INNOVATIVE SHIP DESIGN

Can Innovative Ships be designed in a Methodological Way?

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ABSTRACT

The most common way to describe ship design has been the spiral model, capturing the sequential and iterative nature of the process. The task structure is “design-evaluate-redesign”. This model easily locks the naval architect to his first assumption and he will patch and repair this first and only design concept rather than generate alternatives. An approach that better supports innovation and creativity must be used. The design should start from the mission specified for the ship, define the functions needed to perform the task and base the different solutions on this system description. There are two types of input data, demands that must be followed and preferences that describe goals. Dividing the requirements into “musts” and “wants” makes it easier to find alternative solutions and find a technically feasible and economically preferable solution.

Figure 1: Development of ship concepts

1. CREATIVITY IN SHIP DESIGN

1.1 Theory of technical systems

In their book ”Theory of Technical Systems” Vladimir Hubka and Ernest Eder describe the base for technical systems and the benefits of system thinking in the design work of complex products. The essentials of the system thinking they summarize as follows (Fig 2).

- **The theory of technical systems delivers the relationships that are valid for all products**
- **System thinking presents an opportunity to treat problems as a whole**
- **This is a necessary pre-condition for a successful design and engineering effort**
- **System thinking provides a framework for the design task and formalize many logical operations**
- **Use of computers during the design process depends on formulating algorithms for those design operations, where logical treatment is possible**
- **System thinking also supports those human operations, that are not strictly logical, like intuition and creativity**

Figure 2: System thinking

Their thinking can be of much help also in ship design, especially in the development of new, novel solutions (Fig 1). The ship must perform many different functions, which all can be described as an individual system, but integrated into the “total” ship function. By defining each function and the requirements for performing this function we get a framework for the ship design task. This can be called “System Based Ship Design”. By adding simple algorithms much of the ship design calculations can be “automated” and performed by computer. This automation of the design work makes it possible for the naval architect to spend more time on improving and evaluating the design and finding alternative solutions.

Mission ® Function ® Form ® Performance ® Economics

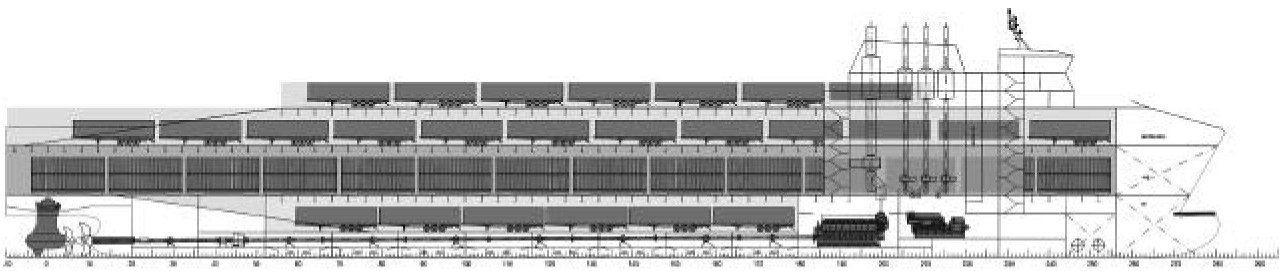

Figure 3: All ships consist of several, interacting systems

1.2 Creativity in the technical design work

To find new solutions we need creativity. Creativity could be described as the ability to recognize problems in an existing design, but also to see new possibilities to improve the product. There are always several applicable alternatives and solutions in the ship design work.

The only limit to our creativity in the design work is our imagination. But our creativity and imagination are limited to things we know of, human beings cannot create from nothing. The solution of a technical problem always requires relevant technical knowledge. If you want to be a creative naval architect you have to know both Archimedes, Chapman and Froude. Technical knowledge and skills alone do not ensure that a novel solution is found (Fig 4). We also need to learn some basic creative work methods to be successful in technical design.

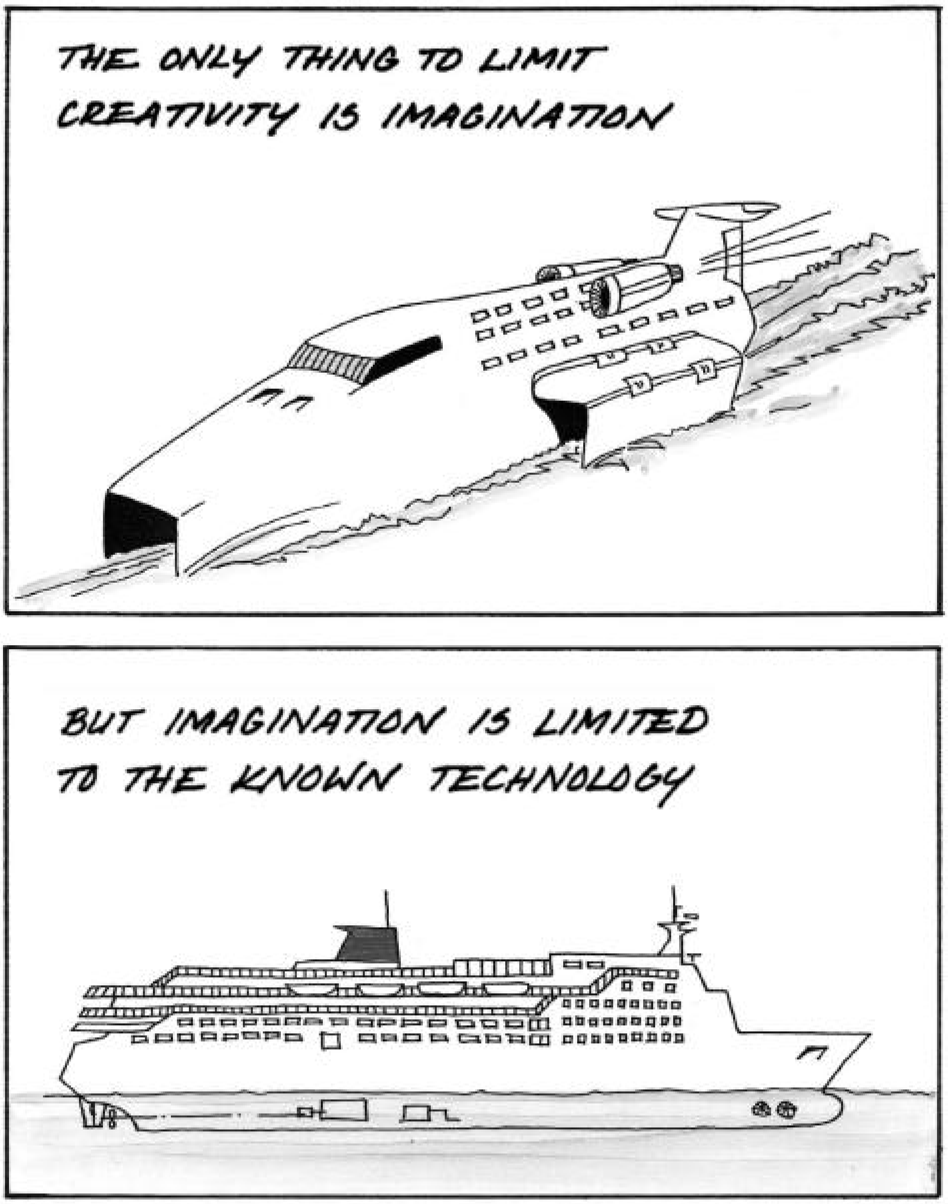

Figure 4: The base for creativity is knowledge

1.3 Design problems

Creativity is not always the right answer to the problems we meet in ship design. The tasks can be divided into three different types: analytical, synectic and selection problems (Fig 5).

Typical for analytical problems is that there is only one “right” answer to them. We can find this answer by means of conclusions, calculations and examinations. The teaching we get in schools is concentrating on the skills needed to solve analytical problems, like most tasks in mathematics, geometry and physics. In spelling , foreign languages, history and similar courses there is only one right answer, which we must learn from books or from the teacher. For solving analytical problems we need knowledge and skills, not creativity.

Synectics means identifying and solving problems that demand the combination of the skill and experience of several people. Here we need creativity, because we are searching for alternatives. For synectic problems there are more than one solution and we should try to identify as many as possible. Many alternatives increase the quality of creative work.

To find the best alternative is a problem of selection. The selection requires clear targets as a base for the comparison of the alternatives. These targets must be agreed upon by all involved in the creative design process. Targets can be different for the shipyard and the ship owner.

	ANALYTICAL PROBLEMS	SYNECTIC PROBLEMS	SELECTION PROBLEMS
QUESTION	WHY ? WHAT ? WHEN ?	HOW ?	WHICH ?
WHAT IS SEARCHED	CAUSES AND EFFECTS OF A PROBLEM	ALTERNATIVE SOLUTION	THE BEST ALTERNATIVE
CHARACTER OF THE PROBLEM	THERE IS ONLY ONE RIGHT SOLUTION TO THE PROBLEM	THE PROBLEM CAN BE SOLVED IN MANY PRACTICAL WAYS	THERE ARE SEVERAL ALTERNATIVES TO CHOOSE FROM
SOLUTION	CONCLUSION CALCULATION EXAMINATION	IDEAS	TARGET COMPARISON SCORING

