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Development of Preliminary Design Model for Ultra-Large Container Ships by Genetic Algorithm †

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Abstract

In this study, we carried out a precedent investigation for an ultra-large container ship, which is expected to be a higher value-added vessel. We studied a preliminary optimized design technique for estimating the principal dimensions of an ultra-large container ship. Above all, we have developed optimized dimension estimation models to reduce the building costs and weight, using previous container ships in shipbuilding yards. We also applied a generalized estimation model to estimate the shipping service costs. A Genetic Algorithm, which utilized the RFR (required freight rate) of a container ship as a fitness value, was used in the optimization technique. We could handle uncertainties in the shipping service environment using a Monte-Carlo simulation. We used several processes to verify the estimated dimensions of an ultra-large container ship. We roughly determined the general arrangement of an ultra-large container ship up to 1500 TEU, the capacity check of loading containers, the weight estimation, and so on. Through these processes, we evaluated the possibility for the practical application of the preliminary design model.

Keywords: Optimized design model, Principal dimension estimation, Genetic Algorithm, Required freight rate, Monte-Carlo simulation

1. Introduction

The development direction for ships, which are the foundation of sea transport, largely involves increases in their speed and scale. Particularly, with the scale-up of container ships continuously driven by the economy of scale logic, Kim (2001) forecast the advent of ultra-large container ships with a capacity of 15,000 TEU in the near future. However, in the case of ship design, especially for ships whose prototype has never been built, relatively correct decisions about the principal particulars to decide ship's performance, etc. Thus, optimized design techniques have been widely sought to obtain the data used in ship design.

However, with an optimized technique, if the models used for the estimation of the objective function and design parameters contain uncertainties and must be changed under a new user environment regardless of the designer's target, it is difficult to correctly specify these parameters during the design stage and obtain values for an optimum design that guarantees an excellent performance under all of the environments where the product is used. To resolve these issues, Kim (2001) and Koh (2002) et al. developed a design technique using genetic algorithms.

Generally, it is known that a product's performance and manufacturing cost are greatly affected and the largest design flexibility, etc. can be achieved in the preliminary design stage, as shown in Fig. 1.

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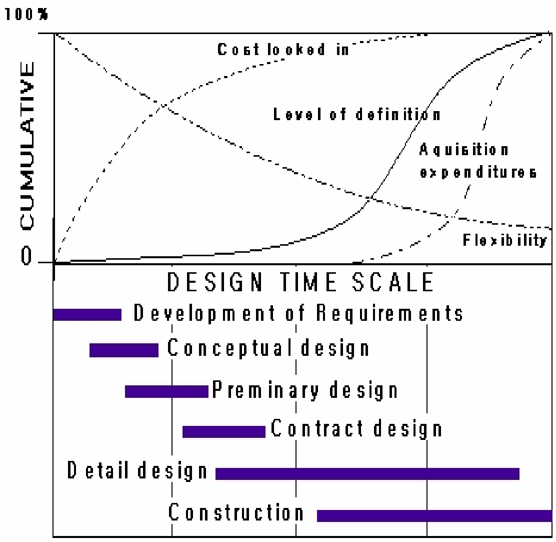

Fig. 1 Significance of design stages.

Table 1 Constraints for Container Ships.

Item	Limitations	
	Factors	**Existing**
LOA	Berth & Drydock	350 m
Beam	Crane Outreach	Less than 50m
Depth	Hold container Operation	9 tiers
Draft	Channel & Port Water Depth	13~14 m
Speed	-	25.0 kts
Propulsion System	Maximum available Power	Single Screw
Structure	Torsional Strength	Narrow wing
Loading & Unloading	Port facilities & Infrastructure	-

This logic also applies to ship design. Thus, if a reliable design model could be developed, along with a technique for values that are not sensitive to the ship's operating environment, during the preliminary design stage, this would be a very useful design tool. Therefore, in this study, models to reduce the weight and building cost of a ship were developed by using the data from actually built ships, and the presumed model for generalized ship operating expenses was implemented for the estimation of the operating costs.

