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"OPTI-MARINE-WARE" (OPTIMIZATION OF VESSEL'S PARAMETERS THROUGH SPREADSHEET MODEL)

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Abstract

The objective of this paper is to describe and evaluate a scheme of engineering-economic analysis for determining optimum ship's main dimensions and power requirement at basic design stage. We have divided the optimization problem into five main parts, namely, Input, Equation, Constraint, Output and Objective Function. The constraints, which are the considerations to be fulfilled, become the director of this process and a minimum and a maximum value are set on each constraint so as to give the working area of the optimization. The outputs (decision variables) are optimized in favor of minimizing the objective function. Microsoft Excel-Premium Solver Platform (a spreadsheet modeling tool is utilized to model the optimization problem). This paper is commenced by the description of the general optimization problems, and is followed by the model construction of the optimization. A case study on the determination of ship's main dimensions and its power requirement is performed with the main objective to minimize the Economic Cost of Transport (ECT). After simulating the model and verifying the results, it is observed that the spreadsheet model yields considerably comparable results with the main dimensions and power requirement data of the real operated ships (tanker). It is also experienced that this kind of optimization process needs no exhaustive efforts in producing programming codes, if the problem and the optimization model have been well defined.

Keywords: Optimization, design , Ship power requirement

NOMENCLATURE

PSP	Premium Solver Platform
ECT	Economic Cost of Transport
DWT	Dead Weight Tonnage
NLP	Non-Linear Programming
GRG	Generalized Reduced Gradient
GUI	Graphical User Interface
LP	Linear Programming
B/T	Breadth by Draft Ratio
BHP	Brake Horse Power
LPP	Ship's length between perpendiculars
DHP	Delivered Horse Power
T	Draft
HFO	Heavy Fuel Oil
DO	Diesel Oil
LO	Lub Oil
ME	Main Engine
GE	Generator
SFOC	Specific Fuel Oil Consumption
RFR	Freight Rate
ATC	Annual Tons of Cargo
LWL	Length of Water Line
L/B	Length by Breadth Ratio
Ap	Blade Area
Sim	Simulation
LOC	Lub Oil Consumption

1. Introduction

The problems in designing ship and marine machinery appear due to numerous considerations that must be taken into account. These conditions increase the capital cost and the complexity of the design option. Therefore, ship's design and its selected machinery must guarantee that the ship and its machinery will operate with low level of failure, safely and efficiently, with high level of availability and will deliver an optimum rate of return on the capital being employed.

Thorp and Armstrong (Thorp *et al*, 1982) utilized a comprehensive method to select the machinery arrangement for a Panamax-size bulk carrier of 70,000 DWT. Their economic assessment was only focused on two alternatives of slow speed diesel installation and medium speed diesel installation. Some parameters that were included in their study are also taken in our study. One of the major differences with their study is that our study tackles the problem at the basic design process allowing the optimization process to determine the ship's main dimension and its machinery characteristics within the given constraints.

This paper proposes an alternative method for optimizing marine designs, particularly in determining ship's main dimension and its power requirement at basic design stage. Spreadsheet modeling is utilized and non-linear programming (NLP) can express our problem. The Generalized-reduced gradient (GRG) method can work in conjunction with the NLP problems. Basic diagrammatic concepts of the optimization process and a case study are also given comprehensively

2. Premium Solver Platform and the basic optimization model

The determination of ship's main dimensions and its machinery power requirement encounters many constraints and considerations in its synthesized process (Sen, 1998). A number of methods are available to solve the multi constraints and multi variables optimization problem such as those are summarized in (Rao, 1991).Furthermore, the optimization of ship's design can be defined as an attempt to resolve the conflicts of a design situation, in such a way that the variables under the control of the decision-maker take their best possible value.

Generally, a classic multiple constrained optimization problems can be represented as follows.

$$\textit{Find} \quad X = \left\{ \begin{array}{c} X_1 \\ \vdots \\ X_n \end{array} \right\} \qquad \text{which minimize/maximize } f(X)$$

Subject to constraints

$g_{(lb)i} \leq g_i(X) \leq g_{(ub)\,i}$ for i = 1,2,3,…,m and

$X_{(lb)j} \leq X_j \leq X_{(ub)j}$ for j = 1,2,3,…,p

where X is a vector of n variables and the function $g_1,\ldots,g_m$ all depend on X. *lb* and *ub* stand for low bound and upper bound respectively.

