Technical and economic benchmarking of existing and new ship designs.[1]

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Abstract

Judging the technical and or economic performance of cargo vessels is important. It is essential when chartering vessels, buying second hand vessels or designing a vessel. However, it is not always that transparent because the performance of a vessel depends on many characteristics and also, not unimportant, the purpose of the vessel, the specific trade and planned sailing pattern. This paper attempts to give an answer on questions like, how can I judge the fuel consumption of a specific vessel, what is its technical and financial performance in a certain trade in comparison to other vessels and why. The paper gives a methodology how to approach these questions in a systematic way. The methodology will be explained by applying it to "Roll on Roll of" vessels with examples.
The paper is divided in 2 parts. The first part "**Methodology of benchmarking designs**" will go into the methodology to benchmark designs. A worked out example will be given in the second part "**Results for RoRo carriers**".

Keywords: Benchmark, design evaluation, technical performance, economic performance, vessel, ship, RoRo.

[1] We thank both anonymous referees and prof v.d. Voorde for their valuable comments.

1. Methodology of benchmarking designs

1.1 Introduction in benchmarking vessels

There are many vessel designs, often with different main dimensions even servicing the same business. The question arises when is a new design better than the existing ones?
The main answer is when it can operate more efficiently than its predecessor and equipped with more efficient and effective equipment on board. The only advantage the older vessel has, is its low investment in comparison to the investment of the new building.

To explain this lets look to figure 1.

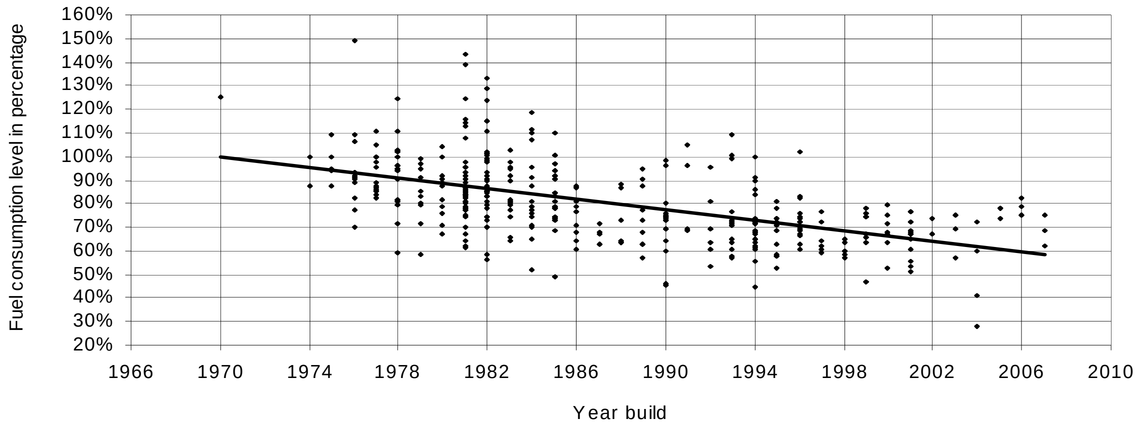

Figure 1. Fuel consumption level in percentage versus year built.

Vertically you will find the fuel consumption in per cent, set on 100 % in 1970 coming down to 60 % in 2006. This graph is based on a research where 400 bulk carriers build since 1970 are analysed. The database is from Clarkson added with vessels from Rina (1990-2011)Mainly quoted from Chen Shun, Koos Frouws et al (2009):
Fuel consumption per ton-mile is taken as a first indicator to examine changes in fuel consumption of dry bulk vessels in the past decades. Suppose they are all sailing on their design service speed. Then the fuel consumption per day can be calculated using the installed power at a given design speed.
However, the higher the speed, the higher the fuel consumption per ton-mile. The choice of the design speed is a technology independent factor. The design speed is an **economical** choice. So, in order to measure the fuel consumption performance of the vessel correctly we developed a benchmark per vessel which is determined by the calculation of the required power at the design speed of the vessel according to the method of Holtrop and Mennen (1979 - 1984) per vessel, and at a consumption per kWh of the engine set at such a level that the trend line is 100 % in 1970. Actually it is the ratio between the real required fuel consumption and the calculated fuel consumption per vessel according the method from

Holtrop Mennen. The latter adjusted in such a way that this ratio is 100 % in1970. This approach rules out the impact of speed and main dimensions.
Figure 1 shows a drop in fuel consumption on average with 40 % since 1970, from which around 20% due to improved engine design shown in figure 2.

