Journal of Korea Port Economic Association, Vol.26(3), 2010, pp.42~55
한국항만경제학회지 제26집 제3호 (2010. 9)
www.kportea.or.kr

Optimizing Total Transport Cost Incurred under Specific Port System: With a Case of Managing POSCO-owned Berths

Weon Jae Kim*

목 차

Key Words : specific port structure, sea transport cost, queuing cost, inventory cost

Abstract

This paper primarily deals with a decision-making for determining the number of voyages in each ship size under a specific port structure in order to minimize the total transport cost consisting of transport cost at sea, queuing cost in port, and inventory cost in yard. As a result of computer simulation using queuing model characterized by inter-arrival time distribution, we were able to find out some combination of voyage numbers of 3 ship-size(50,000-ton, 100,000-ton, and 200,000-ton), where the total transport cost can be minimized under a specific port structure.

The simulation model also allows us to figure out any trade-off relationship among sea transport cost, queuing cost in port, and inventory cost in yard. Put it differently, an attempt to reduce the sea transport cost by increasing the number of voyages of the largest ship size, the transport cost incurred in both port and yard is hypothesized to be increased and vice versa. Consequently, Port managers are required to adjust the number of annual number of voyages allocated in each ship size, put into the sea lines for importing raw materials, in order to optimize the transport costs incurred under the specific port system.

We may consider a net present value(NPV) model for performing an economic feasibility analysis on port investment project. If a total discounted net benefit, including cost savings, exceeds the initial investment for an additional berth construction, then we accept the port investment project. Otherwise, we reject the proposed port investment plan.

▷ 논문접수: 2010.07.22 ▷ 심사완료: 2010.08.31 ▷ 게재확정: 2010.09.06
** 인천대학교 무역학부 교수, casablanca2002@yahoo.com, 032)835-0786

I. Introduction

In this paper we deal with the optimization of total transport cost incurred, including marine transport cost of ships running at sea, waiting cost in port, and inventory cost in yard, under a specific port owned by the Pohang Iron Ore and Steel Company(POSCO). POSCO has constructed and used its own port for importing such raw materials as iron ore and coal in bulk. We assume that the port has 4 berths, among which two berths are able to accommodate ships sized 100,000-ton and the other ones for ships sized 50,000-ton and 200,000-ton respectively.

Recently POSCO has faced a problem of ever-increasing waiting costs in port because of its tendency to carry the raw materials by larger ships in an attempt to reduce the marine transport cost through economies of scale merit, whereas the port has the limited facilities, including berths, to unload the imported raw materials. In other words, the POSCO's effort to reduce the transport cost at sea by increasing the voyage number of the largest ship size results in increasing both the queuing cost in port and the inventory carrying cost in yard. As a result, some trade-off relationships, among these costs, can be hypothesized to optimize the total transport cost breaking into three different components.

Firstly, a deterministic model is hypothesized to estimate the sea transport cost since POSCO has operated ships on the basis of long-term contracts with shipping firms. Secondly, a stochastic model is hypothesized to estimate the waiting cost incurred in port which varies over ships' inter-arrival time, service time, berth condition, unloading works, etc. Thirdly, a deterministic inventory model is applied for estimating the inventory carrying cost in yard.

Our main concern, in this paper, lies on how to optimize these three different transport costs, which show the trade-off relationships, by figuring out the most economical combination of voyage numbers of three ship sizes. Section II provides theoretical consideration which allows us to understand why we use the particular models to estimate the costs concerned. In Section III, a case analysis is performed to show the process of estimating the transport costs at sea and in port and yard in order to figure out the optimal number of voyages in each ship size, which result in minimizing the total transport cost associated with operating the specific port exclusively used by POSCO. Additionally, several regression analyses are performed to confirm if there is any meaningful relationship among these three voyage numbers allocated to each ship size with a statistically significant level. Finally, Section IV gives some concluding remarks including a model for port investment decision.

II. Theoretical Backgrounds and Models

In solving the managerial decision problem to optimize total transport cost composed of the waiting cost in port, the sea transport cost, and inventory cost in yard, we review the relevant theories, assumptions, and methodology which allow us to formulate the models for estimating the costs concerned.