This paper employs the Microsoft Excel-PSP software (PSP) to deal with the above general expression of optimization problem. PSP combines the function of a graphical user interface (GIU), an algebraic modeling language and optimizers for linear, non-linear, and integer program. Each of these functions is integrated into the host spreadsheet program, which allows us to specify an objective function, constraints and other supporting features interactively. The PSP then makes the complete optimization model and produces the matrix form required by the optimizers. The optimizers itself employ the simplex (for LP model), the GRG (for NLP), and branch and bound methods to find an optimal solution and sensitivity information. For the LP problem, the focus of this model representation is the LP coefficient matrix. This is the Jacobian matrix of partial derivatives of the objective function and constraints with respect to the decision variables. In LP problems, the matrix entries are constant and need to be evaluated only once at the start of the optimization. On the other hand, in NLP problems, the Jacobian matrix entries are variable and must be recomputed at each new trial point.
Assuming linear model for a certain problem, the PSP uses a straightforward implementation of simplex method with bounded variables to find the optimal solution. For a NLP, the PSP uses the GRG method, as implemented in the GRG2 code (Ladson *et al*, 1978) & (Ladson *et al*, 1992). GRG requires function values and the Jacobian matrix, which is not constant for NLP models. The PSP approximates the Jacobian matrix using finite difference method.

The basic format of the offered optimization process is given in Figure 1. There are five folders within the optimization, namely the INPUT folder, EQUATION folder, CONSTRAINT folder, OUTPUT folder and the OBJECTIVE FUNCTION. The INPUT folder consists of all the parameters that are used in the entire optimization process. For a complex problem, such parameters can be classified into several directories, which will make fault identification easier.

All basic calculations of the optimization are located in the EQUATION folder. The result of each equation is continuously updated, since the process in the CONSTRAINT folder and the OUTPUT folder always affect the variables employed in the EQUATION folder.

The CONSTRAINT folder contains all considerations that must be satisfied and becomes the director of the optimization process. A minimum and a maximum value are set on each constraint to give the working area of the optimization. The optimum values are located in the center of the form. The determination of the minimum and the maximum values depend on the characteristics of the constraints.