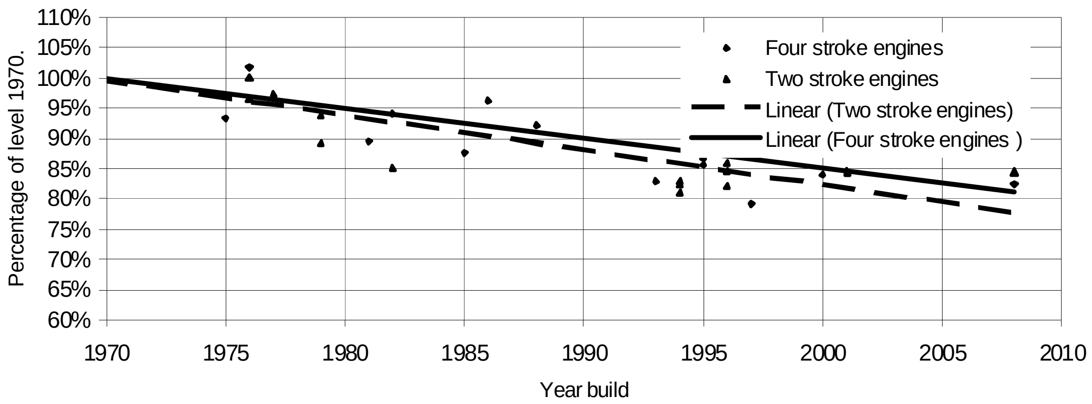

Figure 2. Relative changes in specific fuel consumption of engines from 1970 to 2008

The following conclusions can be drawn from these graphs:

- The innovation in 35 years took care of a decrease in fuel consumption from bulk carriers of 40 % on average. There is no reason to believe that other ship types will differ substantially from these figures.
- The described benchmarking and trend watching methodology is useful to judge new designs by fitting them in the graph. It enables the decision maker to detect the basically well designed vessels on their main earning capacities.

Although the fuel consumption will not be the only parameter to judge a design, it is an important one nowadays. In order to narrow down the benchmarking process or selecting process in the case of charterers the following overall approach has been chosen:

First basic technical judgement of a design

This phase just focuses on the basic technical quality of the design as the outcome from the process of the naval architect. It is limited to the hydrodynamic and mechanical performance of the hull in terms of fuel consumption and weight reductions. When OK it is basically a well designed vessel, suitability for the trade has still to be proven. It assures not the suitability for a certain trade.

The suitability or technical optimum ship for a specific trade.

Having selected technical good designs, or having compared a design with basically good designs brings us to the next phase, namely checking the ability of our design or second hand vessel to perform in the logistical chain in terms of cargo requirements in ton and volume, physical constraints on route, required speed etc. So this phase narrows down the possible second hand candidates or tells us to adjust our concept design to the business.

The final economic evaluation.

The owner is only interested in the possible economic performance of the vessel in a certain trade. By means of determining the required freight rate based on the sailing profile of the proposed trade for all vessel (candidates) in the database, including the design or the candidates to be purchased, the designer, charterer or future second hand ship owner will get a final impression of the choice to be made.

This approach will be used in this paper.

1.2 First basic technical judgement of a design

To get an idea about the quality of a design or ship a first judgement can be made by the approaches mentioned above. However, some characteristics of the vessels are determined by logistics, cargo and trade; others are pure “quality of design features”. The main features determined by logistics, cargo and trade are:

- The design speed of the vessel, sometimes just based on the economical speed (speed with lowest costs per ton-mile) plus a reserve, sometimes based on the ability to deliver goods within a schedule of a larger logistical chain.
- The deadweight/volume ratio of the carrying capacity. This is totally dependent from the planned cargo to be transported. Namely its density and/ or spread in density.
- The main dimensions can be determined by the designer in order to get a good fuel consumption performance but they could also be forced by reasons of physical constraints on the route or in the port. So the quality of this choice from the designer’s point of view should be kept out of the discussion, if this choice is forced by constraints. Later on, they will be included in the decision process.

