SHIP TECHNICAL CHARACTERISTICS AND FLEET PERFORMANCE AND ECONOMICS

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Abstract: The development of a fleet simulation model is discussed. The model brings together in a comprehensive manner the relationship between ship principal dimensions, hull form and speed on the one hand and fleet performance on the other. Fleet performance is measured by the Required Freight Rate (RFR), the freight income needed per unit of cargo to cover all operating costs and to provide the rate of return on the capital invested in the ship. By systematically varying ship technical characteristics and using the model to calculate the RFR for any given set of characteristics, sets with low RFR values may be determined, from which may be chosen the most desirable set. The process involves the determination of technical feasibility for any given set of technical variables followed by the calculation of costs and RFR. For purposes of demonstration a numerical example involving a 900 TEU and an 1100 TEU containership in the same trade route is worked out.

Key Words: ship, containership, fleet, RFR, economics

1. FLEET SIMULATION STUDY

Essentially a fleet simulation study may be employed to select the number of ships, ship type, endurance, payload and speed which best satisfy a given transport demand. A common measure of merit is the so-called Required Freight Rate (RFR), the freight rate at which the Net Present Value (NPV) of all costs equals the NPV of all revenues. The lower the RFR the better.

A usual approach to finding the best combination of the major variables is to systematically vary these variables, compute the figure of merit for each combination and then compare. This method is commonly known as the *systematic variation of parameters* or simply *parametric study*.

A possible search scheme for the best fleet is as graphically depicted in figure 1. In this figure, **N** = number of ships, **V** = velocity, **L** = ship length, **B** = ship breadth, **D** = ship depth, **T** = ship draft and **Cb** = block coefficient. It may be noted that for each combination of payload and speed there is not one but many feasible sets of ship dimensions and other technical characteristics. It is evident from the figure that in order to see how ship technical characteristics qualitatively affect fleet economics it is sufficient to walk through the process