An optimized technique with a minimum RFR (required freight rate) for a container ship as an objective function was used, and the uncertainties under the operation environment were processed by using a Monte-Carlo simulation.

2.1 Constraints in Model Development

As constraints in the operation of an ultra-large container ship for model development, the ship size was changed depending on the operation environment during a voyage (harbor volume). In particular, the constraints of length, bathymetry, and width are critical factors in the voyage of ultra-large ships.

As constraints for building a large-scale container ship, berthing determines the scale of the ship (container loading capacity). The largest factor that limits the width of a ship is the reach of a crane.

The required width for an ultra-large ship is around 60 m, which represents a crane reach equivalent to 22 container loading rows. If a loading method that utilizes both sides of the ship is used, the width requirement would be remarkably reduced.

Besides the bathymetry constraint for the sea routes, ports and channel approaches also limit the draft of a ship. Currently, the draft for a large ship is just less than 15 m, which can be accepted at most of the major ports. It is assumed that if ultra-large container ships are practically realized and operated, major container terminals would quickly secure the needed depth.

The required sailing speed for an ultra-large ship with a capacity of 15,000 TEU is ideally around 25 knots. Thus, it would be difficult to carry out a voyage with a single engine. The sailing speed issue is determined during ship building by the ship owner organization, while considering trading conditions, and a speed of 25 knots is ideal for basic trading using large container ships.

The evaluation results for the design constraint of an ultra-large container ship, with the above considerations, are shown in Table 1.

2.2 Presumed Model for Light Weight

For the calculation of the principal particulars required for the initial design, a reliable model should be developed. To accomplish this, detailed actual ship building data were collected as shown below.

·Daewoo Shipbuilding & Marine Engineering (12 ships with a capacity of 1,700～6,700 TEU)

Hanjin Heavy Industries & Construction (6 ships with a capacity of 1,600～6,500 TEU)

Other ships (3 ships with a capacity of 12,000～18,000 TEU)

Table 2 Lightweight items.

Category	Hull	Outfit	Engine	Electrical	Etc.
Subsection	-body -cont. hold -engine room -cell guide -paint	-pipe -anchor -general outfit -accom.	-piping -engine -propeller -mach. outfit	-cable -electrical equip't	-margin

Light weight is an item that affects both the ship building cost and sailing cost by the resistance propulsion performance. That is, it is the most important item for the optimum design of a ship.

Using the design parameters for the principal particulars, parameters with a large correlation were extracted by a correlation analysis to determine the effect of combining these principal particulars and design parameters, and a regression analysis was performed with parameters having a large correlation with the principal particulars to estimate the weight of the ship.

The weight was then classified as in Table 2 using the classification method generally followed by shipbuilding yards, and an estimation was conducted for each lightweight item. The required design parameters for the development of the presumed model were selected based on the weight estimation variables that are being used by the US Navy, and the top 5 parameters were finalized through a correlation analysis (Pearson). The final presumed model for the weight was developed as in Fig. 2 using the generalized regression analysis program (SPSS) as per the weight of the categorized group.

To verify the reliability of the presumed lightweight model that was developed as described, a comparison was performed between the re-calculated weight with the principal particulars and the collected weight data of the actual ships and actual ship design. Therefore, the usefulness of the developed model was confirmed.

Fig. 3 shows the results of the comparison between the lightweight presumed model and the weight of an actual ship.

2.3 Presumed Model for Shipbuilding Cost

The shipbuilding cost in a shipbuilding yard is classified as labor cost, materials and depreciation, capital in a broad sense, and other costs. Consistency in model development was sought by utilizing related data in conjunction with ship price estimation by the involved shipbuilding yard, while utilizing the ship weight estimated via the previously mentioned detailed lightweight presumed model. The estimation of the shipbuilding cost was carried out mainly with the procedure below.