So, what we are looking for is:

1. The relative fuel consumption performance from a specific vessel **regardless** its main dimensions. This should rule out the impact of design constraints.

2. The relative light-weight of the vessel again regardless its main dimensions. Any tons saved here will save fuel and building costs and as a consequence generally increase the earning capacity in terms of tons.

These two items determine basically the technical quality of the design as long as the trade is not involved in the discussion. So a first determination of the technical quality could be done by judging a design or vessel on those two items as sharp as possible.

The proposed approach is:

$$\text{Power Ratio} = \frac{\text{Real required power at design condition.}}{\text{Calc.required power at design condition.}}$$

$$\text{Lightweight ratio} = \frac{\text{Real lightweight.}}{\text{Calc. Lightweight based on statistical data.}}$$

Where both calculations should be defined as calculation methods based on statistical data. However, to keep it relative simple, as a function of the following limited amount of 7 main variables: Lpp, Breadth, Depth, Design draft, Design speed, Block coefficient and Installed power (incl. mcr and sea-margin) meant to be used for the propulsion.
For some of these calculations you will need more detailed information like for example the entrance angle of the vessel or the wet surface etc., they will be estimated based on statistical information again as a function of the main variables. Those more detailed shape dependent factors are actually detailed design choices. By introducing these parameters statistically in the calculation, its quality of choice is measured in the real required power. With other words the effects of the design choices will be measured by this approach.

Well known calculation methodologies based on such an approach are:

Required power : Holtrop Mennen (1979, 1984) plus the Wageningen B serie for the propeller efficiency.
Lightweight : Weight estimation method with the “Lloyds equipment number E” as basic parameter from 1962, described in Watson D.G.M. (1998) and Watson Gilfillan (1976)

Both approaches are chosen to fulfil the job. Holtrop Mennen, because it is known as a reliable method based on a substantial database from Marin in Wageningen in the Netherlands. The method is published and rather complete, including statistical approaches of the additional required information.
The “Lloyds equipment number” method is the only known lightweight estimating methodology which uses just the mentioned variables as described above. Despite the limited variables its accuracy is reasonable, if tuned on the ship-type. Both methodologies will have to be tuned and are tuned on the ship type.

1.3 The technical optimum ship for a specific trade

There is no sense in building a vessel which has no service. The service will determine the required functions. Absolutely and relatively. Continuing this approach leads to the description of the main money earning features of a vessel looking to a specific service. This will be set up starting from the logistical chain. The logistical chain will set some requirements in order to transport goods safely and in time. They are:

- Speed of the vessel at sea
- Required time for manoeuvring in port.
- Loading and discharge rate.
- Cargo amount in tons, average, maximum, minimum and standard deviation per shipment in combination with the Cargo density, average, maximum, minimum and distribution.
- Contract type (for example liner or tramp service)
- Sailing route, (determining distances, wave and weather conditions).
- Unexpected days of hire and cargo damage.

All under the condition that the vessel will fulfil the legal requirements, current environmental requirements and safety requirements. Also under the condition that the vessel is able to sail the route looking to draft, air draft, width and length.
In order to deliver this service, the first choice between possible ships should be based on:

Quantitatively:
- Are the loading and discharge rates, required time for manoeuvring and speed at sea able to cope with the required “transport speed” ?
- Does the maximum and minimum on cargo mass and volume fit precisely into the vessel? If they do not, something is oversized with inefficiency as the consequence.
- Is the lightweight relative low in order to limit the displacement and as a consequence the fuel consumption? And if not, is there a good reason?
- Are the main dimensions in line with the physical constraints on the route and in port?
- Will the fuel consumption be acceptable?

Qualitatively:
- Is the vessel suitable for the sailing route in terms of possible damage and loss of speed in adverse weather conditions?
- Can the cargo be stowed in such a way that it will be transported safe and undamaged looking to the lay out and equipment on board in relation to the proposed sailing route and cargo type?
- Are the unexpected days of hire acceptable?