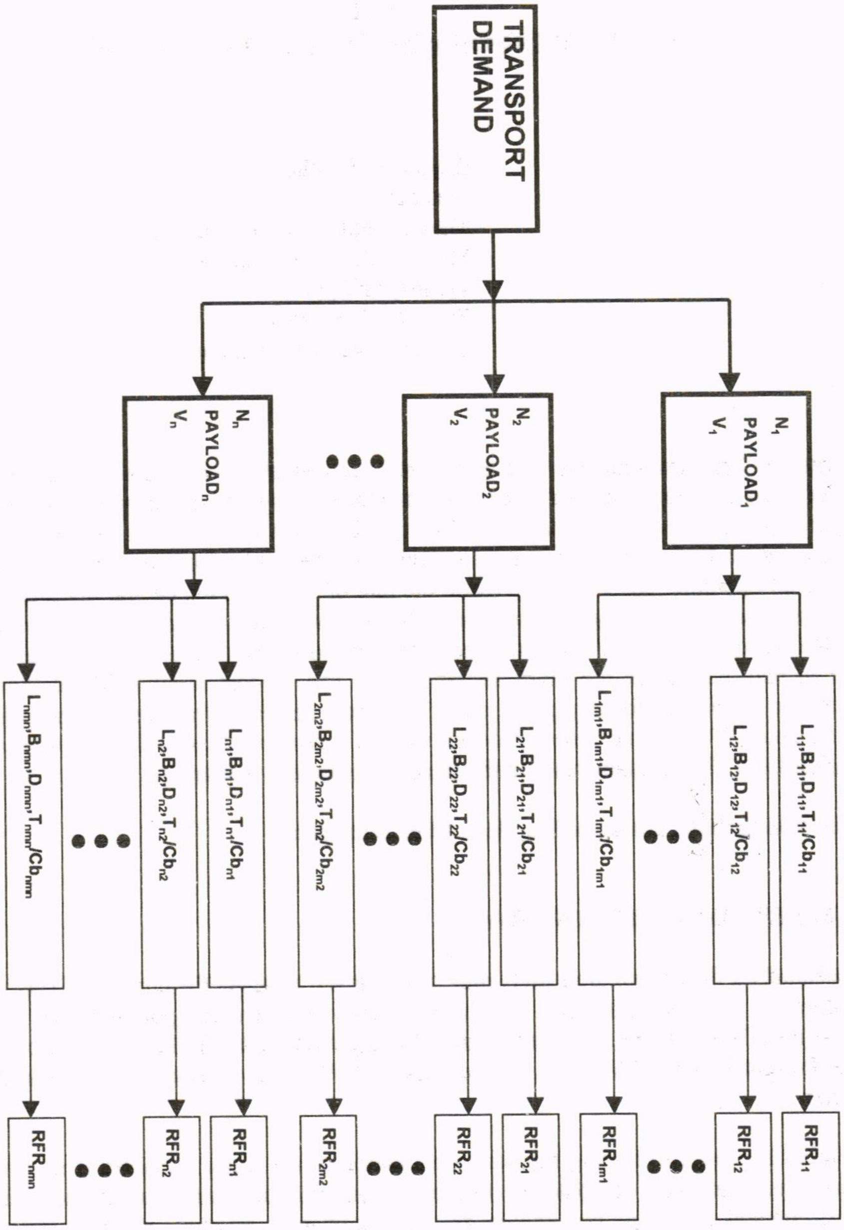

Figure 1. Parametric Study

involved in arriving at the RFR from only a single given set of ship characteristics. The process involves determining the technical feasibility of the assumed ship characteristics and then, once technical feasibility is established, calculating the associated costs and RFR.

In this paper a mathematical model for containerships is studied. It is thought to be indicative of the relationships of the variables for other ship types as well. Section 3 gives the forms of some of the empirical mathematical relationships used in the model. The other mathematical relationships are based on various standard means of calculations, such as, for example, the estimation of ship resistance and powering.

It may be well to note that in the case of containerships the dimensions come in steps since container vans come in standard sizes. It must be noted as well that the number of ships come as integers. These two factors greatly affect the possible values for the other variables.

This study is confined to a few important technical characteristics, namely, **L**, **B** and **D** as well as either one of the two variables, **T** or **Cb**. The figures that follow omit items that are not related to these technical characteristics, such as, for example, some items of ship's weight.

2. TECHNICAL FEASIBILITY

2.1 Displacement and Engine Power

Under the technical feasibility portion, the initial hurdle is getting consistency in ship displacement and engine power. There exists a cycle of interdependence of displacement and powering. Ship resistance, and therefore engine power, is a function of the volume of displaced water, the draft and the block coefficient. In other words, resistance depends on displacement. In turn, displacement is a function of machinery weight and fuel oil weight, which both depend on engine horsepower. The vicious cycle is broken with an iterative approach as shown in figures 2 & 3. A very rough estimate of ship displacement is initially employed. From this estimate comes a powering estimate from which in turn follows a new displacement estimate. In the first iteration this new displacement estimate would in all probability be at significant variance from the initial estimate. The new displacement estimate is used in place of the initial estimate and the process repeated until there is convergence in the value of displacement. Failure to converge would be an indication of infeasibility of the inputted ship dimensions and other characteristics.

In figure 2, **CN** = cubic number = L*B*D/100, **VCG** = vertical center of gravity, **K** = elevation of keel, **B** = elevation of center of buoyancy, **G** = elevation of center of gravity, **M** = elevation of metacenter, **GM** = metacentric height.