1. Model for Estimating the Sea Transport Cost

The transport cost at sea(TCS) in year 't' can be estimated with the following deterministic model:

TCSt = (1)

Where, : the average unit freight rates in ship class 'i' and year 't'
: the average cargo volume loaded in ship class 'i' and year 't'
: the number of voyages in ship class 'i' and year 't'

Since the POSCO has made a shipment contract with the shipping companies on long-term basis for carrying specific cargo and shipping routes, '' and '' are assumed to be the known parameters. As a result, we may formulate a linear programming model for estimating TCSt using a couple of constraints. This model allows us to minimize the TCSt by figuring out the optimal number of voyages of each ship class without considering other transport costs incurred.

The model is: Minimize a + b + c (2)

Subject to:

Where, : the quantity of cargo required to be carried in year 't'
(i = 1,2,3) : the minimum quantity of cargo to be carried by ship class 'i' due to loading ports' draft and particularly assigned quantity of cargo
, , : Ship classes of 50,000, 100,000, and 200,000

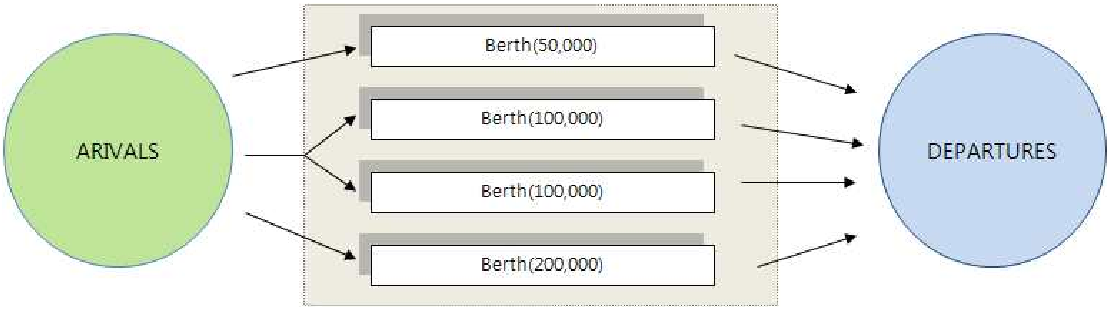
Meanwhile, the parameters of a, b, c represent the average transport costs at sea per voyage for the ships classed 50,000, 100,000, 200,000 respectively. Intuitively this model yields a trivial solution in determining the optimal number of voyages of each ship class regardless of both queuing costs in port and inventory costs in yard. Namely,

= /50,000, = /100,000, = (−−)/200,000

In other words, since the average unit freight rate of is less than those of and due to economies of scale, POSCO is expected to put the ships classed at 200,000 and 100,000 rather than at 50,000, except the unavoidable cases resulting from loading ports' condition, in order to minimize the sea transport cost. However this decision causes another problem of increasing the ships' waiting costs owing to berth congestion.

2. Model for Estimating the Queuing costs in Port

<Fig. 1> Queuing System under the Specific Port Structure



We consider some stochastic models in attempting to estimate the queuing cost that is expected to increase exponentially according as the POSCO depends on either the ships classed 200,000-ton or classed 50000-ton because of both the limited number of berths and the increasing number of voyages.

Since the port, independently operated by POSCO, has 4 berths, we apply an M/M/1 queuing model for two berth accommodating ships classed 50,000 and 200,000 respectively and an M/M/2 queuing model for two 100,000-ton berths. It is worthwhile to review the fundamental mathematical techniques associated with queuing models. The four major assumptions for the M/M1 queuing model are as follows:

1) The probability that a ship's arrival will occur and that its unloading service will be completed during a time interval is dependent only on the length of . Thus

the events occurring prior to the beginning of the time interval or the starting point of the time interval have no effect on the probability of occurrence.

2) There is a positive probability that an arrival or service will occur in a non-zero time interval.

3) If the time interval is made sufficiently small, no more than one arrival can occur and no more than one service can be completed.

4) Only one waiting line is formed.

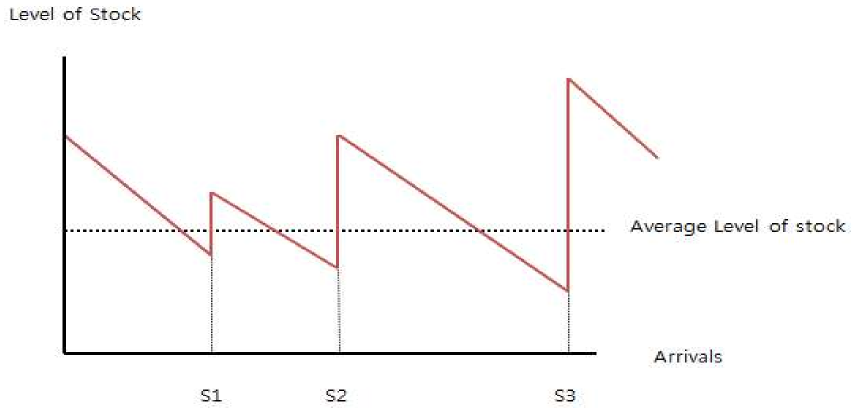
5) Berth shifts are programmed to take place in attempting to increase the utilization factors of each berth.