Model		Non-Standard Coeff.		Standard Coeff.	t	Significance probability	95% Confidence interval	
		B	Standard Deviation	beta			Upper limit	Lower limit
1	(const)	433.287	1256.922		.345	.734	-2197.480	3064.055
	CONT_IN	-8.65E-02	1.121	-.094	-.077	.939	-2.433	2.260
	LBD_100	1.064	1.066	1.136	.998	.331	-1.168	3.296
	LB	4.117E-02	.405	.137	.102	.920	-.807	.890
	LB_D	-5.10E-2	.247	-.253	-.206	.839	-.568	.466

a. dependant variable: BODY

Fig. 2 Regression Analysis for Body weight (SPSS).

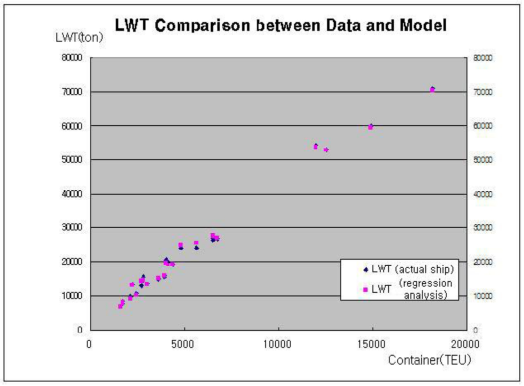

Fig. 3 LWT Comparison between Data and Model.

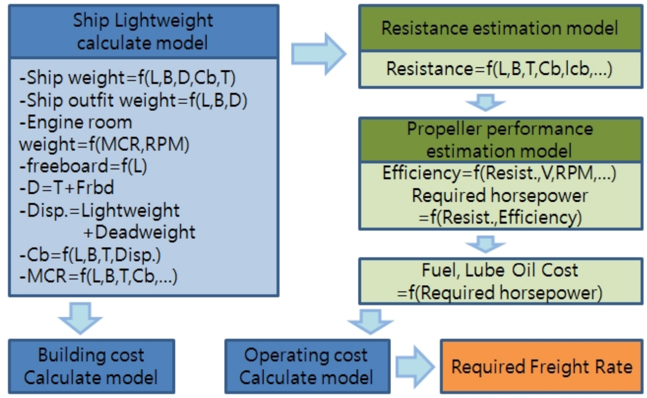

Fig. 4 Scheme of Economical Efficiency Analysis.

First, the presumed model was developed with the empirical steel cost used for the weight estimation of the ship body and outfitting, and then a steel cost computation model for the estimation of the production processes and labor cost was developed considering the steel weight and block coefficient (Cb). The presumed model for the required horsepower calculation and engine materials cost was developed using a presumed model of the resistance and propulsion efficiencies. Because the estimated shipbuilding cost is an item that is either classified or cannot be disclosed because it is confidential sales data, it was categorized as a materials presumed model and labor cost presumed model, and a new model was prepared to express the materials cost and labor cost for the shape of the ship based on the weight estimation data.

<u>Presumed model for materials cost</u>

. Materials cost for ship body = (a-b*Cb)*weight of ship body*price per ton

. Materials cost for ship outfitting = c*weight of ship outfitting

. Materials cost for engine = d*HP of engine*e

. Electrical parts cost = f*weight of electrical parts

<u>Presumed model for labor cost</u>

. Labor cost for ship body = g*materials weight of ship body

. Labor cost for ship outfitting = h*weight of ship outfitting

. Labor cost for engine = i*weight of engine

. Labor cost for electrical parts = j*weight of electrical parts

. Painting and other labor cost = k*materials weight of ship body

2.4 Presumed Model for Ship Operation

The cost that is consumed by transport ships, including container ships sailing on a sea route, is called the operation cost, and the estimated operation costs for a container ship are categorized below.

1. Cost of risk: this consists of insurance for the ship body and goods, insurance for loss/damage, and other costs; generally it is around 5% of the shipbuilding cost
2. Repair and maintenance cost: statistically, this is sampled from the data of similar ships
3. Engine performance related: fuel cost of the engine, lubrication oils
4. Labor cost: wages, food, and various insurance premiums
5. General expenses: various taxes and port entrance fees, and general fees for shipping lines and brokers, good's loss and damage costs
6. Storage and other expenses: this is calculated in proportion to the ship size, engine, and number of sailors; it is fairly small and thus ignorable
7. Goods handling cost: this occupies a considerable portion of the total expenses

The above operation costs were used by modifying a simplified empirical formula derived from the estimated values such as the principal particulars and horsepower used by the bulk carrier.