It may be noted from figure 2 that L, B, D, T, and Cb affect displacement, power and stability in a complicated manner. Tracing all the arrows that emanate from any one of these ship characteristics shows how each simultaneously affects various independent items that further interact with one another. Figure 3 gives a greater level of detail than figure 2. In this figure **R** = ship resistance; **Rn** = Reynold's number = VL/μ, where μ = the kinematic viscosity of sea water; and **Fn** = Froude number = $V/\sqrt{(g * L)}$ where **g** = the acceleration due to gravity;

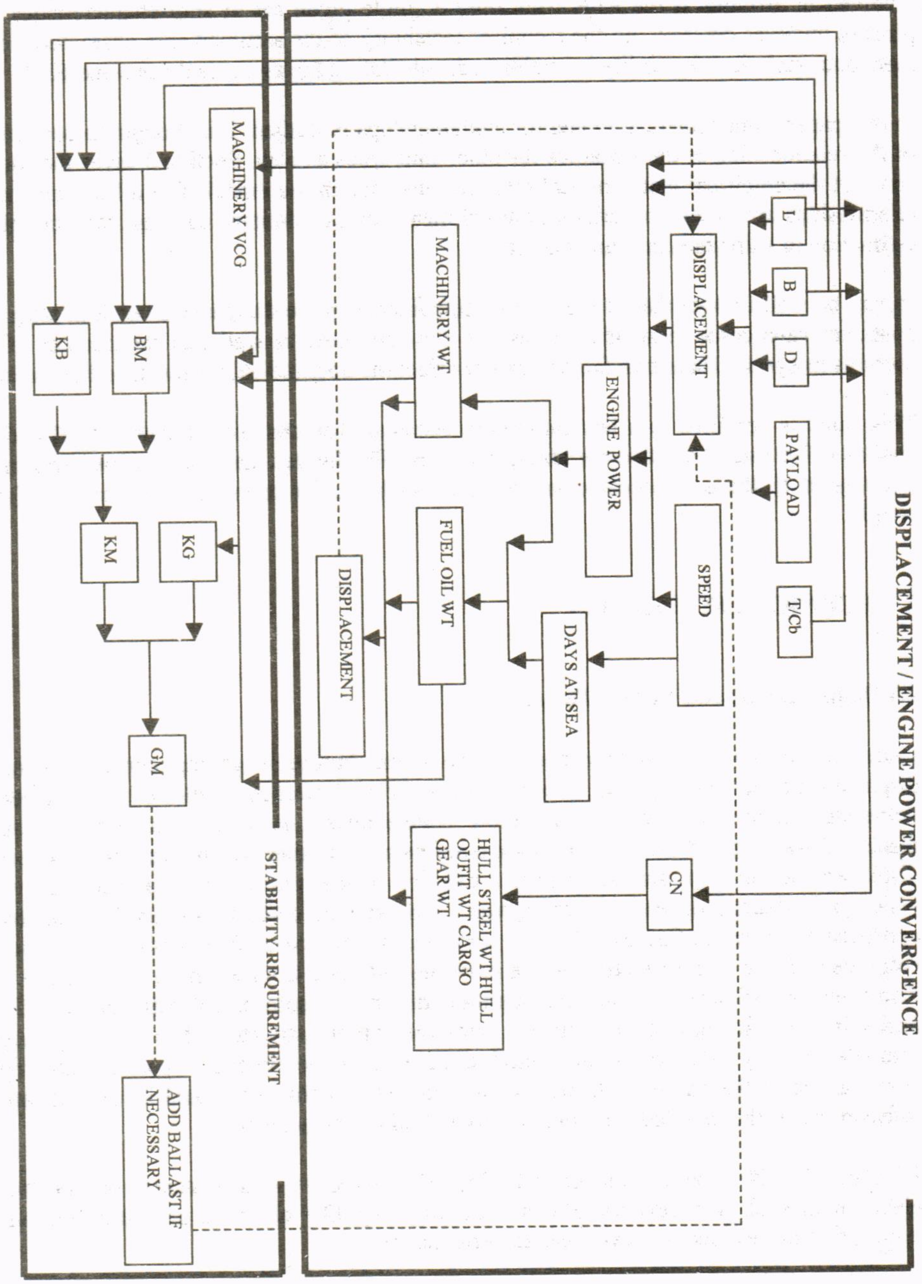

Figure 2. Technical Feasibility