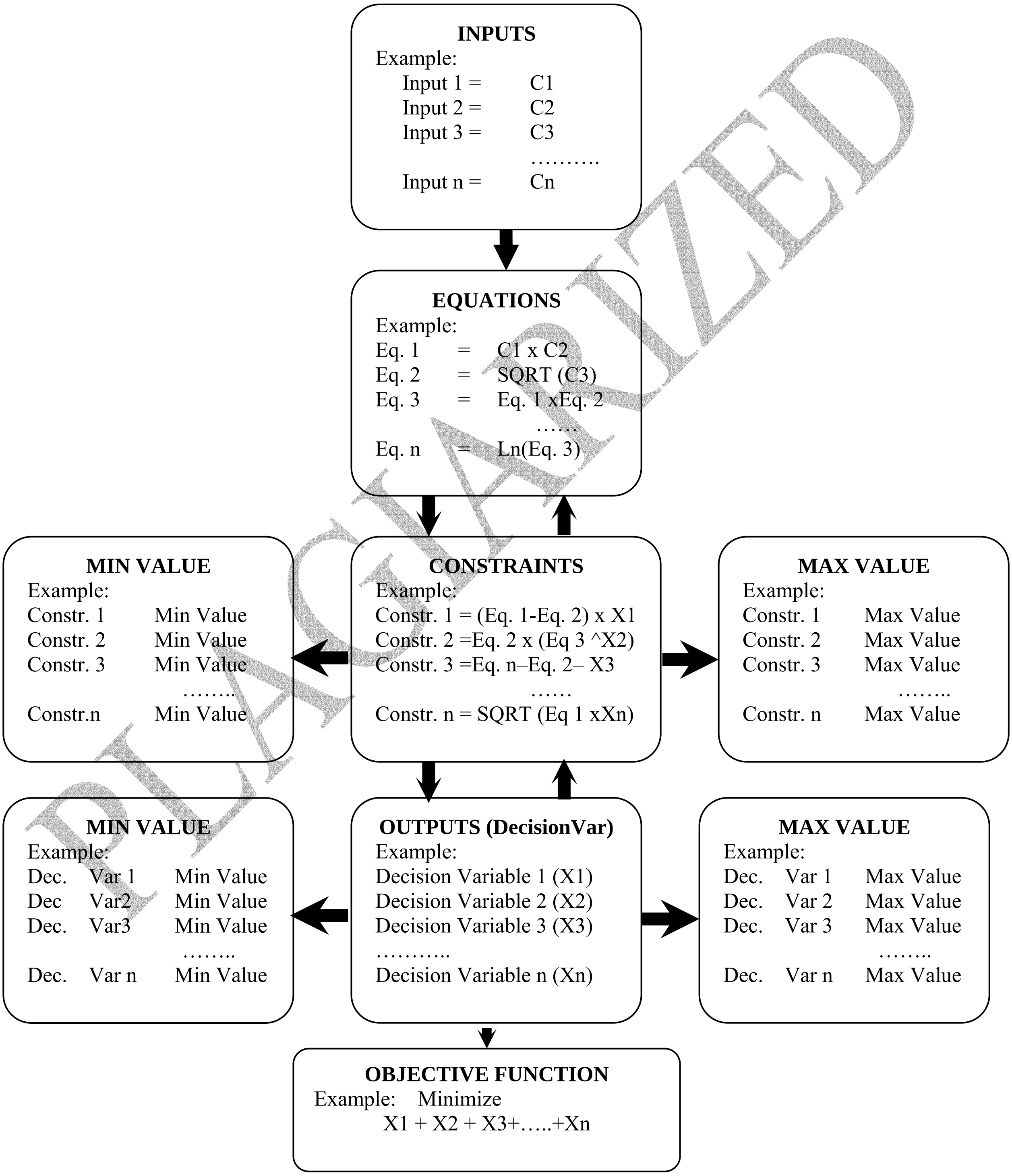

Figure 1: Basic format of the optimization process

3. Case Study: Basic Design Optimization Process For Tanker With Specified Throughput

3.1 Problem statement

At the basic design stage, it is required to design a numbers of series ships (tanker) delivering contract of a certain throughput, which have optimum main dimension and optimum specified power. ECT is utilized as the objective of the optimization problem. Port characteristics require such constraints, as the ship must not exceed 200m in length and 11m in