Figure 5: Problem types

1.4 A Systematic Approach to Creativity

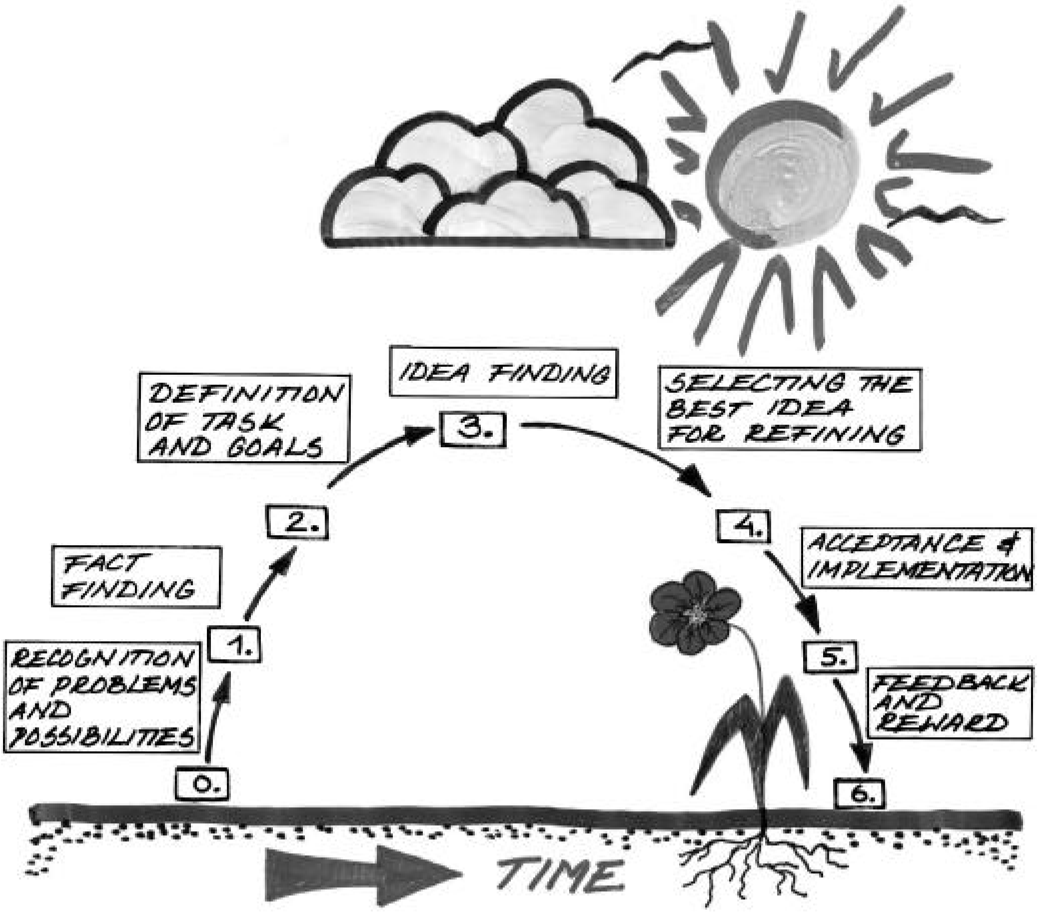

Figure 6: Steps in the creative design work

The actual idea generation is only one part of the creative problem solving process. The amount of work for this phase is also small compared to the preparation and finishing work phases, but idea generation in one form or another, is necessary for finding new and novel alternatives. The whole process includes the following work phases (Fig 6):

0. Recognition of problems and possibilities

The recognition of problems and possibilities starts the creative process in the design work. We must evaluate previous constructions and continuously look for more efficient, more practicable, more reliable or cheaper solutions. By following the technical development not only in naval architecture but also in other fields, we learn about new possibilities that can be adapted also in shipbuilding.

1. Fact finding

Previous designs should be checked by analysing the capacity, performance and economics and compare the data with other ships or competing means of transport. All information on costs are important, both building costs and operating costs. High material-cost items direct the ideas to the selection of material and suppliers. High labour costs require checking of the design itself, use of standard solutions or improved production facilities.

2. Definition of the task and the goals

The problem definition should be based on facts. The problem definition controls the whole searching of a solution and if the idea finding is done by several persons all members of the team must “understand” the problem in the same way. Now the goals for the task should also be stated, otherwise it will not be possible to rank the created alternatives in an objective way. It is often practical to divide the goals into “musts” and “wants”. Musts are hard facts, like class rules or safety criteria, that must be followed. Wants are performance related and graduate the ideas in good, better, best.

Sometimes it is hard for a team to agree on the problem definition and the goal. This can be solved by appointing a “client” for the idea generation. The client owns the problem, makes the problem statement and sets the goal. The team members agree to work for him on his terms, based on his power and responsibility.

3. Searching for ideas

The idea generation is the most important phase of the problem solving. To help in finding the solutions various creativity methods can be used. Regardless of the method used, it is important to remember the rules for all creative team work:

- we want to have several alternatives, “quantity creates quality”
- it is necessary to look beyond dominating, traditional solutions
- all criticism is prohibited during the idea generation
- each idea is valuable and has the right to live, at least for a while
- creative work can be carried out both alone and in a group
- each person has creative ability, which can be developed further

The team should consist of persons with different skills and experience. They need not be experts in ship design. A team of only naval architects thinks “like one man” and will not generate many new solutions. The best way to keep ideas alive is to write them down on paper for all to see. Wild ideas from the non-experts might not be applicable as such, but often triggers follow-on ideas that might give the answer to the problem. A small team of 4...6 persons can easily generate 75...100 alternatives within half an hour.

4. Selecting the best idea for refining

All ideas are screened against the “must” criteria. The most promising ideas that passes are given some “analytical” further development before the final selection based on the “wants”. Often it is also reason to check side effects, like investment demands, environment friendliness, etc.

5. Acceptance and implementation

The acceptance of new ideas is an important phase of which the “client” takes charge. Here it is reason to review, why the solution to this problem was important and how well the new idea complies with the targets. Most ideas need much work before the final solution is ready for application. New ideas are easily killed by the “organisation” and the client must support and defend the solution to get it accepted and implemented. Any change in a large organisation does not go through without active support from those in charge.

6. Feedback and reward

Responsibility for the ideas generated belongs to the client, honour to the team taking part in the creative work session.

1.5 The cargo transport business

Transportation by sea is often the best alternative for large volumes and long distances. But the owner of the cargo should also evaluate other alternatives, like transport by road or rail or perhaps by air if fast delivery is important. The cargo owner has in fact the possibility to relocate the factory closer to the market to reduce the logistic cost. If transportation by sea is chosen the cargo must be transferred to the port, loaded into the ship, unloaded in the port of destination and distributed to the customer. The products must be packed and protected from damages, heat, cold, moisture and theft. Selecting a suitable "package" or cargo unit is now important.

The sea transportation is the responsibility of the ship operator. The freight rate for the ship is affected by the daily running cost, the voyage cost and the capital cost for the ship. The ship owner needs a vessel with suitable cargo capacity, performance and operating cost. The capital cost for the ship owner depends on the price of the vessel and the financing arrangement. The newbuilding cost at the shipyard is influenced by the ship design, material cost and production man-hours.

The cargo owner, the ship owner and the shipyard are all "partners" in the business of sea transportation. All of them have several different factors to consider and decide on. These factors can be arranged into a "hierarchy" showing the influence and responsibility of the shipyard, ship operator and the cargo owner (Fig 7).

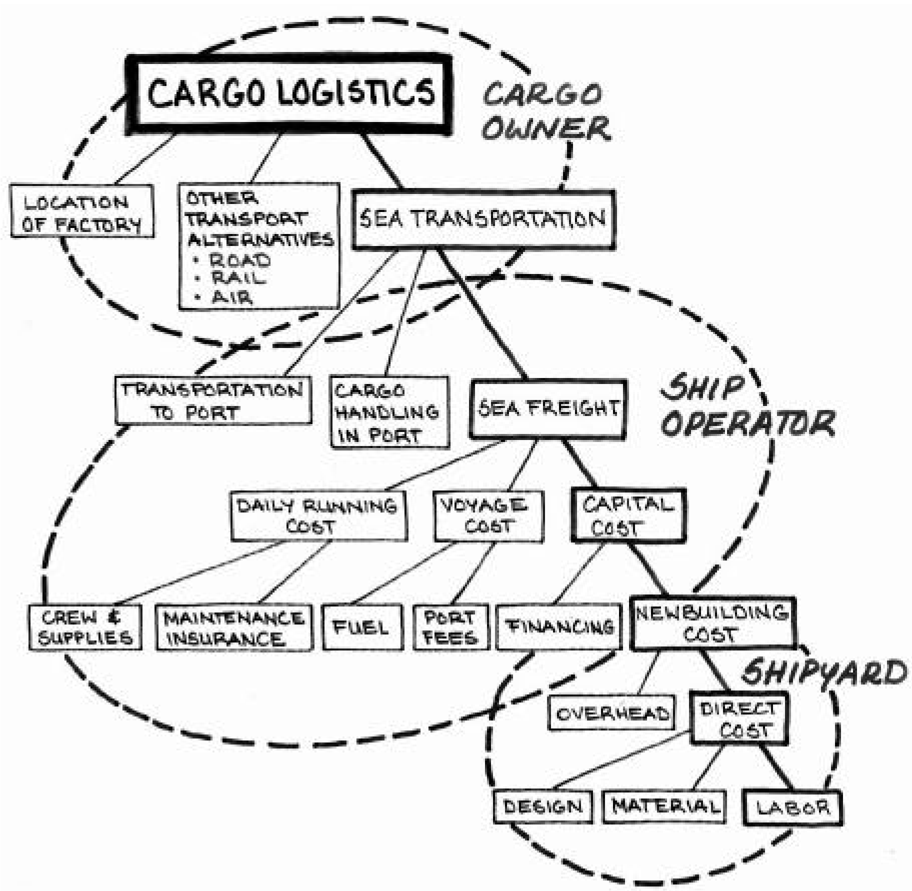

Figure 7: Cargo transportation business

1.6 Problem hierarchy

All the different factors listed in the hierarchy show "problems", which are important in the transport business. In fact it might be better to call them "possibilities" because they show where innovation and improvements can be made. A transport cost calculation ranks the importance of each factor and indicates where creative problem solving should be done.

Your customer is always higher up in the hierarchy. The ship operator is above the shipyard and the cargo owner above the ship operator. By asking "why a factor is important" you move up in the hierarchy. Low fuel cost is important because it affects the voyage cost and the voyage cost affects the sea freight. But the required freight rate can also be reduced by lower daily running cost or lower capital cost. When you move upwards in the hierarchy you get more possibilities for improvements (Fig 8).

By asking "how a factor can be improved" you move downwards in the hierarchy. Lower fuel cost can be achieved by burning cheaper oil, improved propulsion, less transmission losses, etc. For solving these problems you need technical knowledge and experience. But before you dig into any of the "how" problems it is always worth asking "why". This forces you to examine the problem from a higher level in the hierarchy, more from your customers' point of view.