3. Development of Optimization Program

3.1 Analysis of Economic Feasibility (RFR)

Though there are many methods for estimating the invested capital to analyze the economic

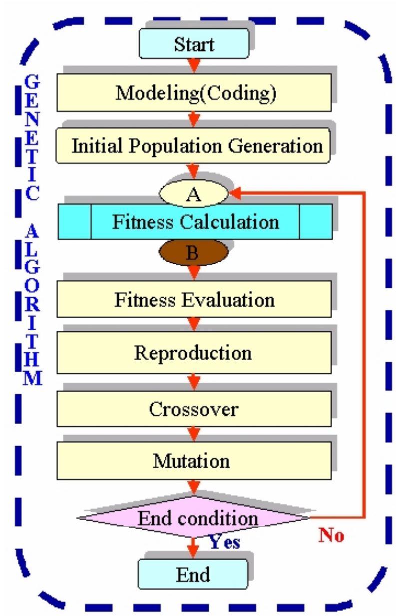

Fig 5 Genetic Algorithm.

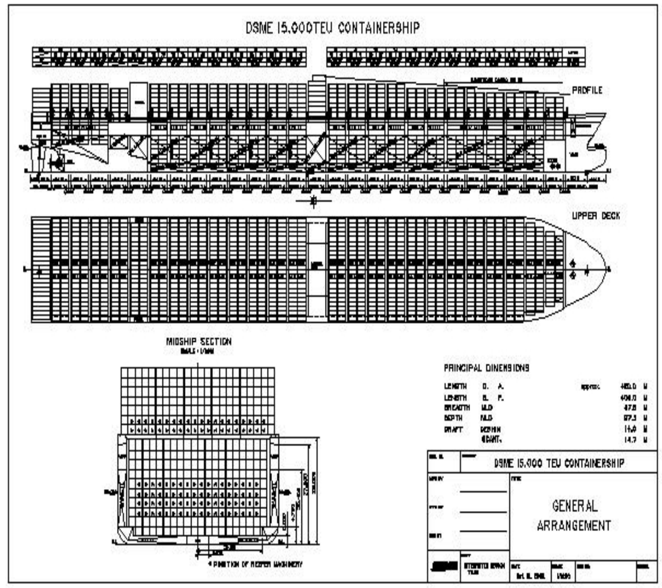

Fig. 6 General Arrangement of 15,000TEU Class Ultra-Large Container Ship.

feasibility of building and operating a ship, the required freight rate (RFR) is generally used today. Therefore, an RFR comparison was used in this study to determine the economic feasibility of building and operating the container ship.

$$RFR = \frac{(P \times CR + Y)}{C} + f \tag{1}$$

Here, P: Initial procurement cost of ship
CR: Capital recovery factor
Y: Yearly sailing operation cost (fuel cost, lubrication cost, sailor's wages, repair and maintenance, etc.)
C: Yearly cargo amount
f: Fixed cost for cargo handling

Models were developed for ultra-large container ship capacities of 9,000 TEU and 15,000 TEU, and a modeling method for the selection of the optimum data for the ultra-large container ship was prepared by following the procedure shown in Fig. 4.

3.2 Optimization Program for Principal Particulars

For the selection of the optimized key data for an ultra-large container ship during the preliminary design, a program that can minimize the objective function RFR (required freight rate) was developed using a genetic algorithm as an optimization technique.

For the interest rate, oil price, and cargo amount, which act as uncertain variables in the operation environment of a container ship, a Monte-Carlo simulation was used with variables having a normal distribution probability.

A genetic algorithm is a non-linear optimization program. Its performance has been proven in a variety of fields, and it has recently been implemented in numerous engineering fields (Fig. 5).

The optimum data obtained for an ultra-large container ship with a capacity of 15,000 TEU are as follows.

