operation policies, port design, port productivity improvements, economic impact study, navigation risk evaluation, management training, staff education and training, simulation of ship and cargo operations, port activity simulation, port planning and so on. The purposes of these studies can be classified into three categories: short-term operational analysis[4], long-term investment appraisal[5] and shipping market analysis.[6] A typical example of the simulation study in the respective category can be summarized as the following: UNCTAD (1969) developed a simulation model that is designed to permit evaluation of operations of a port and to work out programs determining the problems affecting the port. This model is based on satellite programs for data accumulation, forecasting and traffic generation. The UNCTAD model was developed for use in the rationalization of port operations, including optimizing of ports operations under static conditions which implies improvement of the port as a whole. As for the simulation models related to investment appraisal, Frankel et al.(1973) discussed the use of system analysis and simulation methods to help the choice between multi-purpose offshore port facilities. They presented optimization of investment and other costs by allocating resources and developing utilization strategies. Regarding simulation for the ship market analysis, Buxton and Akgul (1989) developed a model to compare by simulating a number of multi-purpose general cargo vessels suitable for the trade of a Turkish shipowner. The model simulated the operation of each vessel under a variety of operating scenarios, i.e. fuel prices and freight profiles and estimated the distribution of resulting net present values. It was a typical Monte Carlo simulation model since the passage of time plays no substantive role. In spite of these various applications of the simulation model, its application in the economic appraisal of port development has been comparatively rare. Even though there are a few models applied to the economic appraisal, they do not appear to reflect recent new developments of simulation model (for instance, new system parameter estimation techniques for validity and output analysis) or they tend to be used from only the view points of port operators, companies and port authorities rather than from the view points of national economy, thus not sufficiently reflecting the economic soundness of port development project. The parameters estimated for a port simulation are the parameters for such distributions as interarrival time of ships, service time of each berth, vessel size, cargo types, etc.

In simulation, experimental design provides an efficient way of economizing simulation runs since a considerable number of simulation runs that originally were planned can be reduced by this approach. Carefully designed experiments are much more efficient than 'hit and miss' trial runs that are made for a full number of different configurations unsystematically only to see what happens. The experimental design is particularly useful when a simulation is planned for a long-term port investment analysis. The long-term port investment analysis often requires us to look into a system of study for several decadal years and so to simulate the system becomes very costly considering the long-duration and also many thousands of replications. Therefore, this can be a daunting job for even today's powerful computer. This experimental design method is an active area of research together with the output analysis and so no single panacea seems to exist so far. Thus, selection of techniques of experimental design and output analysis more likely depends upon the objective of simulation analysis, budget constraint and sometimes the analyst's subjective judgment.

This paper describes the experimental designs particularly for port investment analysis before production runs are undertaken using a case study in a bulk terminal. Although this paper shows only the part on experimental design for port investment analysis, it should be recognized that this study was done as a part of the author's PhD dissertation research, whereby whole process of simulation analysis was undetaken, ranging from data collection and parameter estimation, and validation and verification to pilot runs and experimental design, production runs and output analysis in its serial order. Therefore, any detailed concerns should be referenced from the dissertation.[7]

2. Case description

The Port of Pohang is located in the

southeastern part of Korea at latitude 36o 02′ N and longitude 129o 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. There are eight piers dealing with the cargoes and the products. Of the eight piers, pier no. 1 handles the raw materials and the other piers the finished products (steel) and general cargoes.

Four berths (berth nos. 10, 11, 13 and 14) on pier no. 1 at present are used to serve large ocean-going vessels for carrying iron ore and coal up to the size of 250,000 dwt. All the vessels for carrying iron ore and coal are chartered from Korean shipping companies by POSCO. The company suffered from a great deal of demurrage cost due to the waiting time in the port since before constructing berth no. 10, the port had to use another berth on pier no. 2 which can handle only smaller vessel up to 50,000 dwt size. In order to reduce the demurrage cost and facilitate larger vessels, the company constructed one new, large berth (berth no. 10) which can handle a 250,000 dwt vessel in 1990.

The present port situation for iron ore and coal can be seen in table 1.

The table shows the berth no. 10 is used only for the largest vessel due to the draft and capability of unloader installed in the quay. All three other berths can serve up to 150,000 dwt vessels due to the draft and lower capability of the unloaders.

Table 1. Berth characteristics of pier 1 in Pohang

Berth No.	Draft (m)	Max dwt vessel that can berth	Handling equipment[a)]
10	18	250,000	2000ton/h*2
11	18	150,000	1600ton/h*2
13	16	150,000	1600ton/h*2
14	16	150,000	1600ton/h*2

Note : a) refers to unloaders and the productivity in the column is official nominal handling rate expressed in ton per hour.