With this first rough quantitative and qualitative assessment the conceptual design can be evaluated or possible second hand candidates chosen. This paper focuses on the quantitative aspects.

1.4 The Economic evaluation

The costs of operating a ship can be split in two types of costs:

1. **Time dependent costs.** They could be regarded as a fixed amount of costs per unit of time. They can be influenced but not strongly. From the moment the vessel is owned, this financial structure is fixed, loans and crews have to be paid regardless the occupation of the vessel and dry-docking is obliged by the classification society.

2. **Voyage dependent costs.** These costs especially the fuel costs are a choice which has to be made for each trip. Fuel costs are strongly influenced by the chosen speed, even exponential with increasing speed

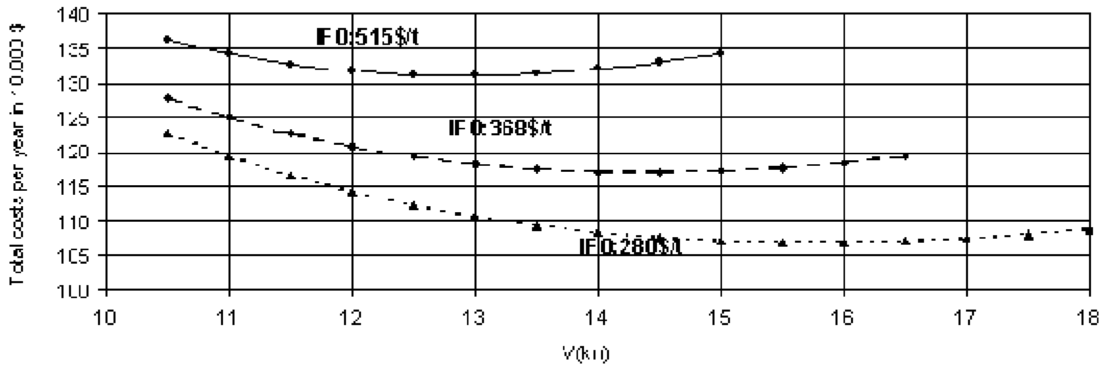

Figure 3. The optimal speed at different freight market levels bulk carriers Chen Shun et al (2009)

Figure 3 shows this battle between time dependent costs and voyage costs as a function of the speed. In this case it goes about the profit, but you could also replace this by the costs per ton-mile. With increasing speed the time dependent costs per ton-mile will decrease but the voyage dependent costs will increase. The optimum, a speed where the costs per ton-mile are the lowest, is in this paper defined as the economical speed Vec.
This leads to the first very important aspect in comparing the economics of vessels to each other. If the speed is fixed due to the logistical requirements, often the case in line services, or if it is not fixed and more or less a free operational choice the comparison should be made as follows.

- Fixed speed: Calculate the costs per ton-mile and/or cbm-mile at the required speed.
- Free choice: Calculate the costs and compare the vessels on the costs per ton-mile and/or cbm-mile **at the economic speed**. Which implies that the economical speed has to be calculated first. (Otherwise there could be substantial differences, in the comparisons due to the large impact of the fuel costs on the costs per unit-mile.)

The costs per ton-mile are calculated by dividing the required freight rate, based on time charter basis (excluding fuel) and the one based on a full cost rate (including fuel) by the ton-miles and/or cbm-miles.

The developed economic model, is built according to Aalbers A. (2000), evaluation of ship design, which on its turn, is based on Harry Benford (1965), Kerlen H. (1981), Carreyette, J. (1977) and Spencer F.A. (1983). The split of costs is according Martin Stopford (2008). It is a building costs and voyage calculation model having the ability to vary the speed, if required, with 3 different speeds, vary the cargo weight per chosen speed, while compensating the fuel consumption for that, and the voyage profile in terms of sailing time, port time running days etc. The latter is extremely important in order to judge differences in time related and voyage related costs for a specific trade.
On top of that, there is the possibility to influence the results by separate escalation rates per cost item. The model for the diesel engine calculating the sfoc's compensates for partial loads and is basically dependent from the max RPM of the main engine. Its accuracy is rather high, validated against a diesel database, and based on Aalbers A. (2000).
The required freight rates of all vessels in the database are determined using the same input. With other words all vessels in the shown results, are regarded as a new design.
All maintenance and operational costs are parameterised and vessel size dependent, easy to adjust to different situations.