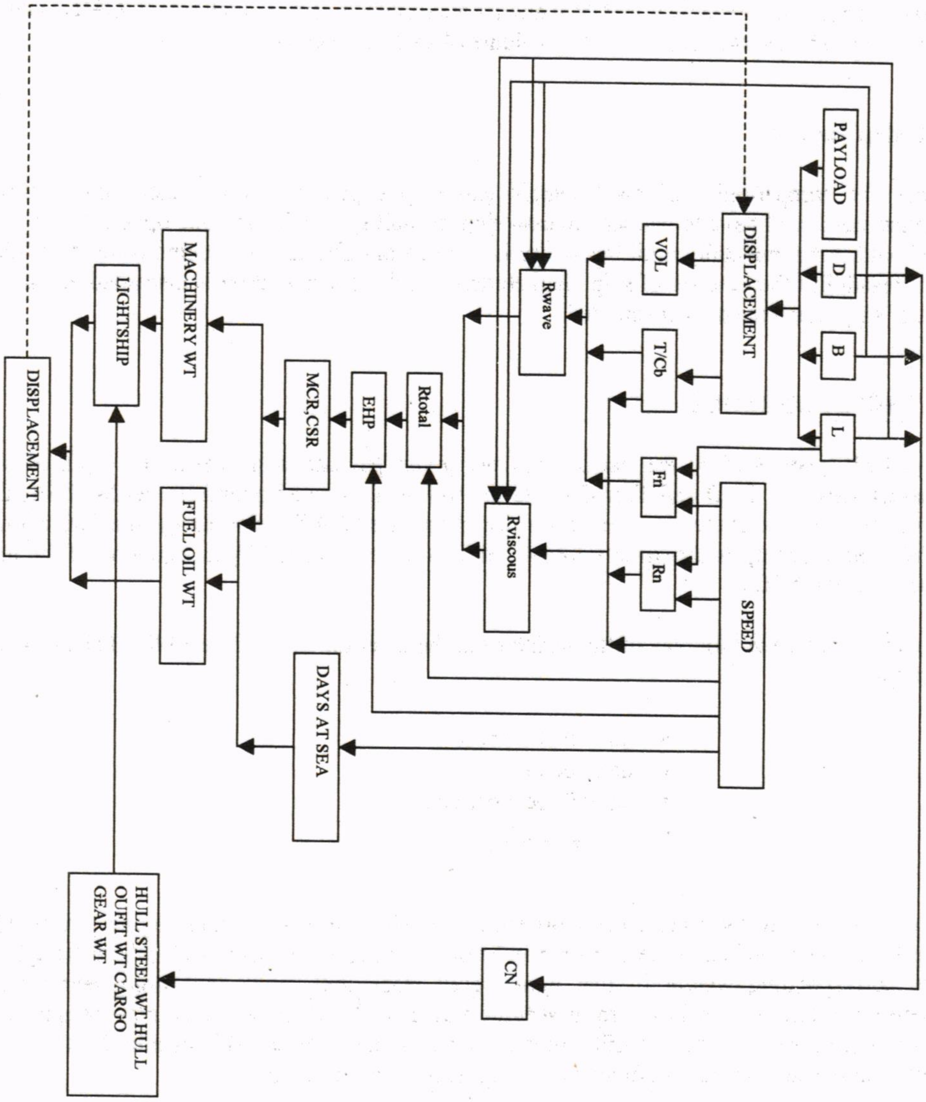

Figure 3. Displacement and Engine Power

EHP = effective horsepower; **MCR** = engine maximum continuous rating and **CSR** = engine continuous service rating; and **VOL** = volume of ship displacement.

2.2 Ship Stability

Once the compatibility of displacement and engine power is established, ship stability requirements will have to be met. In case ship instability is indicated one option would be to add ballast incrementally until feasibility is attained or infeasibility is demonstrated. If there is infeasibility then the set of ship characteristics under consideration is discarded and a new set of ship characteristics considered.