draught. The conceptual problem is shown in Figure 2. Some economic data are employed during the optimization process, as shown in Table 1(Refer Appendix)

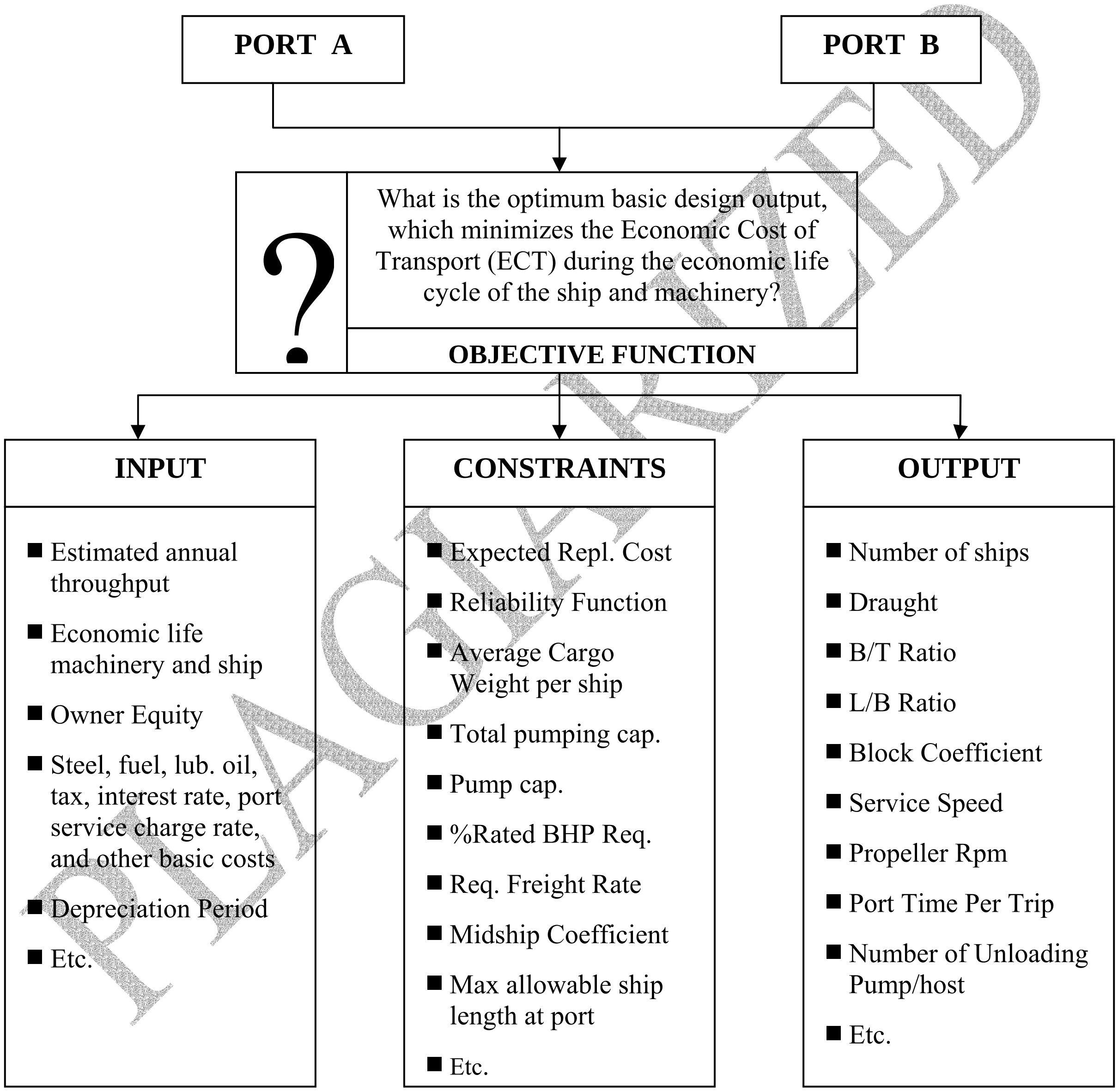

Figure 2: Problem statement

3.2. Model structure

To simplify the optimization problem, the INPUT folder and the EQUATION folder are grouped into several directories. In this particular optimization, the INPUT folder covers: the ship data, machinery data, and reliability data. Each directory represents collection of parameters that are used in the calculation process.