Theoretically, the Poisson distribution plays an important role in the development of queuing models including M/M/1. As a result, we analyze both the ships' arrival process and their departure process using the stochastic theory including Poisson(see Taha 1982). Put it differently, the inter-arrival time or the service time for M/M/1 model has an exponential distribution. A logical extension of the M/M/1 is the model M/M/2 or the multiple channels waiting line with Poisson arrivals and exponential service time.

In reality, we need some other assumptions for using the simulation model in order to estimate the most likely amount of queuing costs. We will discuss these assumptions more in the real case analysis.

3. Model for Estimating the Inventory Costs in Yard

<Fig. 2> Changing Behavior of Inventory Level Unloaded in Yard



Inventory management problem occurs when it needs to stock physical goods, commodities, or materials for the purpose of satisfying demand over a specific time period. The total inventory cost consists of purchasing cost, setup cost, holding cost, and shortage cost.

In case of managing the specific port, an inventory cost in yard depends on an average quantity of imported raw materials stocked in yard as well as on interest rate. <Fig. 2> shows a typical behavior of inventory stocks in operating the port using three different ship classes including small(), middle(), and large() sizes.

As a result, the inventory cost in yard(TIC) can be estimated with the following model:

TICy = r (3)

Where, TICy : Total Inventory Cost Incurred in Yard
r : Interest Rate(6%)
: Value of Average Level of Stock 'I'

Since the inventory cost incurred in yard depends on the number of voyages of each ship class and interest rate, we put these factors into the simulation model for estimating both the queuing cost in port and inventory cost in yard simultaneously.

III. Results of Case Analysis

1. Estimation of the Transport Cost at Sea

We are required to set up some more assumptions in estimating the total sea transport cost under the specific port condition. These assumptions may include:

a. POSCO used to make a decision on the amount of importing iron ore and coal from the loading ports contracted annually. Thus the quantity of raw materials in each loading port remains fixed as shown in Appendix 1.

b. We also assume that the freight rates of all loading ports for three ship classes remain fixed annually as shown in Appendix 2.

c. We assume all the parameters to be estimated be integer in this case analysis.

Combining the above assumptions with those made in the previous Section, we are able to take a further step in estimating the sea transport cost for importing ore and coal. The following model allows us to make its estimation:

WOS = (4)
WOM = (5)
WOL = (6)

Where WOS, WOM, WOL: weighted freight rates of ore in the three ship-class(50,000, 100,000, and 200,000)

P: Loading ports(i.e., Dampier, Hedland, Tubarao….)

Wosp, Womp, Wolp: Each loading port's annual ore quantity contracted/ Total ore quantity carried by ship classes of 50,000, 100,000, and 200,000 respectively

Fosp, Fomp, Folp: Each port's average freight rates of 3 different ship classes

Using this approach we are also able to obtain the three different weighted average freight rates of coal carriers with the following equations:

WCS = (7)
WCM = (8)
WCL = (9)

The equations of (4), (5), (6), (7), (8), and (9) allow us to figure out the average freight rates as follows:

WOS = US$18.79 WOM = US$14.78 WOL = US$11.50
WCS = US$18.82 WOM = US$15.30 WCL = US$11.03

Next, we take into account a proportion of the ore and coal quantity imported annually for calculating a general weighted average freight rate per LT in each ship class regardless of cargo and loading port. Appendix 3 provides us with the proportion of ore and coal in each ship class. These weighting factors allow us to figure out the general freight rates of each ship class as below:

Gfs = (10)
Gfm = (11)
Gfl = (12)

Where, Gfs: General freight rate of the ship class 50,000
Gfm: General freight rate of the ship class 100,000
Gfl: General freight rate of the ship class 200,000

In equations (9), (10), and (11), the parameters of and denote the ratios of annual ore quantity carried by each ship class respectively. Using these equations, we obtain:

Gfs = US$18.81 Gfm = US$15.02 Gfl = US$11.35

Plugging the above values into the equation (1), and analyzing the data in Appendices 1, 2, and 3, we may reformulate the linear programming of (2) as follows:

Minimize $940,500 + $1,502,000 + $2,270,000
Subject to: 15, 84474, 5237

As we have already indicated, the minimum number of voyages of both X1 and X2 should be assigned in order to enjoy a maximum effect of scale. Therefore, we get the following trivial solutions:

= 15, = 84, and =191

However, this solution may not ensure an optimal combination in minimizing the total transport cost due to different behavior of queuing cost incurred in port.