· LBP = 400.0 m

· B = 57.5 m

· T = 14.7 m

· LWT = abt. 57,500 ton

· Displ. = abt. 213,700 ton

· Cb = 0.652

Table 3 Comparison between model and yard's design results.

<table>
<tr><td colspan="2">Principal Dim.</td><td>Estimation</td><td>Concept Design</td></tr>
<tr><td colspan="2">Loa</td><td></td><td>420.0 m</td></tr>
<tr><td colspan="2">Lbp</td><td>400.0 m</td><td>400.0 m</td></tr>
<tr><td colspan="2">Bmld</td><td>57.5 m</td><td>57.5 m</td></tr>
<tr><td colspan="2">Dmld</td><td></td><td>27.2 m</td></tr>
<tr><td rowspan="2">Draft</td><td>Td</td><td rowspan="2">14.7 m</td><td>14.0 m</td></tr>
<tr><td>Ts</td><td>14.7 m</td></tr>
<tr><td colspan="2">Light Weight</td><td>57,500 ton</td><td>58,000 ton</td></tr>
<tr><td rowspan="2">Disp.</td><td>Td</td><td rowspan="2">213,700 ton</td><td>216,000 ton</td></tr>
<tr><td>Ts</td><td>230,000 ton</td></tr>
<tr><td colspan="2">Container Capacity</td><td>15,000 TEU</td><td>14,580 TEU</td></tr>
</table>

To validate the optimum data in the preliminary design by utilizing the developed genetic algorithm, a comparison was performed between the optimum data derived from the developed model for the computerized preliminary design of an ultra-large container ship with a capacity of 15,000 TEU and the empirical preliminary design at a shipbuilding yard under similar required conditions with the help of the shipbuilding yard.

The results for the validity and loading capacity estimated by assuming a general arrangement of containers in the ship, which was initially designed by a design team at a shipbuilding yard as seen in Fig. 6, revealed that this container ship can accommodate 14,580 TEU containers.

The results of the comparison of the key data estimated by the developed optimization model and those from the ultra-large container ship preliminarily designed at a shipbuilding yard show similar trends, as shown in Table 3. Therefore, the usefulness of the newly developed model was confirmed.

5. Conclusion

By using the research findings from the present study, it was possible to derive the principal particulars of an unrealized ship with the least RFR per TEU such as an ultra-large container ship, which is expected to be in demand in the future. In addition, a robust and reliable optimization model was successfully developed by which the optimum principal particulars could be determined, considering the uncertainties of the harbor volume, fuel cost, interest rate etc., which may affect the final design results regardless of a designer’s target during a preliminary stage of ship design.

Still, continuous efforts need to be made to secure a reliable model by reproducing the collected data and reflecting feedback in the design process for more precise model development.

Reference

[1] H. Schneekluth (1987). "Ship Design for Efficiency and Economy", Butterworths

[2] Hunt, E. C., and Butman, B. S., 1993, "Marine Engineering Economics and Cost Analysis", Cornell maritime Press

[3] Ko, Chnag-Do et al. (2002). "Optimized Preliminary Design of 15,000 TEU Class Ultra Large Container Ship", 2002 The Society of Naval Architects of Korea thesis presentations memoirs.

[4] Ko, Chang-Do (2000). "A study on the Design technique for robust by Genetic Algorithm", Pusan University a doctoral thesis.

[5] Kim, Chul-Nyun (2001), "Ultra-Large Container Ships advent prospects", Bulletin of the Society of Naval Architects of Korea, Vol 38, No 2, pp42-46.

[6] Kim, Su-young et al. (2001). "Design Optimization Technique Using Genetic Algorithm and Neural-Taguchi", Korea Ocean Research Development Institute, researches commissioned report.

[7] Lee D.K., Kim S.Y. et al. (1994), "A Study on the Efficient Optimization Method by Coupling Genetic Algorithm and Direct Search Method", Journal of the Society of Naval Architects of Korea, Vol31, No.3, pp12-18.

[8] Scher, R.M., Benford, H., Sep. 1980, "Some Aspects of Fuel economy in Bulk Carrier Design and Operation", Society of Naval Architects and Marine Engineers, No. 228, Univ. of Michigan