The EQUATION folder consists of several directories such as the ship coefficient, machinery, reliability, loading and unloading, fuel, operating cost and the economic considerations. The CONSTRAINT folder comprises of the expected replacement cost, reliability index, unloading pump capacity, specific fuel oil consumption (SFOC) for Maine Engine (ME) and and the maximum allowable ship length in port. The OUTPUT folder yields the optimum preventive maintenance interval, block coefficient, optimum design draught, optimum, B/T ratio, and the number of ships. These values are sought with the main objective to minimize the ECT of the ship. ECT, the objective for this particular optimization problem is composed by several variables, namely the required freight rate (RFR), the inventory cost of cargo and the annual tons of cargo carried (ATC) (Hunt *et al* ,1995).

The optimum value of RFR itself depends on the annual capital recovery of the vessel cost, the annual operating cost, and the annual throughput (Gransberg et al, 1998). The sequence of this design process indicates strict relationship among each design consideration.

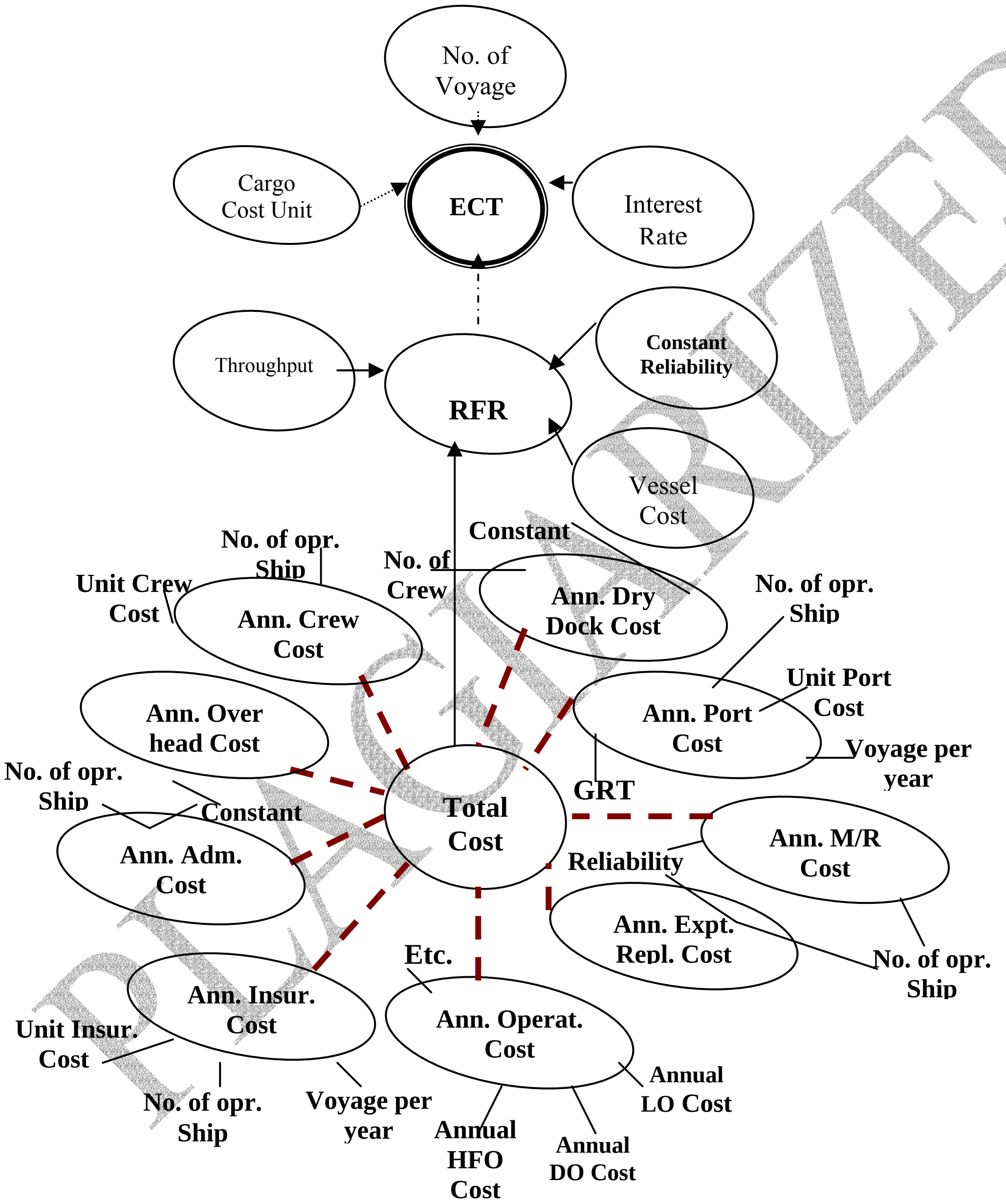

Figure 3: Interdependency between variables

For instance, it might be not a simple work to relate the optimum number of shore connection, which must be fitted on a tanker with the resulted RFR or outcomes of the loan repayment scheme. However, it is believed that those variables somehow interconnect and affect each other. Hence, the basic nature of ships and its machinery design optimization process would lie on the ability of the engineers to accommodate all of the design considerations and to provide adequate flexibility in altering the decision variables, while fulfilling the main objective of the optimization process.