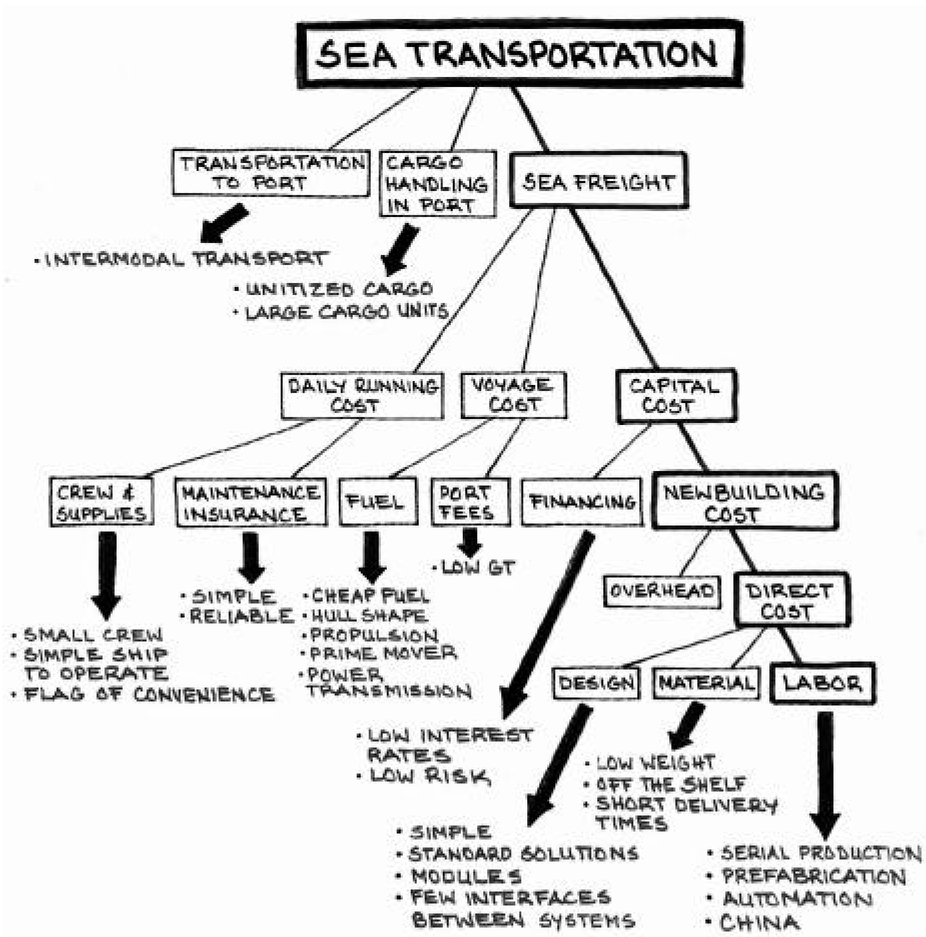

Figure 8: Problem hierarchy for sea transportation

2. SHIP DESIGN METHODOLOGY

2.1 The ship design task

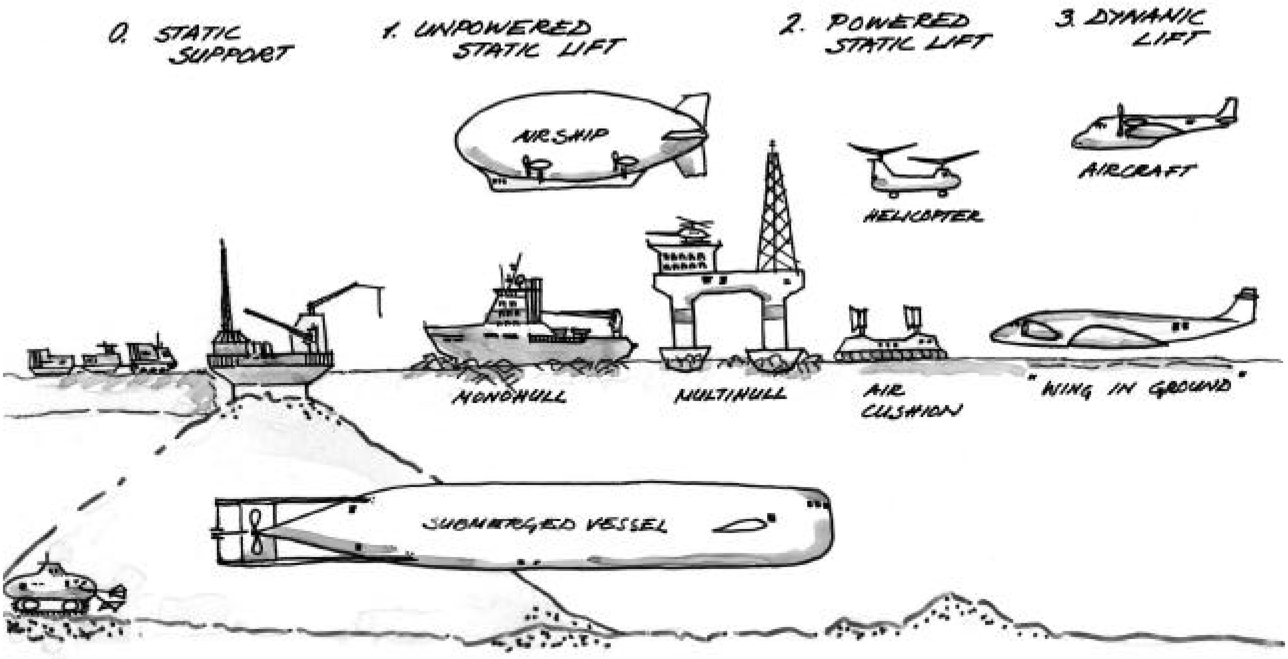

Figure 9: Possible means of transport

There are many different means of cargo transport across the sea (Fig 9). Traditional ships, based on the static lift from the displacement force on the hull are still the dominating solution. On short sea routes shipping is meeting more and more competition from solutions based on static support, like bridges, tunnels and pipelines. But let us concentrate on the ship design task, which can be described as four major steps:

1. Initial sizing of the ship

Capacity carriers, like container vessels, ferries and cruise ships, where the volume of the payload determines the size of the vessel (Fig 10)

Deadweight carriers, like oil tankers and bulk carriers, where the weight of the payload determines the size of the vessel (Fig 10)

2. Parametric exploration

Variation of main dimensions, hull form and lay out of spaces onboard in order to satisfy the demand of "space" for the payload and the ship functions