2. Estimation of Queuing Cost in Port

A couple of processes are taken to perform a simulation model using computer. First, we performed a diagnostic check in attempting to confirm if the vessels' inter-arrival time follows an exponential distribution. The result was that the gamma distribution (k=1) fits the reality far better than the other (k=2). The Chi=square tests also verify the result. We also tested the simultaneous cases for 3 berths in checking a service time probability distribution. The major statistics of the three cases include average service times and their standard deviations, Ks and Chi-values. Particularly, unloading time distribution at the three berths shows almost a normal distribution primarily due to homogeneity in ship sizes, raw materials, and other working condition.

Secondly, two additional conditions, including berth shifts and breakdowns, were considered in order to make the estimation of queuing cost in port more realistic. As a result, we use a simulation model to estimate the queuing cost in port.

Thirdly, we estimate the number of voyages of the three ship sizes for importing the annual quantity of 47,400,000 LT. After running more than 5,000 computer simulations, we selected 15 simulation results where we are able to figure out the range of optimal combination as shown in Appendix 4.

3. Estimation of Inventory Cost in Yard

Theoretically, total inventory cost includes purchasing cost, setup cost, holding cost, and shortage cost. However, since the company imports the raw materials, including ore and coal, we regard the inventory holding cost as the unique inventory cost in yard. Actually, POSCO kept the level of inventory relatively high in order to avoid the stock-out cost. Other inventory costs remain negligible. Using the simulation model and equation (3), we estimate the inventory cost in yard as shown in Appendix 4.

4. Estimation of Total Transport Cost under Specific Port System

Appendix 4 also provides the informative simulation results such as number of ships in queue and berth shifts, utilization of three berths, sea transport costs, queuing costs in port, inventory costs in yard, and total transport costs, which allow us to figure out the most likely combination minimizing the total transport cost as below:

= 59, = 186, = 118 Total no. of voy.: 363

Judging from the simulation results, the optimal number of voyages is expected to lie between 350 and 370, where the company is able to minimize the total transport cost under the specific port system.

Ⅳ. Concluding Remarks and Limitations

The results of case analysis in dealing with the decision-making for minimizing the total transport cost, consisting of transport costs at sea and in port and yard, suggest a couple of recommendation and implication. Firstly, we advise POSCO to consider the increase or decrease of marginal costs of both sea transport and waiting in port according as the annual number of voyages of three ship sizes is adjusted.

Secondly, POSCO is advised to carefully review such loading ports' conditions as draft, berth condition, loading capacity, distance from the unloading port, and quantity of raw materials available for contract in order to reduce the total transport cost. For instance, the ports in China must be economical alternative loading ports for importing raw materials.

Thirdly, a port investment plan can be another alternative to solving the cost minimization problem in arranging the annual number of voyages. To put it differently, if the company is subject to an ever-increasing waiting cost in port, constructing additional berths or upgrading the existing berths by dredging can be considered.

In addition, the followings are summarized for the future studies and limitations;

1. The models applied for estimating the transport costs, including maritime transport cost at sea, queuing cost in port, inventory cost in yard, if necessary, are subject to revision or improvement.

2. The data used for these analyses are required to be updated if the condition associated with managing the POSCO's specific port for importing raw materials is significantly changed.

3. Since this paper just focused on the decision-making for determining the annual combination of voyage numbers of each ship class, additional assumptions and managerial/theoretical consideration can be furthered in the future studies.