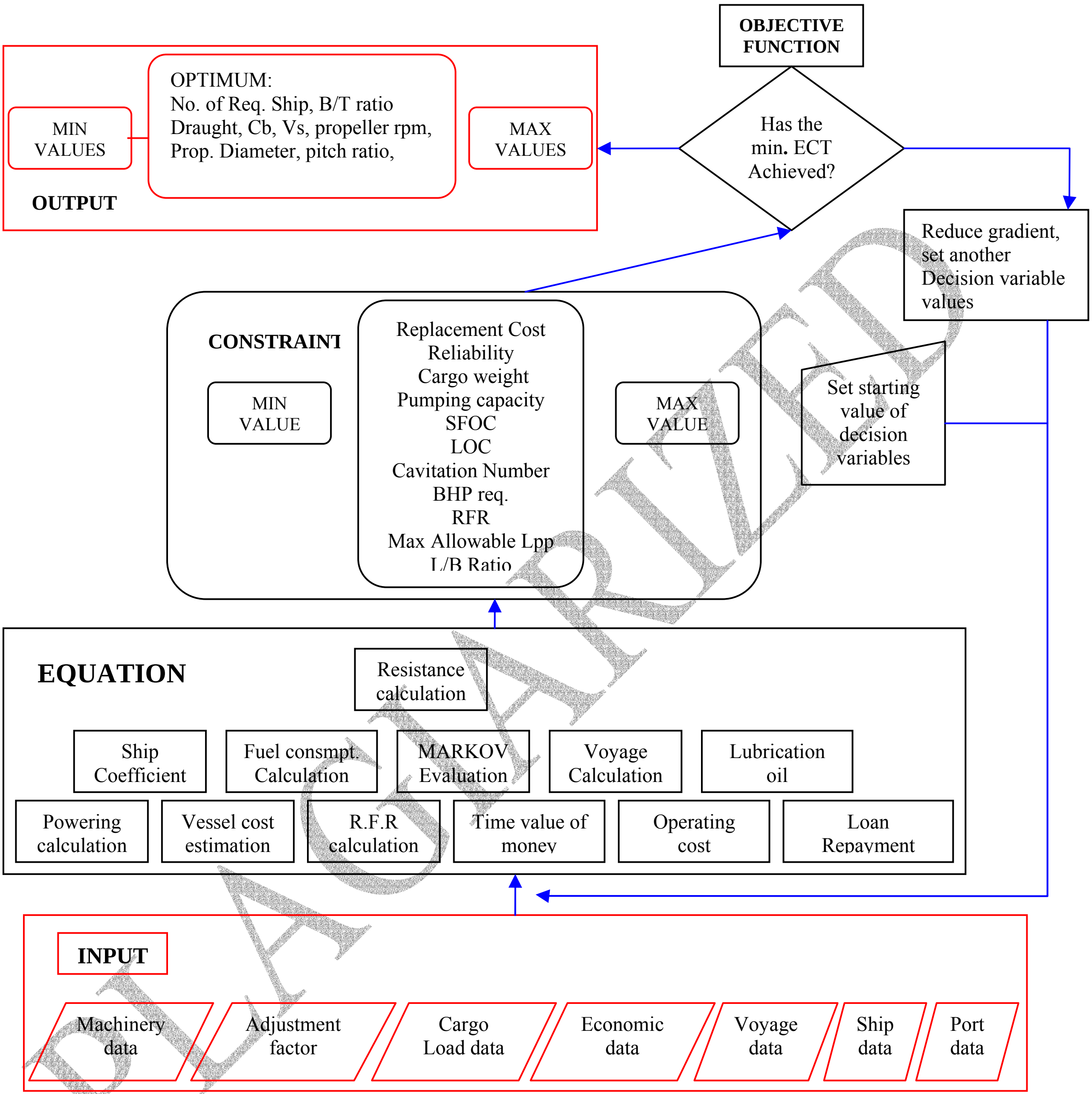

Figure: 4 Optimization Model Structure

Figure 4 shows the general structure of this optimization problem. The optimization process is commenced by setting the initial value of the decision variables. Using relevant basic parameters located in the INPUT folder, all basic calculations are executed in the EQUATION folder. The results are then exported to the CONSTRAINT folder to calculate all constraints accordingly.The optimization problem can be mapped as shown in Table 2 (Refer Appendix). The objective is to minimize f (X), which is the ECT while determining the optimum value of X1 to X12 subject to constraint g1 (X) to g16 (X) , (Refer Appendix Table 2). The basic ship design and ship resistance formulae are mainly taken form Clarke (1975), Oosterveld *et al (*1975, Harvald, (1983) & SNAME (1967) and the economic parameters and major assumptions related to cost calculation from Hunt et al , (1995) and Kiss (1992).

3.3. Further description of the directories

The INPUT folder consists of given parameters and grouped into several directories. The ship data directory takes the cargo density of 915 kg/m^3. Appendages factor, which influences the resistance calculation, is assumed to have value of 0.03. This directory also allocates the need to use a reduction gear for engine speed reduction. The machinery data directory allows the alternative of using either single main engine or multiple main engines. The model also provides flexibility in employing number of generator set. Their reliability model is assumed to be represented by Weibull distribution, and its related parameters (γ,β,η) must be defined accordingly. The Weibull analysis is then used to find the best period/interval to carry out the maintenance program. The unit cost of failure replacement and unit cost of preventive replacement is also assumed before the optimization process can be executed (Jardine, 1973) & (Rasmussen,1990). The voyage data directory is one of the vital directories in the optimization model. Optional trip distance and number of intermediate port make the model flexible. The assumed outbound and inbound load factors allow the model to be more realistic.

The economic data directory, as shown in Table 1 is gathered from many different sources and plays a very important role within the optimization model. The annual adjustment factor provides more realistic calculation of the operating cost.

The EQUATION folder is also divided into several directories. The coefficient and ship directory collects all equations for determining the main dimensions of the ship. Since such equations usually stand as empirical formula, then the interpolation process takes part when some values lie beyond the original range (Kiss, 1992). The determination of ship resistance and power prediction is carried out using Harvald power prediction method (Harvald Sv. AA, 1983). The propeller design and its cavitation prediction are based on the Wageningen *B-series propellers* (Clarke, 1975, Oosterveld *et al,*1975, Harvald, 1983). The vessel cost director y allows us to perform a basic hull cost, outfit cost, machinery cost and estimated overhead cost (Hunt *et al, 1995). The* SFOC-Speed-Power directory estimates the optimum percentage of rated BHP to be used during the service condition. The reliability directory determines failure rate, reliability and unreliability of the main engine based on the given Weibull parameters. This directory also estimates the expected length of operating hours before failure cycle. The number of voyage per year, which strongly influences the ECT, is optimized in the trip per year directory. The Fuel and lubricating oil directory estimates the annual fuel and lubricating oil requirement. Since the model does not refer to any particular engine, the calculation is then made empirically. The operational cost directory determines the annual operational cost for all ships. Because the investment scheme also affects the value of the optimized ECT, the loan repayment directory and the time value of money directory are then allocated to give flexibility for determining the preferred investment scenario.