3. Engineering synthesis

Calculating and optimising ship performance, speed, endurance and safety

4. Evaluation of the design

Calculating building cost and operation economics

2.2 Payload capacity and ship size

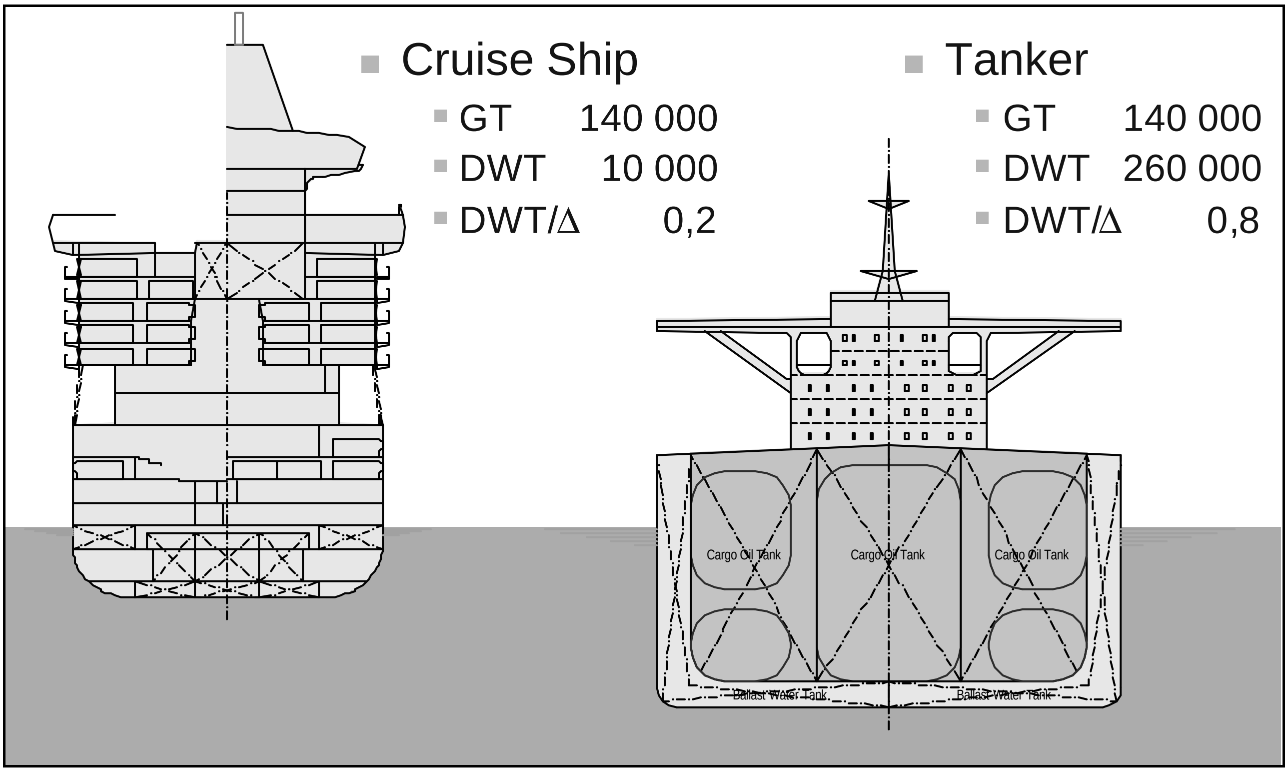

Figure 10: Cruise ships are capacity carriers, tankers are deadweight carriers

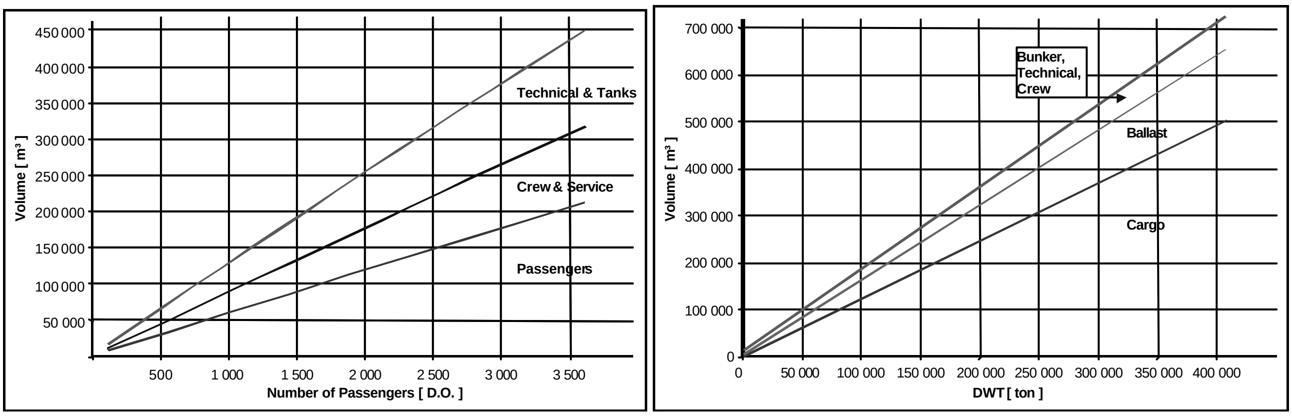

Figure 11: Total volume as a function of payload capacity for cruise ships and tankers

The size of ships are traditionally expressed in Gross Tonnage. Back in time one GT was equal to 100 ft^3 , but today the following formula is used:

$$\mathbf{GT = (0{,}2 + 0{,}02 * \log Vol) * Vol} \qquad \textbf{(1)}$$

Vol is the total volume of the enclosed spaces in the ship in m^3. Because most ship descriptions give the size of the ship in GT it is important to be able to convert this back to the volume in m^3.

$$\mathbf{Vol = 4{,}5 * GT^{0{,}971}} \quad \text{or roughly} \quad \mathbf{=3{,}5 - 3{,}2 * GT} \qquad \textbf{(2)}$$

2.3 Design criteria for successful ships

There are three main factors affecting the technical feasibility and the profitability of a ship. The deadweight / displacement ratio indicates the carrying capacity in relation to the total displacement. The deadweight is low for RoPax ferries with large passenger facilities (Fig 12). RoRo cargo ferries have much higher DWT / Displ ratios, but do not reach the level of container vessels. The tankers and bulk carriers have the highest values. For all vessel types the DWT / Displ improves with size. The speed and power should also be judged in relation to the displacement (Fig 13). For speeds below 20 knots the power demand increases very slowly with increasing displacement. But at 35 or 40 knots the power curves become very steep. The third factor to observe is the lightweight density, which is an easy way for a first weight estimate for different ship types (Fig 14).

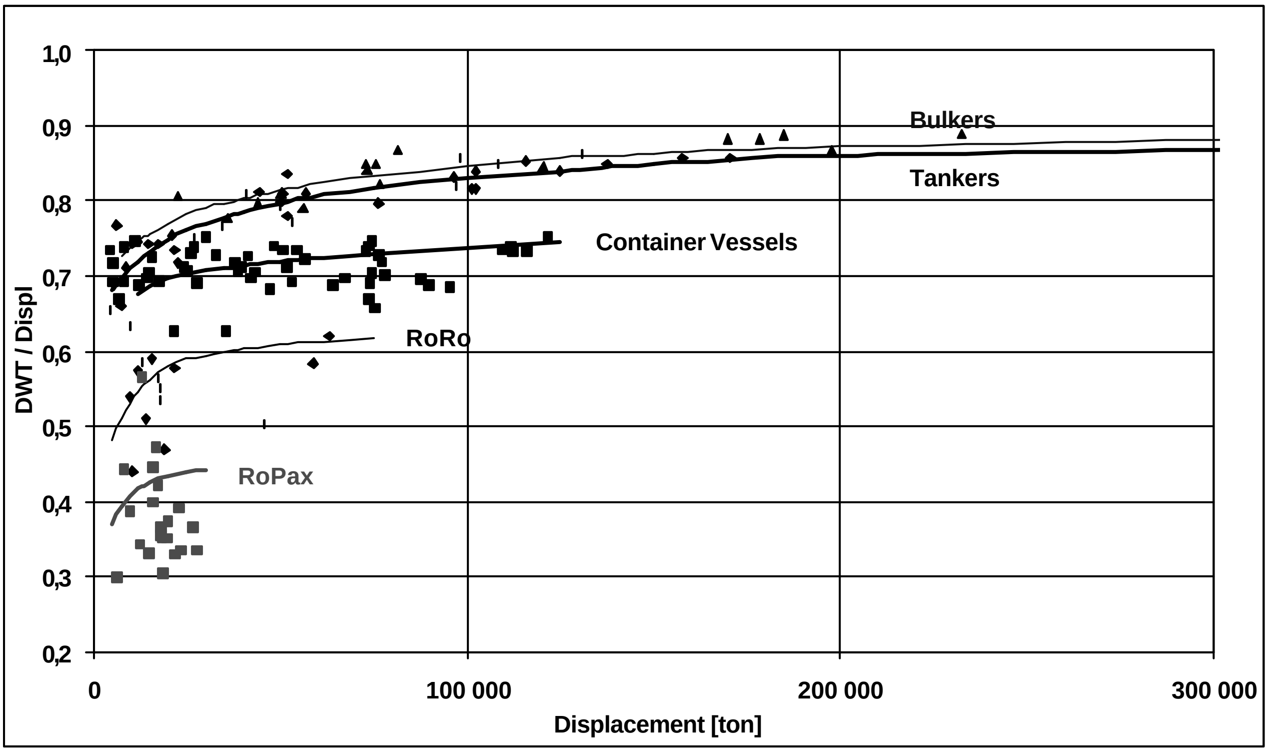

Figure 12: DWT / Displacement

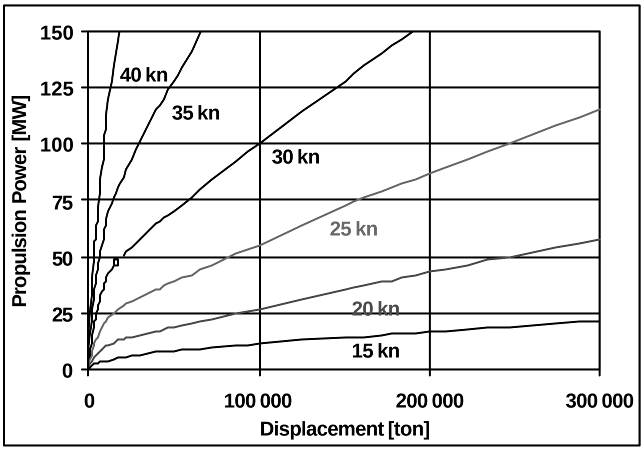

Figure 13: Speed & Power

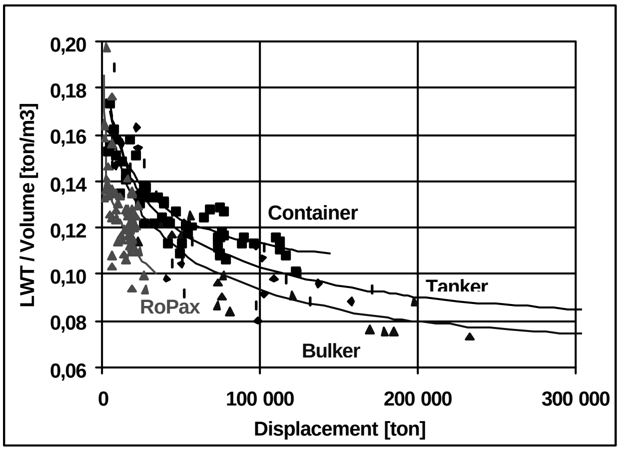

Figure 14: Lightweight density

3. SYSTEM BASED DESIGN

3.1 Payload and ship functions

The ship functions can be divided into two main categories, payload function and ship function. In a cargo vessel the payload functions consist of cargo spaces, cargo handling equipment and spaces needed for cargo treatment onboard. The ship functions are related to carrying the payload safely from port to port (Fig 15). The areas and volumes demanded in the ship to accommodate all systems are then calculated. This design method does not need pre-selected main dimensions, hull lines or standard layouts. System based design is like a checklist that reminds the designer of all the factors that affect the design and record his choices. It gives the possibility to compare the selections with statistical data derived from existing, successful designs. The result is a complete system description for the new ship, including the volumes and areas needed onboard to fulfil the mission. This gives the total volume of the vessel and the Gross Tonnage can be calculated. Based on these data a first estimate of weight and building cost can be made. The next step in the design process is to select main dimensions and define the form. By variation of the main dimensions the space and weight in the selected design is matched to the system description. The best dimensions are selected based on the performance and operating economics.