Appendix 1. Annual quantity of raw materials contracted in each loading port and the weights (2005)

Loading Ports		Average quantity((1,000 LT)	Percent
ORE	Dampier	5,800	12.2
	Headland	4,600	9.7
	Madras	4,200	8.9
	Goa	1,100	2.3
	S.Nicolas	4,300	9.1
	Tubarao	4,200	8.9
	Sepetiba	3,100	6.5
	Others	2,800	5.9
	Sub-total	30,100	63.5%
COAL	N.Castle	2,800	5.9
	P.Kembla	600	1.3
	G.Stone	800	1.7
	H.Point	2,700	5.7
	R.Bank	4,300	9.1
	Us East	3,400	7.2
	LA/LB	900	1.9
	Others	1,800	3.8
	Sub-total	17,300	36.5%
	Total Q'ty	47,400	100.0%

Data: Hanjin Shipping Co.

Appendix 2. Table for average freight rates of each ship class in major ports (2005)

Loading ports(ore)	Ton-class	F.R.($)	Loading ports(coal)	Ton-class	F.R.($)
Dampier	50,000	15.4	N. Castle		
	100,000	10.6		50,000	19.1
	200,000	6.7		100,000	13.4
Headland	50,000	15.8	P. Kembla		
	100,000	10.8		50,000	18.7
	200,000	6.8		100,000	13.3
S.Nicolas	50,000	26.1	R. Bank	50,000	17.6
	100,000	19.8		100,000	12.5
	200,000	13.4		200,000	8.5
Sepetiba	50,000	27.8	Vostochiny	50,000	13.4
	100,000	19.9		100,000	11.1
	200,000	13.7		200,000	9.5

Data: Hanjin Shipping Co.

Appendix 3. Weight factors required for calculating general freight rate of each ship class(2005)

(Unit:)%

Percent to total voyages							
Port(ore)	50,000	100,000	200,000	Port(coal)	50,000	100,000	200,000
Dampier	20.1	22.3	20.0	N.Castle	18.2	18.4	n.a.
Headland	18.2	16.5	21.4	P.Kembla	4.1	3.8	n.a.
Madras	12.8	12.1	n.a.	G.Stone	3.5	3.2	7.3
Goa	3.5	4.8	5.0	H.Point	15.5	17.0	32.4
S.Nicolas	14.3	14.6	18.7	R.Bank	20.8	26.9	50.8
Tuba	13.9	12.3	15.4	U.S.East	16.6	15.0	n.a.
Sep.	9.8	10.2	10.8	LA/LB	6.5	5.8	n.a.
Others	7.4	7.2	8.7	China	10.6	6.2	n.a.
				Others	4.2	3.7	9.5

n.a. not applicable

Data: Hanjin Shipping Co.

Appendix 4. 15 Simulation results and total transport cost estimated under the specific port system

Cost Unit: 000 US$

No. of voyage				TCS	TCP	TCY	TTC	Shift	Que	Occupancy rate(%) L	M	S
286	25	96	165	542,254	118,650	33,456	694,360	54	50	99.99	56.98	12.06
292	36	106	150	543,570	94,920	32,786	671,276	49	42	99.99	58.82	21.39
301	35	119	147	545,345	77,758	31,967	655,070	41	33	99.99	62.60	22.82
310	36	134	140	552,926	69,172	31,168	653,266	43	26	99.99	72.76	22.56
325	30	162	133	573,449	46,644	30,233	650,326	45	24	96.54	88.49	15.28
341	44	172	125	583,476	31,433	29,326	644,235	40	20	95.12	89.69	18.43
363	59	186	118	602,721	11,320	28,153	642,194	36	7	97.38	81.40	29.25
378	73	193	112	612,782	20,175	27,450	660,407	27	9	98.17	76.37	31.22
392	99	188	105	613,835	23,660	26,764	664,259	30	13	97.13	80.53	50.06
407	124	182	101	619,256	86,182	25,961	731,399	22	29	85.33	86.41	78.53
418	132	188	98	628,982	163,906	24,922	817,810	18	54	78.15	78.63	95.36
430	159	176	95	629,541	204,374	23,926	857,841	15	70	72.36	68.55	96.81
446	186	170	90	634,573	255,468	22,731	912,772	11	91	58.41	62.03	99.81
468	228	158	82	637,890	362,330	21,367	1,021,587	7	152	39.96	47.78	99.86
495	286	149	60	628,981	500,115	19,871	1,148,967	3	188	18.81	52.99	99.87

(S):50,000-ton Size, (M): 100,000-ton Size, (L): 200,000-ton Size

* The above simulation results are subject to change where we may observe some inconsistent cases.