When an iron ore or coal vessel arrives in the port, she is supposed to berth at one of

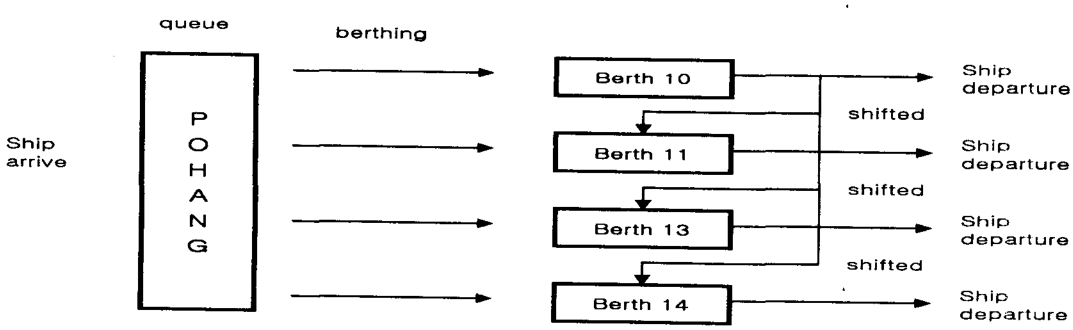


Figure 1. The Queueing system in the Port of Pohang

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.

After berthing, once she finishes the discharging of cargo, it is usual cases in normal ports that the ship is supposed to leave the berth and not to berth again for another service. However, in the Port of Pohang, the ships in the berth no. 10 moved to another berth frequently while loading and discharging cargoes before finishing the stevedoring work (henceforth shifted). The main reason of the frequent shifting from berth no. 10 to other berths was that smaller vessels were guided to berth in the berth 10 when it was not occupied in order to use the higher production capabilities of the larger unloaders. So while using these larger unloaders in the berth 10, if any larger vessel that can only berth in the berth 10 enters the port, the smaller ships had to be shifted to other smaller berths in the midst of the stevedoring work. For instance, about thirty three percent vessels of the berth 10 shifted to other berths in a recent year.

This port system can be graphically presented as in figure 1. This figure shows that the ships assigned to the berth 10 can either leave the port after completing cargo works or be shifted to one of the berths 11, 13, and 14 and reberthing, stevedoring for the remaining cargoes and leaving the port should be continued.

The frequent shifting implies that there might be need to expand the berths (build another berth or enlarge existing smaller berths) or at least install larger unloaders in berths 11, 13, and 14. For instance, the berth 11 seems to accommodate 250,000 dwt vessel if the 2,000 ton unloaders of the same capability to that of the berth 10 are installed since water depth is already enough for that size vessel. In fact, the POSCO considers these alternatives in the future and the question is how many unloaders and berths should be installed and built or enlarged, respectively and how will these changes of the system affect system performance and how much cost-saving will be incurred. Therefore, each alternative should be evaluated in comparison with present system by the simulation model and the seemingly best choice should be recommended.

3. Experimental design

3.1 Alternative Configurations

To begin with, alternative configurations should be thought in port planning of the Port of Pohang. The possible alternatives in improving the port performance can be provision of additional equipment and/or berths and/or different port operating policies. The first alternative in improving the port efficiency seems to be replacement of the two existing unloaders in berth 11 by bigger unloaders as big as those in berth 10 (2,000 tons per hour). The replacement will enable berth 11 to accomodate up to 250,000 dwt vessels since the water depth in both berth 10 and 11 is 18 meters and berth 11 has only smaller unloaders. This alternative can even be divided into two options like one additional unloader and two additional unloaders. Another alternative can be expansion of the two existing berths 13 and 14 into bigger capabilities, one at a time. The third alternative can be a policy variable in operating the port. Of the possible policy variables, the shifting decision seems the most critical decision in affecting the port efficiency. Therefore, whether vessels will be shifted or not will be also analyzed in connection with the provision of unloaders and berths, respectively. Putting the alternative configurations another way, the total space of alternatives are three dimensional: first, unloader dimension: second, berth dimension; third, shifting dimension. The unloader dimension has a value of two choices (one unloader and two unloaders) and the shifting dimension has also a value of two choices (shift 'yes' and 'no'). The berth dimension can have a value of four choices in terms of the number of the 250,000 dwt berths ranging from one berth (existing system) to four berths (three berths expanded). This configuration is presented in the following table:

Table 2. Dimensions and ranges of alternative system configuration

Dimension	Range	Remark
Unloader	(1,2)	no. of 2,000 ton/hr
Berth	(1,2,3,4)	no. of bigger berths*
Shifting	Yes, No	from bigger berths to smaller berths

Note : bigger berths* refers to the same size of existing berth 10, which can handle up to 250,000 dwt ships.