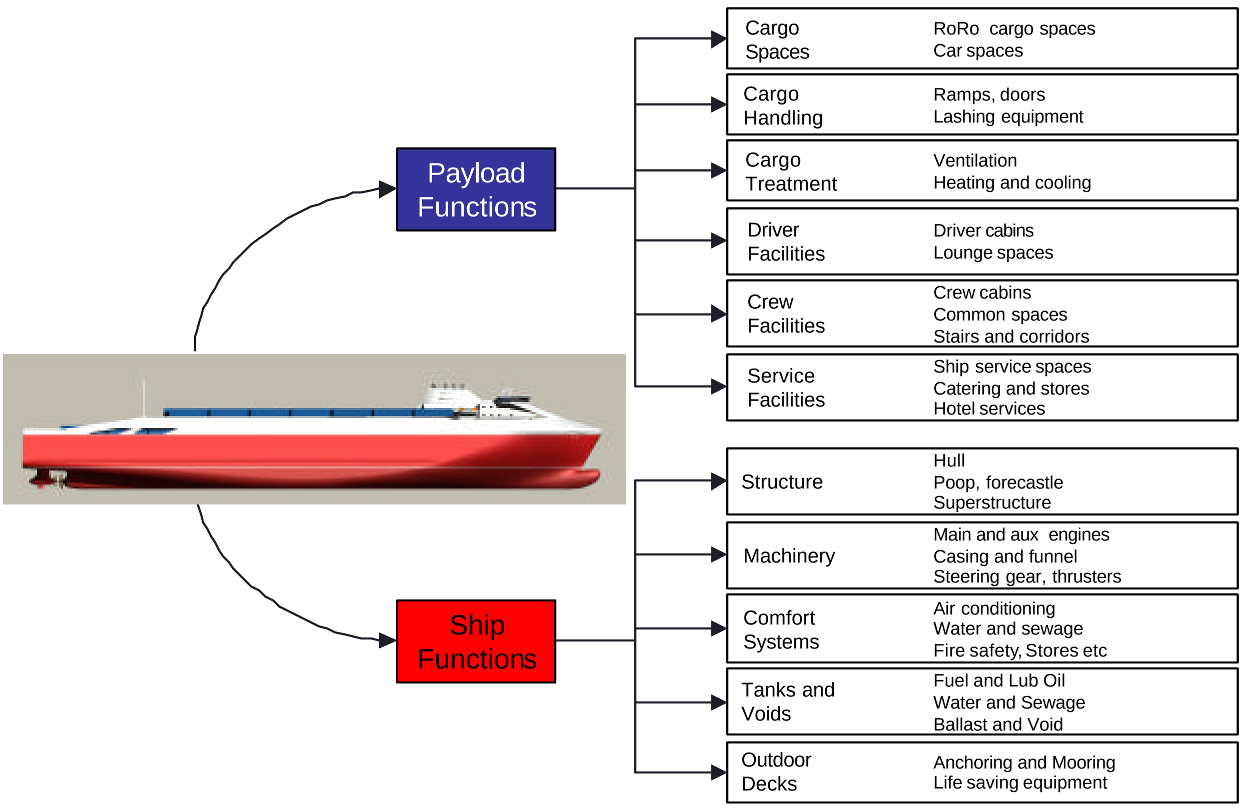

Figure 15: Payload and ship functions

For the System Based Design a spreadsheet program is very useful. The complete design process is represented in a workbook with separate sheets for each system. The system summary defines the size of the vessel, followed by weight and building cost calculations. The spreadsheet program updates the complete workbook if a change is needed in the system descriptions. In the same way the selected main dimensions are checked against the space demand and weight balance (Fig 16)

3.2 SeaKey System Based Design

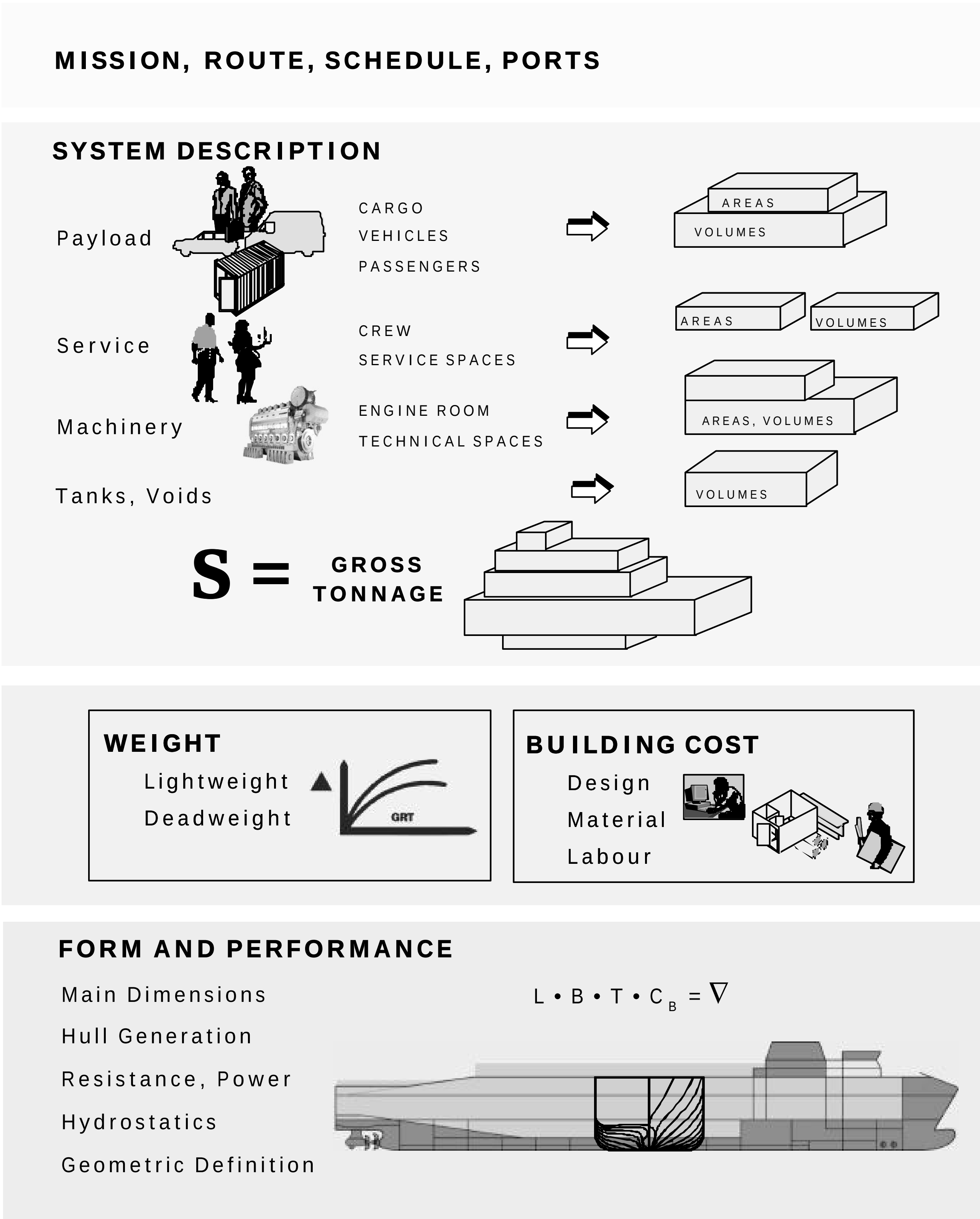

Figure 16: System based design process

3.3 Cargo capacity and cargo spaces

In the mission statement for the ship the payload capacity, type of cargo and cargo units are defined. RoRo spaces are calculated based on the length and width of the cargo lanes (Fig 17). When describing the cargo space it is important to show how much of the cargo is carried inside the ship in enclosed spaces and how much is carried on an open deck or on the hatch covers. Both RoRo vessels and container ships carry much of the cargo outside. Only the enclosed cargo spaces are included in the volume of the ship and in the gross tonnage (Fig 18). Statistics from built ships can be used as a base, but the designer should avoid copying if he is looking for new alternatives.

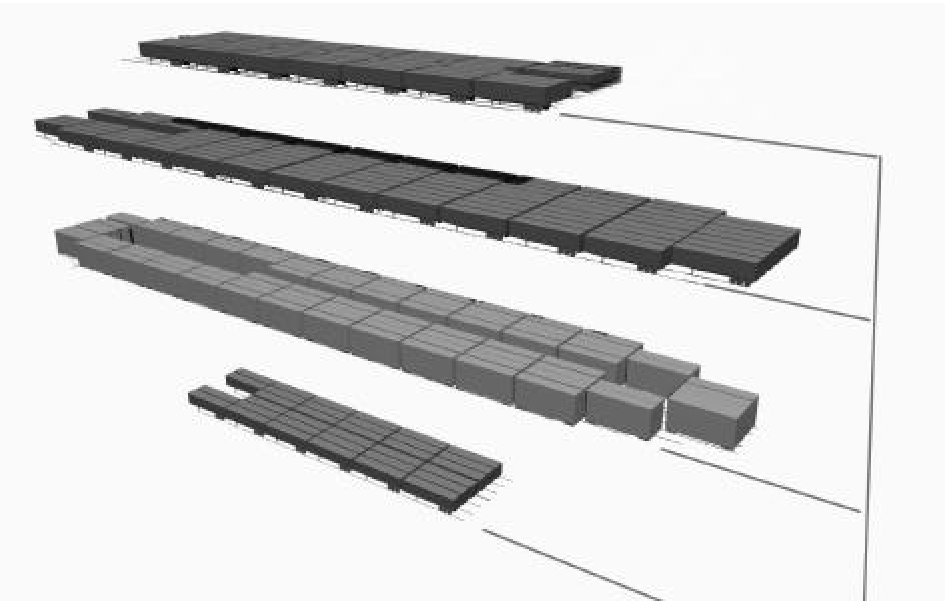

Figure 17: Payload description

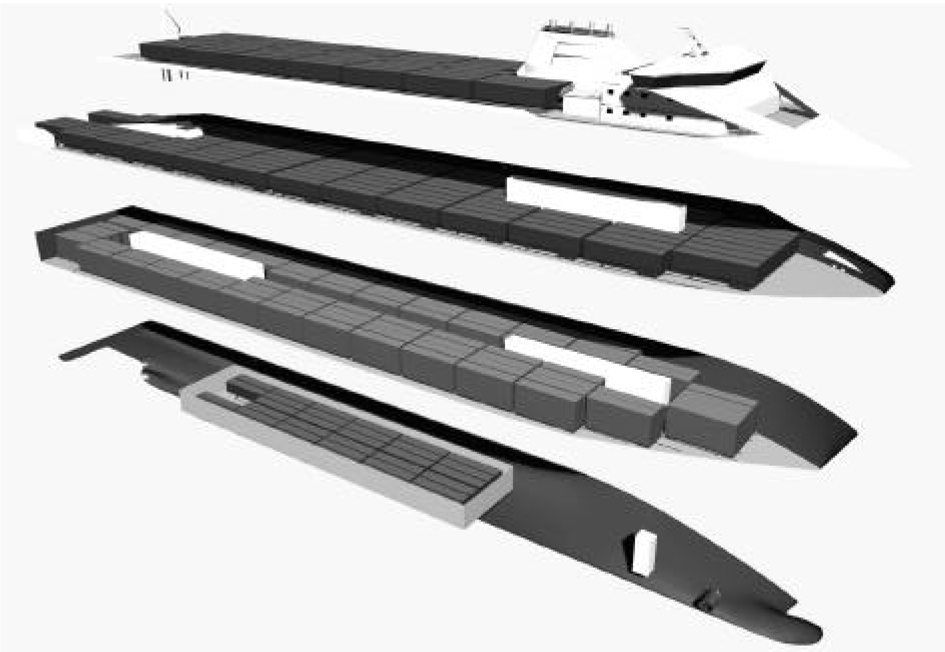

Figure 18: Enclosed and open cargo spaces

3.4 Ship systems

The area needed for crew accommodation is based on the number and size of the cabins. To account for the cabin corridors and for the wall lining a correction factor is used. The area for mess- and dayrooms is based on the number of seats in each space. The space needed for stairs is calculated from the average area and the number of decks they run through. All areas and volumes must be measured "from steel to steel" to include space lost behind ceilings and interior bulkheads (Fig 19).