3. SHIP ECONOMICS

The RFR may now be estimated from the given payload and speed; the inputted ship characteristics L, B, D and T or Cb; and the following derived quantities: MCR, CSR, CN, gross registered tonnage (**GRT**) and deadweight tonnes (**DWT**). For clarity, the derivation of DWT and lightship is shown in figure 4. GRT may be estimated by an equation of the form coefficient*CN*Cb.

Figure 5 shows the interplay of the variables in the determination of the RFR. It shows 4 cost groups:

- construction costs
- daily costs
- capital recovery costs
- voyage costs.

The construction costs are chiefly dependent on ship dimensions and engine power. Hull steel, hull outfit and cargo gear costs may be put in the form **α (weight)** $^{\beta}$, where "weight" is the corresponding weight of that item. Hull steel, hull outfit and cargo gear weights themselves may be put in the form **γ(cubic number)** $^{\delta}$. Machinery cost may be put in the form **ε (MCR)** $^{\zeta}$. Owner's outfit cost may be put in the form **η(cubic number)**. The Greek letters above are various coefficients derived from empirical data.

It may be noted that the ship dimensions are lumped together under one variable, the cubic number. At a later stage of ship design the separate effect of each ship dimension on construction costs may be appropriately modeled.

The maintenance and repair (M & R) costs for hull and outfit depend primarily on ship dimensions. The M & R costs for the engine depend on operating hours which in turn is a function of ship speed and payload. Stores and supplies depend on operating hours and engine power. Drydocking and survey fees depend on the ship's DWT.

The daily costs in part depend directly on construction costs because the items of ship insurance are dependent of total ship price, with the exception of P & I insurance which depends on GRT.