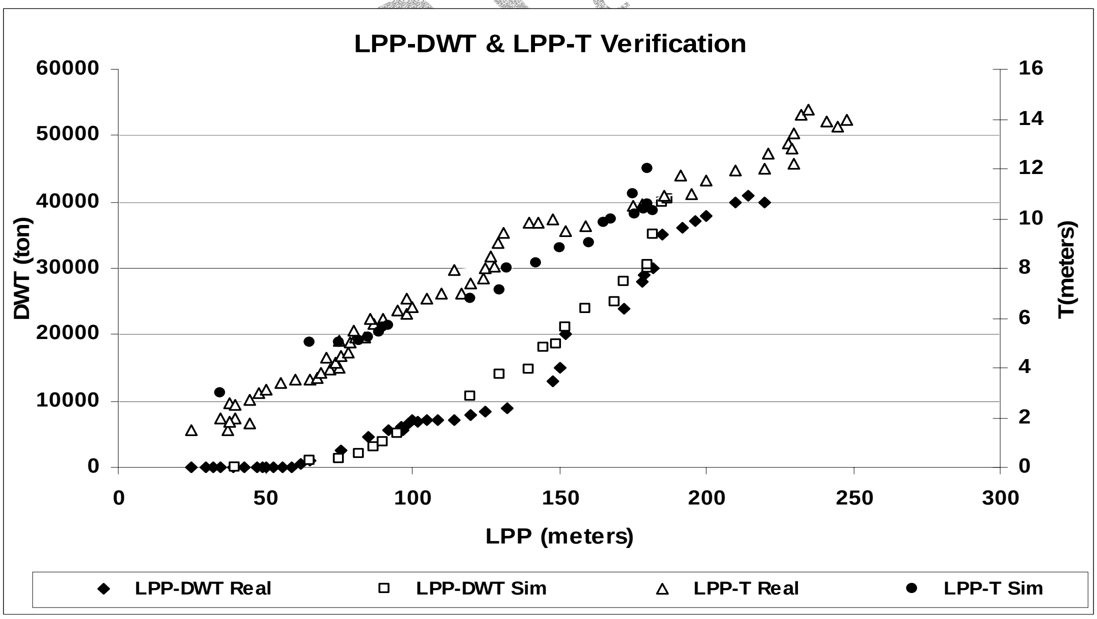

Figure 8: LPP-DWT & LPP-T Verification

3.5. Results verification

To verify the performance of this optimization program, comparison on BHP, DWT, and T (draught) has been made on several tanker data (obtained from different shipping companies). The comparisons are shown in Figure 8 and 9. Generally, it is observed that the results of the simulation very closely conform to the real data.

At some points the optimization result drastically shifts to a new point. This is caused by any adjustment made to the optimization program, which is different from that of the previous one. For instance, if the throughput is less than 300,000 ton, then we could set the maximum cargo carrying capacity of the constraint at the value of 25,000 ton. Once we increase the throughput, the optimization cannot produce optimum results, until we increase the maximum value of the cargo carrying capacity.

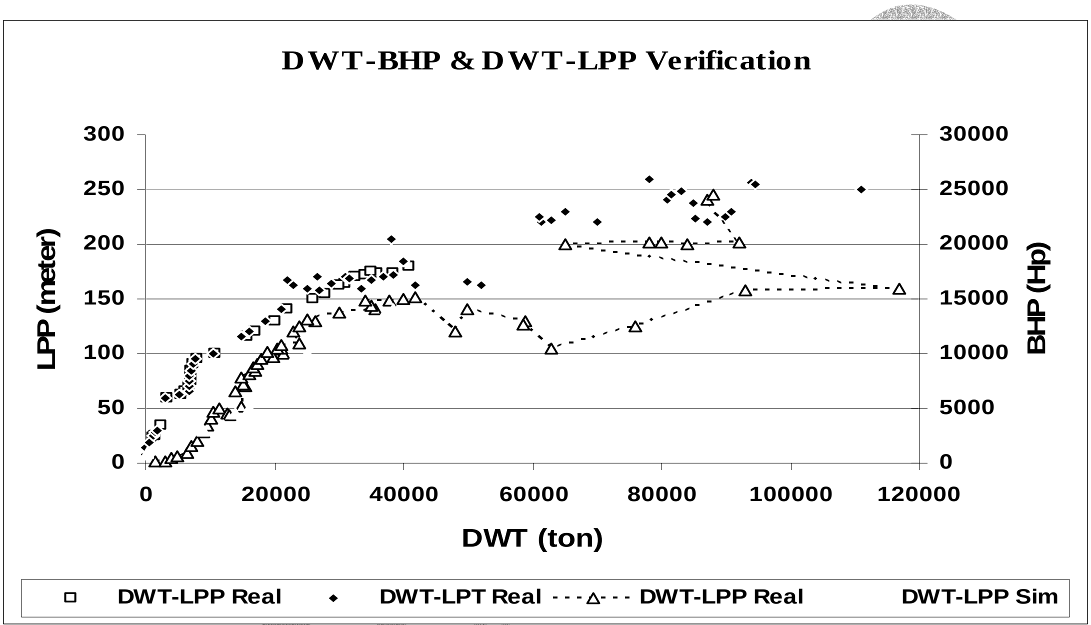

Figure 9: DWT-BHP & DWT-LPP Verification

4. Conclusion

For basic design stage or feasibility study purposes, this method could be employed before commencing any further design stage. The case study presented here shows how this optimization program can effectively and precisely become consistent with the real ship's design. Moreover the most challenging part of the optimization problem is to express the problem in mathematical expressions which can be executed by the PSP.