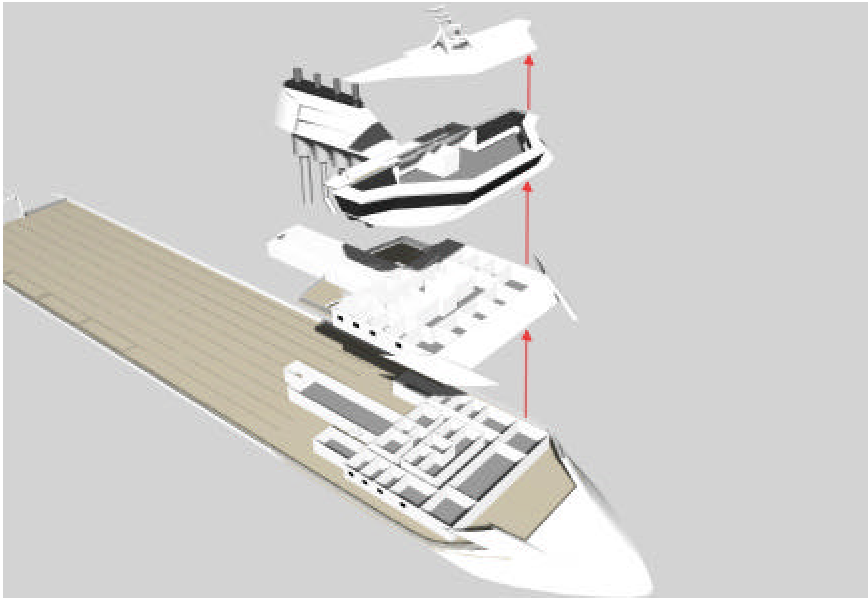

Figure 19: Crew and service spaces

To be able to calculate the space demand for the machinery a rough estimate of the propulsion and auxiliary power must be made. For an exact calculation you need to now both the main dimensions and the displacement of the ship, but these are not available at this stage. The easiest way to proceed is to estimate the power demand based on statistical data (Fig 14). If you find out later that the estimate is far off, you must go back and change these values. In a spreadsheet any change made to an input variable will automatically update all the related area and volume calculations (Fig 20).

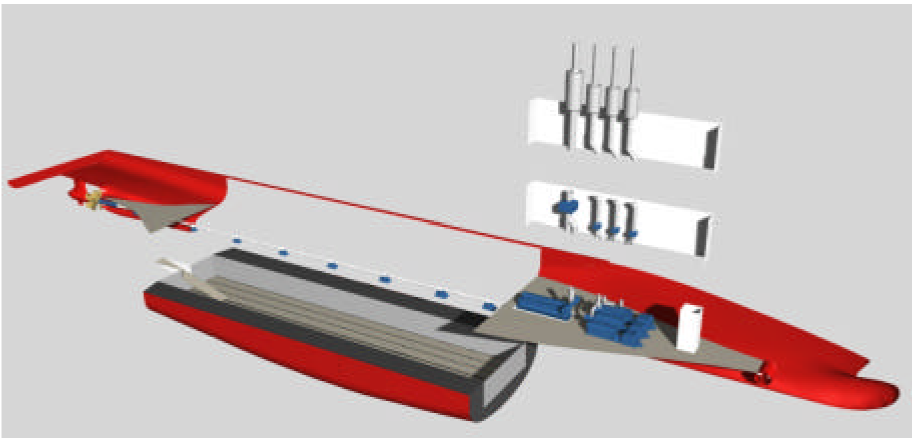

Figure 20: Machinery spaces, tanks and voids

3.5 System summary

All systems are now defined and can be summarized to give the total space demand for the vessel. The total volume is converted into Gross Tonnage and the size can be compared with existing vessels (Fig 21). For RoRo vessels this is best done based on the cargo lane-meters. The deck areas are important for the RoRo decks and furnished spaces. For technical spaces located outside the engine room, like machinery shops and stores or AC rooms the deck area demand is needed. Engine and pump room space is allocated based on volume only.

SPACE ALLOCATION	m²/DWT	m³/DWT	Area m²	Volume m³
RoRo Cargo Spaces	1,2	6,0	15 015	77 970
Car Spaces	0,0	0,0	0	0
Cargo Handling and Other Task Related Spaces	0,0	0,1	560	1 136
TOTAL CARGO SPACES	1,2	6,1	**15 580**	**79 100**
	m²/person	m³/person		
Crew and Driver Facilities	29,3	83,6	820	2 340
Service Facilities	7,5	20,7	210	580
TOTAL FURNISHED SPACES	42,9	120,8	**1 030**	**2 900**
	m²/person	m³/kW		
Engine- and Pump Rooms		0,3	--	8 040
Other macinery spaces		0,1	1 251	3 752
Tech. spaces outside the engine rooms	16,8	0,1	402	1 991
TOTAL TECHNICAL SPACES		0,5	**1 650**	**13 800**
		m³/DWT		
TANKS AND VOID SPACES	-	1,5	-	**19 100**
	m²/person	m³/person		
OUTDOOR DECK SPACE	16,3	50,0	**390**	**1 200**

	m³/DWT		
TOTAL VOLUME	8,9		**116 000**
GROSS TONNAGE			**35 000**

Figure 21: System summary

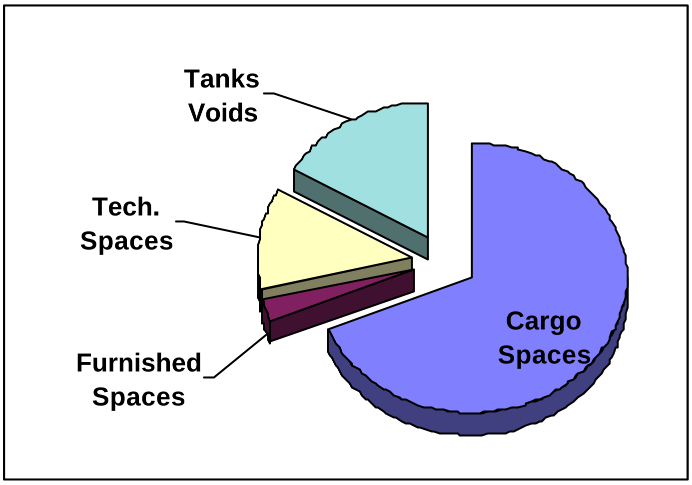

Figure 22: Space distribution

3.6 Weight and building cost estimate

The first weight and building cost estimate can be done based on the system summary. In the concept design phase it is sufficient to divide the lightweight into 6 main groups (Fig 23). The main dimensions have not been selected at this stage and cannot be used for the estimates. Payload related items are best calculated "piece by piece" because they differ from ship type to ship type. The steel weight of the hull is calculated based on the hull volume. The superstructure or deckhouse is separated from the hull, because their weight /m^3 is much lower. Interior outfitting is based on the furnished area. For the machinery the installed power is used and the ship outfitting is based on the total volume. In the building cost calculation the same lightweight grouping is used. To give the necessary accuracy both the weight- and cost coefficients must be based on data from built ships.