The table shows that there are 16 different configurations from multiplicaiton of the each range (2*4*2). Of these, if we put the configuration with a set of three elements, for example (e1,e2,e3), where e1 refers to the value of unloader, e2 refers to the value of berths and e3 refers to the value of shifting, then (2,1,Yes) is the existing system configuration. For each of these alternative configurations, decisions on initial conditions, lenth of warmup period and simulation period, and number of replications have to be made prior to production runs. Some of the decisions can be derived from the outputs of pilot runs

3.2 Major Decision Points of Experimental Design

The experimental designs are planned considering the following respects:

First, the simulation should terminate in a certain period, whereby the period should be determined by the economic life span of major assets such as handling equipment and quay wall structures. In general, a terminating simulation is one for which there is a natural event E that specifies the length of each run whereas a nonterminating simulation is one for which there is no natural event E to specify the length of a run[8]. Although the port system can be continued perhaps for an enormously long time unless its commercial function becomes obsolete, the simulation model is run mainly to be used for the cost-benefit analysis later and so it should have a life span of project in order to compare the results of proposed systems with that of the existing system. The life span of the project is usually determined by economic life span of key assets and the key assets in the alternative configurations are the unloaders and the quay wall structures. International standard of the life span for the berth is more likely forty years and the simulation run period should be forty years as is usual case in port investment appraisa[9]. The most important structure in a port is its breakwater and quay wall structure and the basic materials of the structure are concretes and cements. Although the physical duration of the structure can be a hundred years, their economic life span should be forty years or so as recommended by UNCTAD. This is the reason why the simulation period should be the forty years.

Second, the warmup period and initial conditions should be determined based on the outputs of pilot runs. Although the simulation model is defined as a terminating model due to the simulation purpose, the nature of port system is more likely to be steady-state once new systems are adopted and operated. The steady-state means that random variables will have the same distribution regardless of the time lags. In other words, the steady-state means that turnaround times in the port tend to be approximately stationary regardless of the time passage. This is because the demand for the iron ores and coals are almost fixed by the fixed capacity of the furnace of POSCO, annually about seven million tons and there is no further plan of expanding the capacity at present. Thus, if the new systems are operated, the ships will stay almost same hours on average, for example every year, regardless of time passage. In simulating the alternative systems, the warmup period until reaching the steady-state should be excluded in calculating the system performance and the condition just after the warmup period should be the initial condition. This warmup period can be observed from pilot runs.

Third, the number of replications depends upon the goal of simulationist to achieve the accuracy of prediction or more specifically his/her wished confidence interval. One approach is to run the model arbitrarily chosen number of replications and then calculate the mean value and variance, from which the confidence interval is calculated. This is called the fixed-sample-size procedure[10]. The other approach is to set a specified precision and then necessary replications for obtaining this precision are estimated from the mean value and variance of pilot runs. Irrespective of which approaches to choose, certain number of pilot replications should be made essentially. Complete procedures of replication numbers can not be fixed at this stage but can be more clearly determined during the output analysis.

The pilot runs were conducted paying attention to these three respects. The existing system was simulated for forty years twenty times of replications, chosen arbitrarily and the warmup period was analyzed by moving average method.

3.3 Results of Experimental Design

The result is as follows:

First, existing system was simulated for a year to analyze the warmup period. One hundred and seventy five vessels were simulated for a year from the interarrival distribution and the ships' turnaround times were extracted. Then calculated were moving averages of the times, which is an averaging method of neighboring observations in a series, moving through the path of the series[11]. The simplest and general technique for determining the transient period is as graphical procedure, developed by Welch. Its specific goal is to determine a time index l such that the transient mean curve E(Yi) (for

I=1,2,...) "flattens out". The exact formula is the following equation.

$$Y_i(w) = \begin{cases} \dfrac{\sum_{s=-w}^{w} \overline{Y_{i+s}}}{2w+1} & \text{if } i = w+1, \dots, m-w \\ \dfrac{\sum_{s=-(i-1)}^{i-1} \overline{Y_{i+s}}}{2i-1} & \text{if } i = 1, \dots, w \end{cases}$$