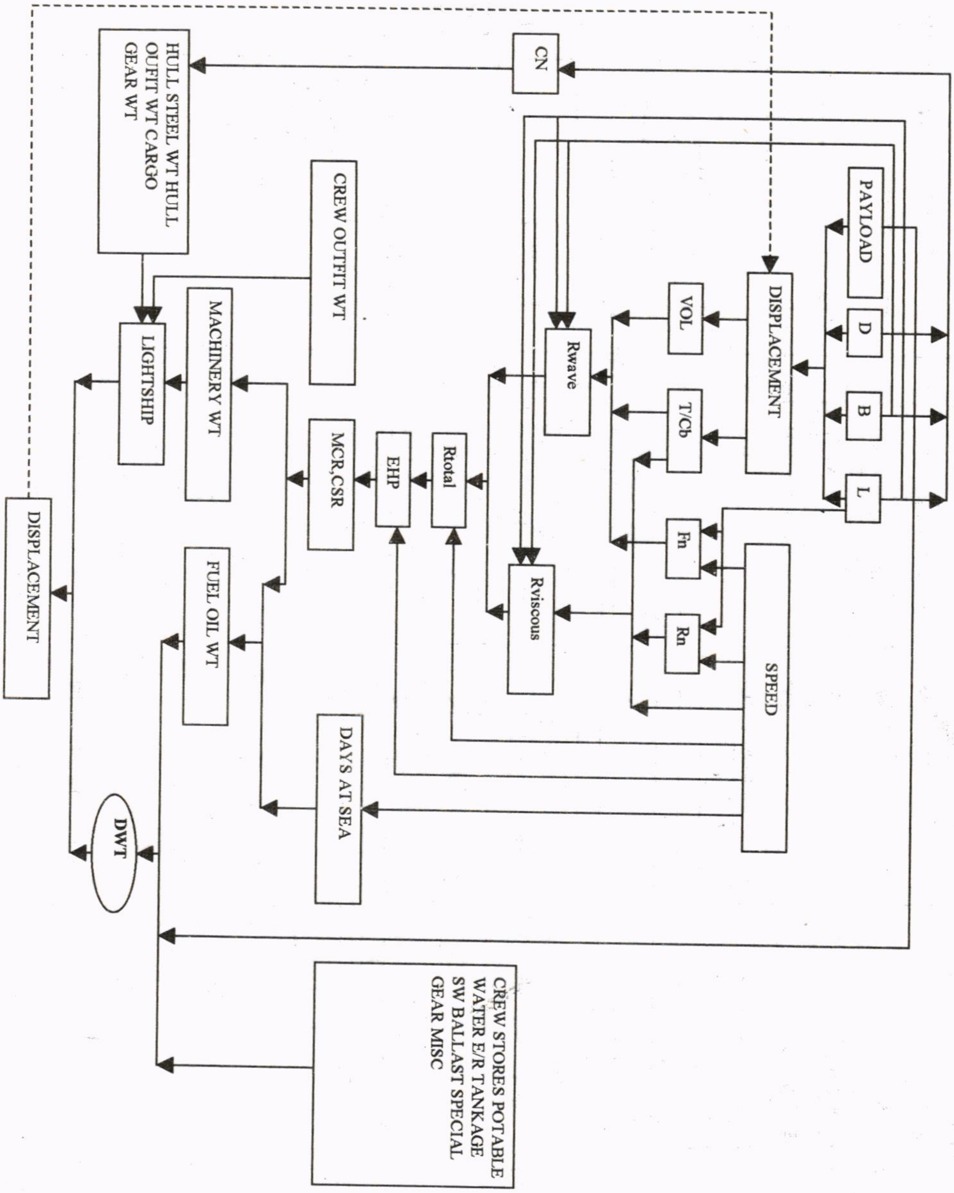

Figure 4. Variables in DWT

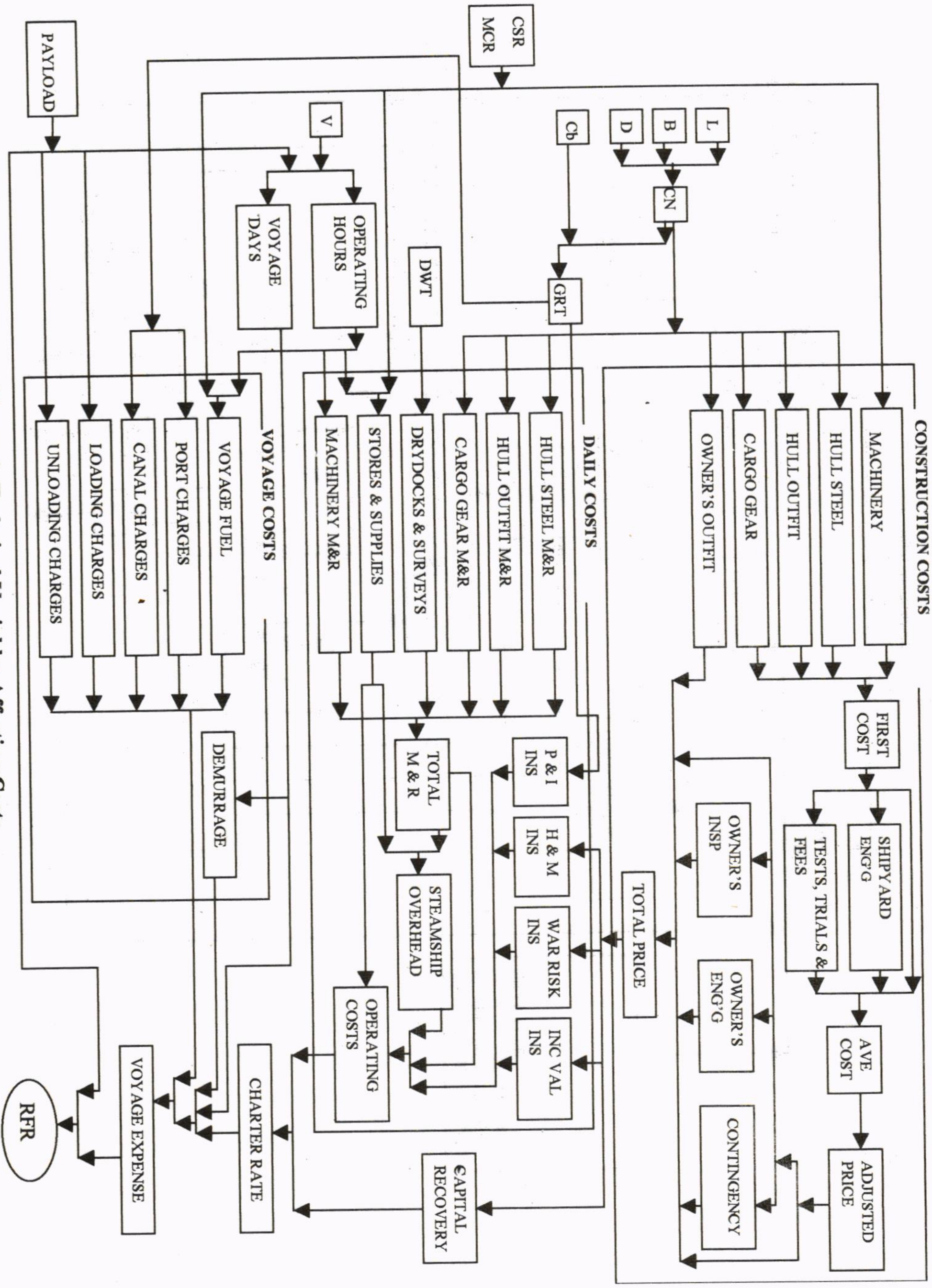

Figure 5. Technical Variables Affecting Costs

Capital recovery costs are totally dependent on construction costs.

Voyage fuel is dependent on operating hours and engine power. Demurrage is determined by voyage days. Port and canal charges are determined by vessel size through GRT. Loading and unloading charges depend on payload.

The capital recovery and daily costs directly determine the charter rate, which together with voyage costs, gives the voyage expense.

The obvious manifestations of the interrelatedness of the cost groups can be found in the direct effect of total ship price on daily and capital recovery costs. In a larger sense, however, the interrelatedness can be traced back to the technical variables themselves. Changing length and engine power, for example, causes changes in all cost groups. Viewed this way, the web of interrelatedness can be considered to be complex. This fact simply underlines the importance of being very mathematical at this stage of the selection of ship technical characteristics without neglecting the significance of intuition, experience and judgment.

4. NUMERICAL EXAMPLE

4.1 Variation in the Search Process

If the process in figure 1 were to be fully implemented, an entire universe of choices will have to be considered. For purposes of demonstration and in order to highlight the part of the process involving the determination of RFR from a given set of ship technical characteristics, only a small number of choices will be studied in this numerical example. A slight variation in the search process outlined in figure 1 is effected. First of all, the voyage mileage is fixed. Secondly, two ship sizes, or payloads, are considered. Next, a set of ship dimensions is chosen for each payload and then the optimal speed for each ship size, corresponding to the point of lowest RFR, is determined. Lastly, assuming the same annual throughput requirement, or transport demand, the ratio of the number of ships necessary for one ship size to the number of ships necessary for the other is determined. This approach will obviously not yield a global optimal, but it shows how to work within the search scheme in order to determine and compare some acceptable or even good values.

4.2 Speed, Revenues and Expenses

Payload and expenses are assumed to be uniform across all voyages so that RFR is simply voyage expense divided by the payload. Increasing the speed will result in more voyages annually and greater revenue. However, the expenses also increase to the same degree. Based on the assumption of uniformity of payload and expense across all voyages, therefore, the determination of RFR based on a single voyage gives a valid basis for the comparison of alternative speeds for a given ship.