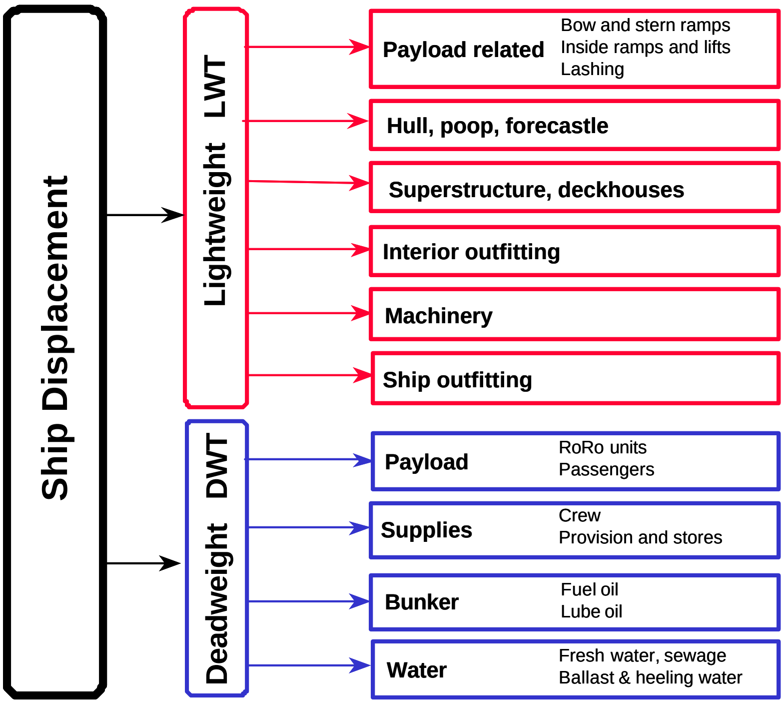

Figure 23: Lightweight and deadweight main groups

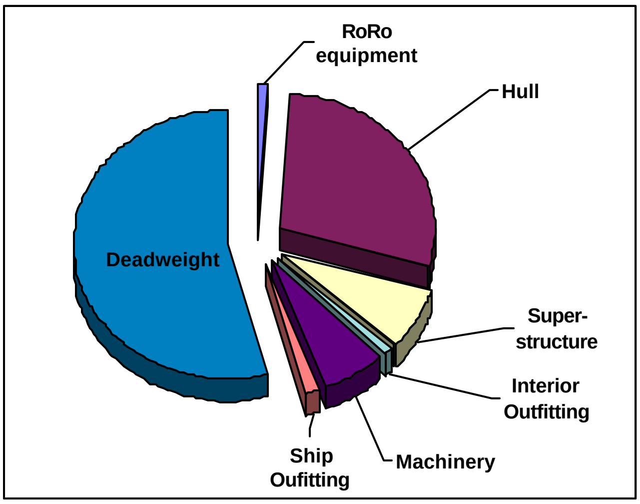

Figure 24: Weight distribution

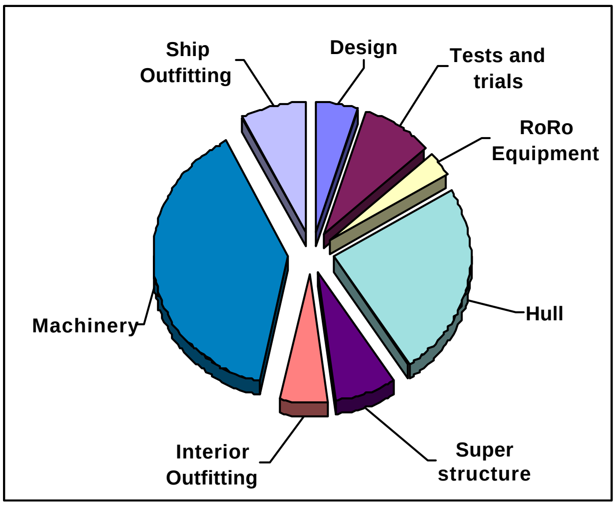

Figure 25: Cost distribution

3.7 Selecting main dimensions

The main dimensions follow very similar tends for all ships with full displacement hull forms. We have already calculated the displacement so the block coefficient and slenderness ratio can be checked for the proposed dimensions. A hull with suitable form parameters keeps the power demand low. If the ship is intended for a selected route, length and draught limitations in the ports must be remembered. Maximum dimensions of the Panama or Suez canals often affect the ship design.

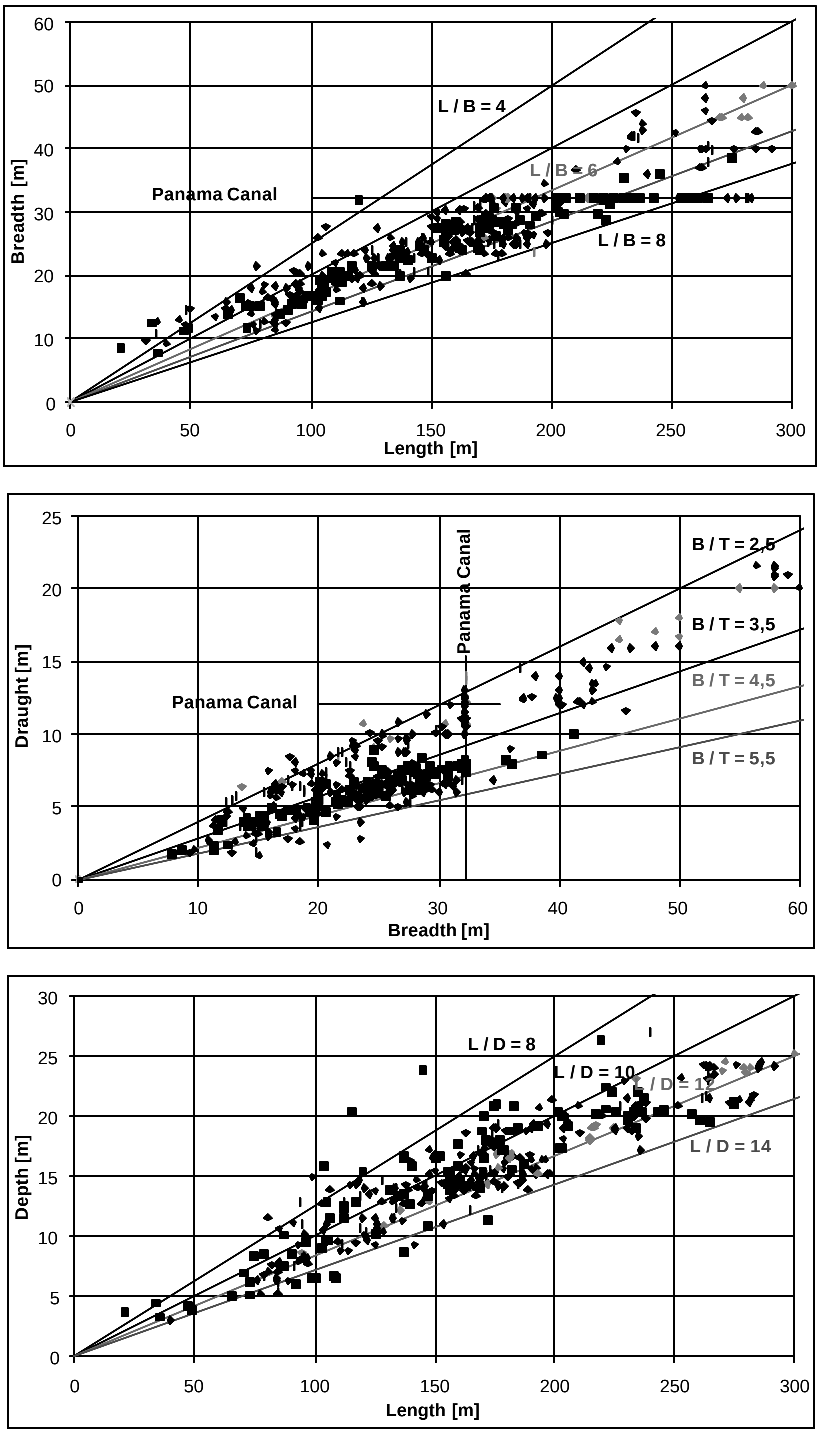

Figure 26: Main dimensions for ships with full displacement hull forms

3.8 Hull form

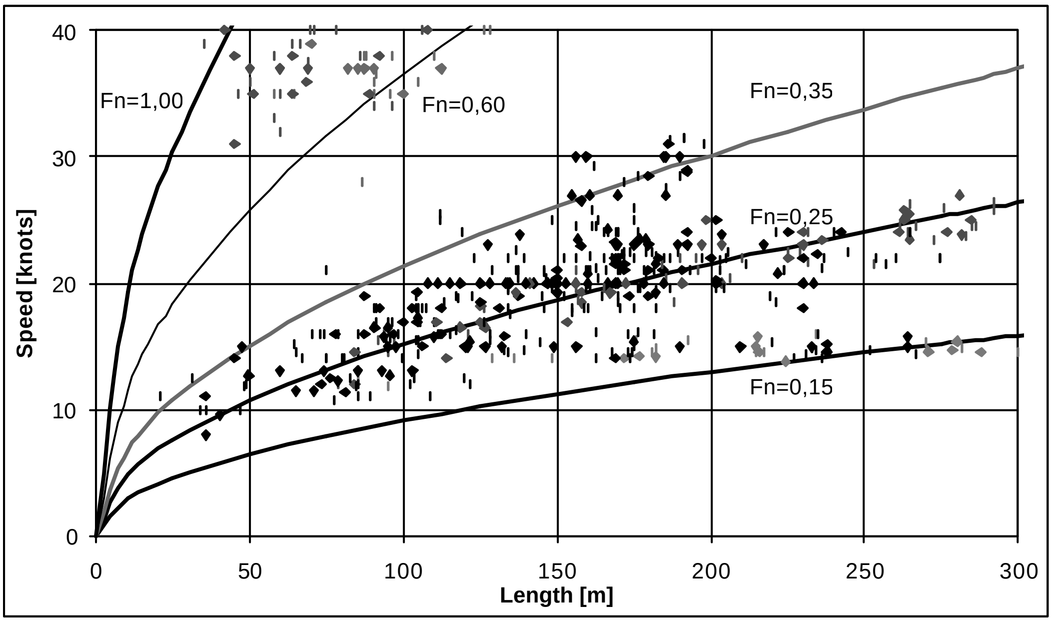

Figure 27: Speed – length ratio

Displacement type hull forms are used for speeds corresponding to Froude numbers below 0,35. But only ferries operate close to that number. Cruise, container and general cargo vessels are scattered around Fn =0,25. Most of the tankers and bulkers operate at about 15 knots independent of length. The "High Speed Light Craft" ferries have Froude numbers between 0,5...1,0 and operate in the semi-planing mode (fig 27). The block coefficients used in ships built during the last 10 years are shown in fig 28. The selected Cb-values vary considerably, but curves for recommended hull form coefficients are indicated. The Cp-value is the important parameter for hull resistance.