References

1. Brown, G.G., Lawphongpanich, S., and Thurman, K.P., Optimizingshipberthing,NavalResearchLogistics,41:pp.1-15,1994
2. Daganzo, C. F.,LogisticsSystemsAnalysis4thed.,Springer-Verlag,Berlin,Germany,2005
3. Frankel, E. G., PortPlanningandDevelopment,JohnWilleyandSons,NewYork,USA,1987
4. Gilman, S., TheChoiceofShipSizeonDeepSeaGeneralCargoRoutes,MaritimeStudiesandManagement3:pp.95-103,1975
5. Imai, A. Nishimura, E., and Papadimitrius, S., Berthallocationwithservicepriority,TransportationResearchB,37:pp.437-457,2003
6. Kleinrock, L., QueuingSystems,Vol.I.Theory,JohnWilleyandSons,NewYork,USA,1975
7. Lim, A., Theberthplanningproblem,OperationResearchLetters,22:pp.105-110,1998
8. Miyashita, K., StructuralChangesintheFreightLevelDeterminationofTramperMarkets,MaritimePolicyandManagement11(1):pp.62-66
9. Langevin, A. and Riopel, D., GERAD, LogisticsSystems:DesignandOptimization,SpringerScience+BusinessMedia,NewYork,USA,2005
10. Langford, ,J.W., Logistics:PrinciplesandApplications,McGrw-Hill,NewYork,USA,1995
11. Park, Y.M. and Kim, K.H., Aschedulingmethodforberthandquaycranes,ORSpectrum,25:pp.1-23,2003
12. Plossl G. W., ProductionandInventoryControl,Prentice-Hall,NewJersey,USA,1985
13. Rushton A., Croucher, P., and Baker, P., LogisticsandDistributionManagement,KoganPage,London,UK,2006
14. Stopford, M., MaritimeEconomics2nded.,Routledge,London,UK,1997
15. Stroh M.B., APracticalGuidetoTransportationandLogistics3rded.,LogisticsNetwork,Dumont,NewJersey,2006
16. Taha, H.A.,OperationsResearch,MacmillanPublishingCo.,NewYork,USA,1982
17. Tersine R. J., PrinciplesofInventoryandMaterialsManagement4thed.,,Prentice-Hall,NewJersey,USA,1994

Optimizing Total Transport Cost Incurred under Specific Port System:
With a Case of Managing POSCO-owned Berths

< 요 약 >

특수항만구조하에서의 물류비용 최적화에 관한 연구

- 포항제철의 원료부두 사례를 중심으로 -

김 원 재

본 논문의 핵심은 일정한 전용항만을 운용하는데 있어 발생되는 물유비용을 크게 3가지로 나누어 이들의 합계가 최소화 될 수 있는 선박톤수 별 연간 발주 항차 수를 최적화하는 것이다. 즉 항만에서 적항과 양항간을 오가며 발생되는 해상수송비용, 도착 선박이 항만에서 선석을 기다리며 발생되는 대기비용, 그리고 수입된 화물이 하역되어 야적장에 보관된 상태에서 발생되는 재고유지비용 등의 비용발생 행태가 대, 중, 소 3가지 선급별 연간 항차 수의 배정에 따라 상이한 만큼, 이들 비용의 합계가 최소화 될 수 있는 최적 항차 배정 의사결정이 요구된다. 이때 해상수송비용은 주어진 선급 별, 항만 별 요율로써 확정할 수 있고, 항만 대기비용은 시뮬레이션 모델로써 추정할 수 있다. 그리고 야적장의 화물 재고유지비용은 연간 평균재고량에 화물 별 單價와 이자율 등을 감안하여 추정할 수 있다.

포항제철㈜의 원료수입 전용부두를 운영하는 사례 분석 결과에서 규모의 경제 효과에 의한 해상수송비용을 최소화하기 위해 대형선박의 연간 항차 배정 율을 증가시킬 경우, 일정 비율을 지나면 선박 대기비용이 급격히 상승하고 야적장의 재고비용도 다소 상승되어 결국 총비용이 증가하는 것으로 나타났다. 따라서 현재의 전용항만 구조하에서 물류비용을 최소화하기 위해서는 중형선은 연간 총 배정 항차 수의 약 50% 정도의 비중으로, 대형선은 약 33% 정도, 그리고 소형선은 약 17% 내외로 구성하는 것이 최적인 것으로 나타났다. 물론 이러한 분석 결과는 추후 새로운 선석의 건설, 수입화종과 화물량, 단가 등의 변수에 따라 달라질 수 있다.

□ 주제어: 최적화, 해상수송비용, 대기비용, 재고유지비용, 항차배정 의사결정