4.3 Sample Ships

The round trip distance is fixed at 13,780 n.m. Two sizes of ship, 900 and 1100 TEU, are considered. The choice of these payloads is based on experience. The 900 TEU vessel is given the following dimensions: L = 140.5 m, B = 21.7 m and D = 11.7 m. The 1100 TEU ship is given the following dimensions: L = 147 m, B = 24.2 m and D = 12.2 m. These dimensions are determined by making rough scale drawings of the ship with containers arranged in the holds and on the deck. The speed for the 900 TEU ship is varied and the RFR calculated for each speed. In this manner the optimal is found. The same is done for the 1100 TEU ship. The results for both ships are compared.

The variation of block coefficient Cb in the mathematical model follows the variation of ship speed V according to the relationship between Froude number Fn and Cb shown in figure 6 which is based on Taggart (1980). This relationship was developed from experience with economically successful ships.

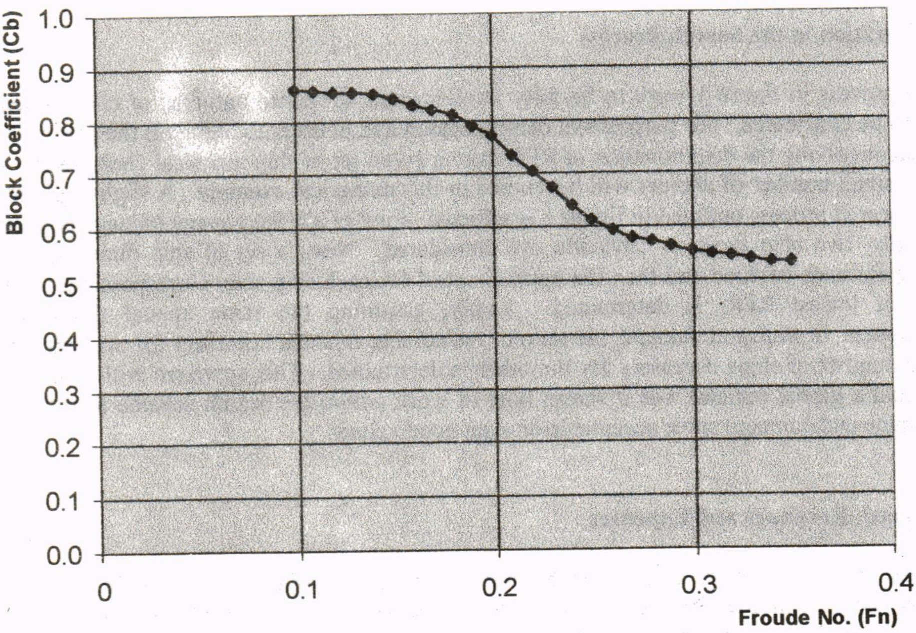

Figure 6. Fn vs Cb

The results are shown on tables 1 and 2 for the 900 and 1100 TEU vessels, respectively. It shows an optimum speed of about 14 knots for the smaller ship with an RFR of 70.86 $/tonne. For the bigger ship the optimum speed is about 16 knots with an RFR of 63.33

tonne. The ratio of the number of 900 TEU ships to the number of 1100 TEU ships to achieve the same annual cargo throughput is 1.4. Obviously the bigger vessel is preferred in this case.

Table 1. Optimal Speed of a 900 TEU Containership

CASE	Cb	V (knots)	RFR ($/t)
1	.810	13.0	71.21
2	.776	14.0	70.86
3	.755	15.0	71.00
4	.722	16.0	71.72

Table 2. Optimal Speed of an 1100 TEU Containership

CASE	Cb	V (knots)	RFR ($/t)
1	.750	15.0	63.87
2	.710	16.0	63.33
3	.665	17.0	65.02
4	.620	18.0	65.03

5. CONCLUSION

This paper shows the development of a fleet simulation model that can be used to determine the effect of ship technical characteristics on fleet performance. It shows that the level of interrelatedness among the variables is very complex but not necessarily intractable. Experience can help narrow down the universe of choices of ship characteristics. But a mathematical approach, based on a valid model and implemented by a computer, is necessary in order to pinpoint the optimum because of the complexity of the relationships.

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