The ship main dimensions and its power requirement that are obtained through this method can be further traced down into a more detail analysis to design the machinery system on board. Additional task can easily be added within the optimization program by inserting a new directory within the INPUT and the EQUATION folder. Associated constraints and expected output can be attached with the objective either to minimize or to maximize the objective function. This kind of optimization process can also be utilized to select marine machinery from a certain number of available alternatives or to determine maintenance management scheme, as utilized by authors in reference (Artana KB *et al*, 2000, 2001)

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Appendix

Table 1 : Economic data input*

Economic life of machinery	Years	20.00
Loan repayment period	Years	20.00
Interest rate	%	0.10
Rate of return on equity	%	0.12
Economic life of ship	Years	20.00
Ship depreciation period	Years	15.00
Machinery depreciation period	Years	15.00
Tax rate	%	0.30
Annual inflation rate	%	0.01
Average fuel price (HFO/DO)	US$/lb.	0.08
Average crew cost per month	US$/month	1,250.00

* Source: mainly obtained from Reference (Hunt *et al ,1*995)

Table 2: Optimization statement

Find

X_1	Min value	$\leq$	Time (t) independent variable	$\leq$	Max. value
X_2	Min value	$\leq$	Number of ships	$\leq$	Max. value
X_3	Min value	$\leq$	Draught	$\leq$	Max. value
X_4	Min value	$\leq$	B/T ratio	$\leq$	Max. value
X_5	Min value	$\leq$	Block coefficient	$\leq$	Max. value
X_6	Min value	$\leq$	Service speed	$\leq$	Max. value
X_7	Min value	$\leq$	Propeller rpm	$\leq$	Max. value
X_8	Min value	$\leq$	Diameter propeller	$\leq$	Max. value
X_9	Min value	$\leq$	Pitch ratio	$\leq$	Max. value
X_{10}	Min value	$\leq$	Time required for preventive replacement	$\leq$	Max. value

X_{11}	Min value	$\leq$	Port time per trip (loading)	$\leq$	Max. value
X_{12}	Min value	$\leq$	Number of unloading pump/host	$\leq$	Max. value
Which minimizes: Economic Cost of Transport (ECT) (f(X))					
RFR	Total cost		Annual port cost *f* (unit cost, grt, voyage per year, no. of operated ship)		
			Annual insurance cost *f* (voyage per year, weight of cargo, unit insurance, no. of ship)		
			Annual overhead cost *f* (constant, no. of ship)		
			Annual crew cost *f* (unit of crew cost, no. of crew, no. of ship)		
			Annual expected replacement cost *f* (reliability, no. of ship)		
			Annual m/r cost *f* (reliability, no. of ship)		
			Annual dry docking expenses *f* (constant, no. of ship)		
			Annual administration cost *f* (constant, no. of ship)		
			Annual operating cost *f* (lo cost, do cost, hfo cost, etc)		
Owner equity			Constant		
Throughput			Given		
Cargo cost unit			Constant		
Number of voyage			Operating day *f*(docking days, unscheduled maintenance days, time at port)		
			Turn round time		
Interest rate			*Constant*		
Subject to					
$g_1(X)$	Min value	$\leq$	Exptd. replacement cost, *f*(Reliability index,Cost of fail. rep,Cost of Prev. rep)	$\leq$	Max. value
$g_2(X)$	Min value	$\leq$	Reliability function, *f*(failure distribution parameters)	$\leq$	Max. value
$g_3(X)$	Min value	$\leq$	Ave. cargo wt./ship, *f*(throughput,No. of ship, voy./ year,Load factor)	$\leq$	Max. value
$g_4(X)$	Min value	$\leq$	Total pumping capacity, *f*(Pump capacity, No. of req. pump)	$\leq$	Max. value
$g_5(X)$	Min value	$\leq$	Pump capacity *f*(Cargo weight, Port time, Cargo density)	$\leq$	Max. value
$g_6(X)$	Min value	$\leq$	SFOC for full load ME *f*(DHP, engine rpm)	$\leq$	Max. value
$g_7(X)$	Min value	$\leq$	SFOC for full load GE *f*(DHP, diesel generator rpm)	$\leq$	Max. value
$g_8(X)$	Min value	$\leq$	Cavitation no *f*(THP,Projected Blade Area(Ap),dyn. press. at tip radius)	$\leq$	Max. value
$g_9(X)$	Min value	$\leq$	Local cavitation no. *f*(press. at the screw centerline, dyn.press. at tip radius)	$\leq$	Max. value
$g_{10}(X)$	Min value	$\leq$	%Rated BHP requirement *f*(min resulted SFOC at feasible region)	$\leq$	Max. value
$g_{11}(X)$	Min value	$\leq$	Required freight rate *f*(Ann.Vessel cost,total opr.Cost, throughput)	$\leq$	Max. value
$g_{12}(X)$	Min value	$\leq$	Midship coefficient *f*(Displacement, Breadth, Draught, Lpp)	$\leq$	Max. value
$g_{13}(X)$	Min value	$\leq$	L/B ratio *f*(Lpp/Breadth)	$\leq$	Max. value
$g_{14}(X)$	Min value	$\leq$	Max allowable ship length at port *f*(Vol.Displ,Breadth,Draught,Block coef.)	$\leq$	Max. value
$g_{15}(X)$	Min value	$\leq$	Length of water line (LWL) *f* (LOA)	$\leq$	Max. value
$g_{16}(X)$	Min value	$\leq$	Length between perpendicular (LPP) *f* (LWL)	$\leq$	Max. value