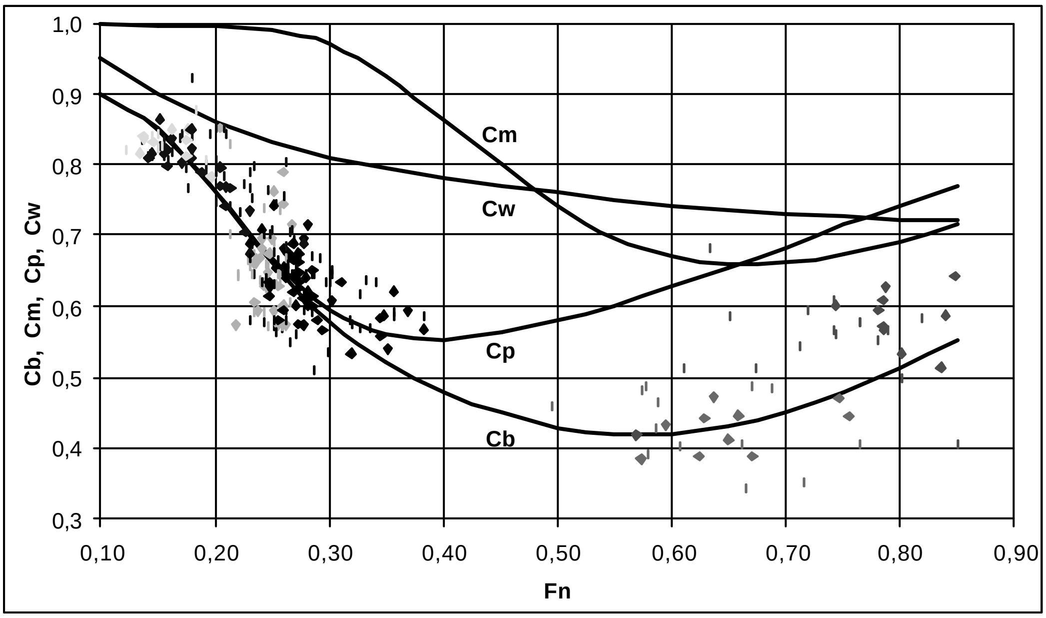

Figure 28: Hull coefficients

3.9 Lay out proposal

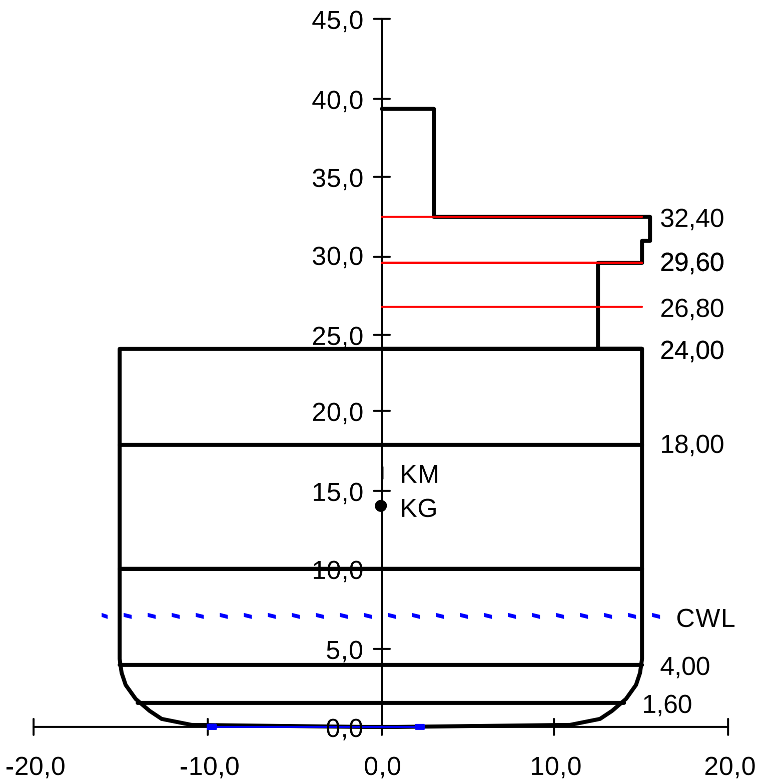

Figure 29: Lay out of hull

Now the designer can start to develop the lay out of the ship. First the number and location of the decks in the hull and the size of the deckhouse is roughly estimated (Fig 29). Based on this geometric definition areas and volumes in the hull are calculated using approximation formulas for the vertical variation of Cb and Cw. The spaces in the superstructure or deckhouse are defined as blocks. The available areas and volumes are compared with the system description to check that all defined functions fit into the ship (equation 2 and 3). When the "space balance" is OK, the "weight balance" is calculated for the selected main dimensions (equation 4). Stability and propulsion power are checked using empirical formulas and available data from other ship.

The developed design must fulfil the five criteria defined by the equations 2 – 6 below:

Volumes: $V_{hull} + V_{\sup erstructur} \geq \sum V_{systemdescription}$ (2)

Deck areas: $A_{hull} + A_{\sup erstructur} \geq \sum A_{systemdescription}$ (3)

Displacement: $\Delta = L \times B \times T \times C_B \times 1{,}025 \geq LWT + DWT$ (4)

Stability: $GM = KM - KG \geq$ intact and damage stability (5)

Machinery Power: $P_{installed} \geq P_{propulsion} + P_{hotelload}$ (6)

4. FINALISING THE CONCEPT DESIGN

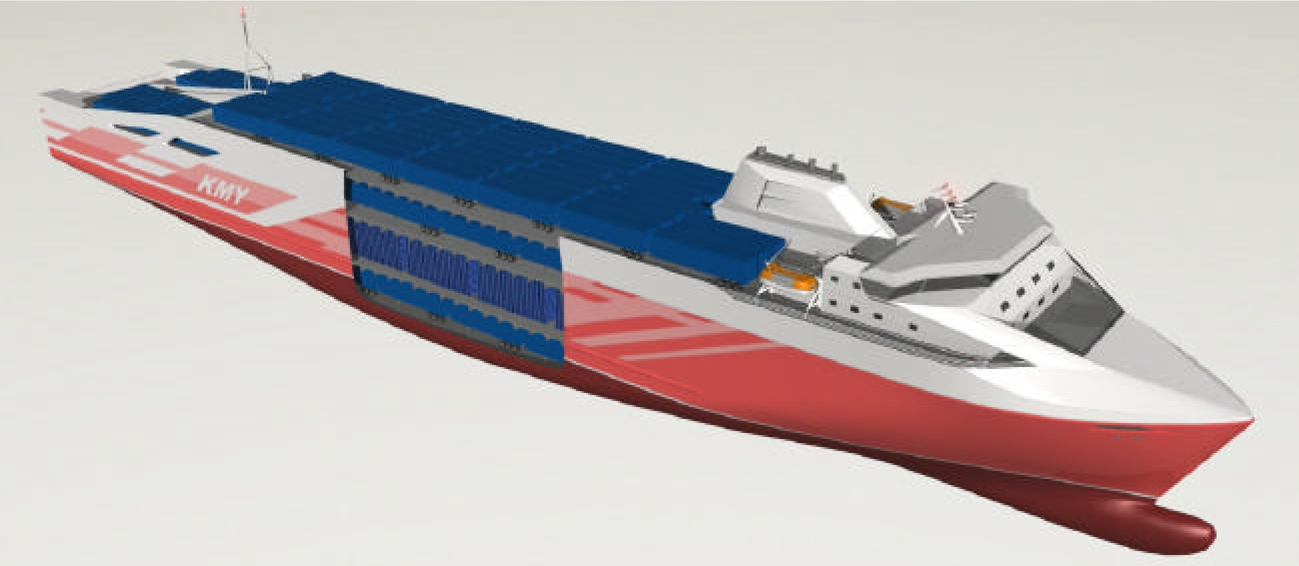

Figure 30: Exterior design proposal

Based on the data from the System Based Design the general arrangement can now be drawn. The proposed design concept should be evaluated against the design objectives agreed upon. The performance data, like payload capacity, speed and power must be evaluated against ship weight and building cost (Fig 24 and 25). The main factors affecting the building cost indicate areas where the designer should concentrate additional development work to further improve the design. Social values, like safety, reliability and environmental considerations must not be forgotten. The operating economics on the intended route should be calculated and compared to existing vessels and alternative solutions (Fig 31). Economical profitability will be the main criterion for selecting the design for the next generation of RoRo ferries.

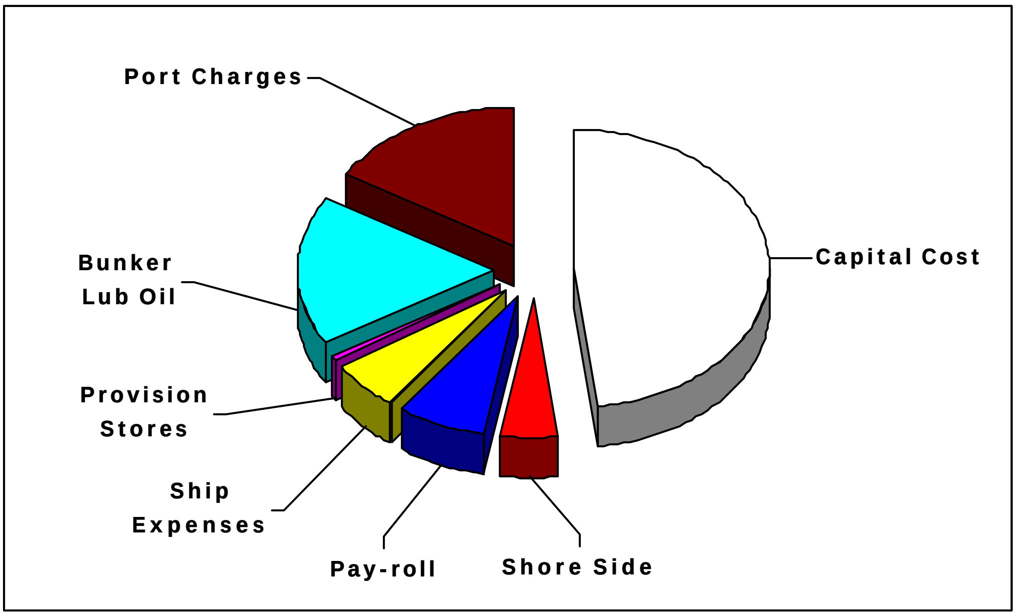

Figure 31: Operating cost distribution

EuroConference on Passenger Ship Design, Crete 2001

Levander Oskar: “Advanced machinery with CRP propulsion for fast RoPax vessels”
Motor Ship Conference, Copenhagen 2002

Liengme, Bernard: “A guide to Microsoft Excel for Scientists and Engi
Butterworth-Heinemann, 2000

Muller, Gerhardt: *“Intermodal freight transportation”*
Eno Transportation Foundation, Washington DC, 1999

Schneekluth & Bertram: *“Ship Design for Efficiency and Economy”*
Butterworth-Heinemann, 1998

Wijnolst, Niko: *“Design Innovations in Shipping”*
Delft University Press 1995