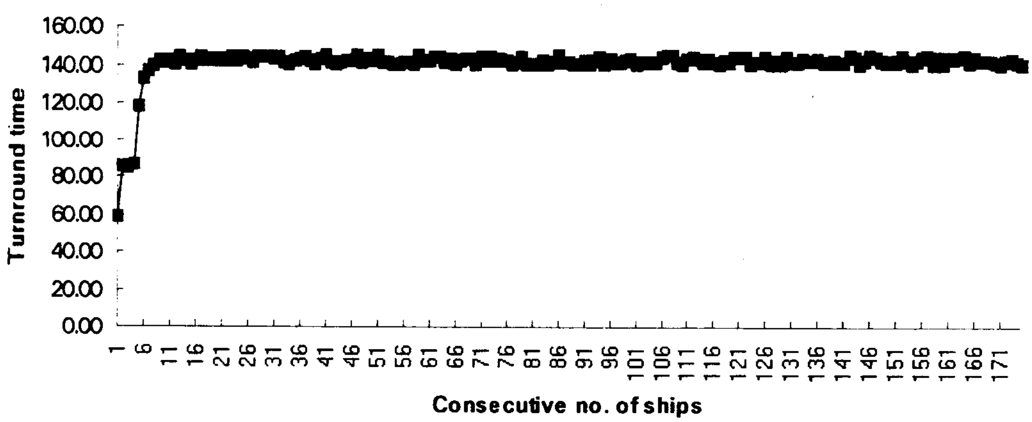
where, w is the window and is a positive integer such that w<= [m/2].

The author attempted to have moving averages ranging from a value of w=1 to the last value of w, plotting the moving averages on the XY plane. Each time of the plotting, the author carefully observed when the moving average converges by increasing the window value by one. Figure 2 is the final output made by w=37.

Although figure 2 is not completely smooth one, it shows that the curve seems to converge from somewhere around the tenth vessel. This implies that the transient period in the simulation might be up to ten vessels for warmup period and these first ten vessels from the beginning of the simulation should be excluded from the calculation of necessary statistics. Therefore, all the first ten vessels in each alternative system are excluded for the analysis.

Meanwhile, the existing simulation model was run for forty years as the maximum run period and twenty times of replication in order to check the confidence interval from the pilot runs and so to check how many replications are needed in production runs later.

As a consequence, the mean value of ship turnround time in each replication was calculated for (the 175 vessels per year)*(forty years)=7,000 vessels and the expected mean value of ship turnround time from all twenty replications and the variance were calculated. The expected mean value was 103.4707 hours and the variance was 29.14387 hours. For this mean value, an approximate 100(1-α) percent (0<α<1) confidence interval is given by



Fiiguer 2. Moving average of ship tims

$$mean[\overline{X}(n)] \pm t_{n-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{n}}$$

where, n: no. of replication; S2: sample variance

$$\therefore 103.4707 \pm t_{19,0.975}\sqrt{\frac{29.14387}{20}} = 103.47 \pm 2.53$$

The confidence interval is very narrow and so it is more likely that ships in the existing system will stay in the port about from 100.94 hours to 106 hours with ninety five percent probability. What is more important from the narrow confidence interval is that we do not seem to need any additional replications due to the narrow variance. If a certain precision has been specified, let's say an absolute error of β or a relative error of γ, an approximate expression for the total number of replications required to obtain the absolute error and the relative error can be referred to from the literature[12]. Since the confidence interval is very narrow in the pilot runs, twenty replications seem to be enough number and therefore are chosen as the replication number in production runs.

The findings from the pilot runs are that ten observations from the beginning of simulation should be considered as warmup period and twenty replications are deemed to be enough to obtain a satisfactory confidence interval of ship turnaround times. More accurate replication numbers can not be decided at this stage but can be done in the output analysis later. The production runs are carried out based on these findings for each alternative configurations. In other words, production runs to find out the optimal solution among the sixteen alternatives in terms of the cost-benefit ratio in the case study were carried out. The production run period and number of replications and the warm-up period were decided by the findings of the experimental designs shown in this paper. Even if readers of this journal may be more interested in the processes and outputs of the production runs and output analysis, the description of the results should be done elsewhere as separate papers due to space limit of this paper. Otherwise, the readers can refer to the author's dissertation for the details.

4. Conclusion

This paper attempted to describe an experimental design methodology for port investment analysis using a case study in a bulk terminal in Korea. Experimental design techniques have been focused on simulation period, warm-up period, the number of replications needed in production runs after brief explanation on the system configuration.. Simulation techniques become pervasive in maritime industry thanks to rapid development of computer industry. In spite of cheapness of computer technology, carefully designed experiments are much more efficient than 'hit and miss' trial runs that are made for a full number of different configurations unsystematically only to see what happens. This experimental design method is an active area of research together with the output analysis and so no single panacea seems to exist so far. Thus, selection of techniques of experimental design and output analysis more likely depends upon the objective of simulation analysis, budget constraint and sometimes the analyst's subjective judgment.

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