2. Results for RoRo Carriers

2.1 Typical aspects and development of RoRo carriers

The general trend in RoRo design.
In the abstract from the paper "Design of a 142m RoRo-Vessel" written by Tobias Haack et al (2009) one find the following sentence:

> "In early 2008 FSG (Flensburger Schiffbau-Gesellschaft) has started to design a 142m long RoRo-vessel intended to operate in the Irish Sea. The layout of the ports of call restrict the length and the draft of the vessel significantly (LOA<=142m,T<5.2m). So the hull form design of the twin-screw vessel with its four decks and a design speed of 21knots (FN=0.29) was very challenging resulting in a relatively high block coefficient."

This one sentence clearly indicates the great diversity in design within the ship type RoRo. Limitations in main dimensions who will influence the optimal hydrodynamic performance but are business-wise unavoidable.

A second article from Stefan Kruger, Thomas Stoye (2004) deals with the problem of
Creating space without jeopardizing the property of fast loading and discharging. Figure 4 indicates the problem. There are ships build, but not much, with 4 decks. Some with 3 decks

and the possibility to add one later. The latest designs, for example the ConRo 220 from the Flensburger Schiffbau-Gesellschaft is equipped with 4 decks. A five deck vessel was in development in 2004. Its size:

L x B	195.4 m x 30.0 m
Lane-meters	3,923[2] m

Block stowage of cassettes, Container foundations and Car decks on tank top & main deck.

Service speed	18.0 kn
Installed power	10,800 kW / 500 rpm
Number of decks	4

The background from this trend to increase the number of decks is the bad utilisation of the deadweight in the current market due to the seemingly relative light cargoes. A more deadweight oriented vessel will have to sail with more ballast, or outside its optimised design points in terms of draft. This, with obvious negative fuel consumption consequences.
The figures 4, 5 and 6 do tell us a lot about this development. All figures and results are based on a database composed of pure freight RoRo carriers from RINA (1990 – 2011), unless otherwise indicated. Remarkable but not strange is that there is hardly a relationship between the length and the number of decks. However, there is a strong relationship between the minimum breadth per number of decks and the number of decks. Almost linear. This has everything to do with the stability. A deck more, requires more stability.
Short ships with a lot of decks are wide. The disadvantage is a penalty in the fuel consumption. But the fuel consumption per lane meter decreases, because of the increased lane-meters.

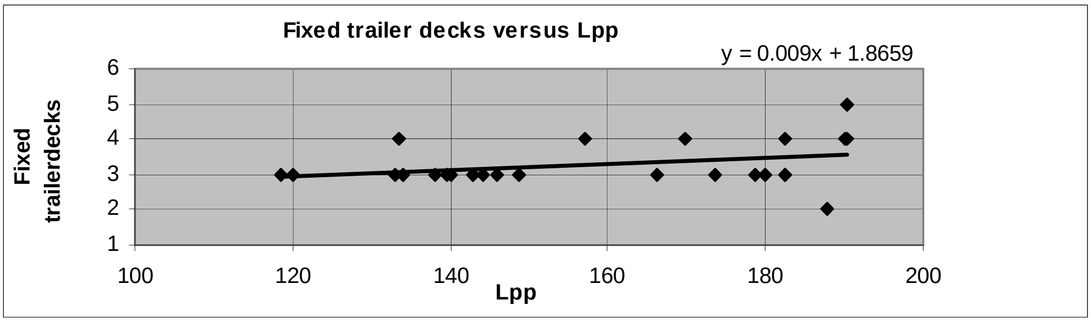

Figure 4. Number of trailer decks versus the Lpp.

[2] The ability to carry cargo, trailers, is expressed in lane-meters. The lane-width varies a little between 2.9 meter and 3 meter. There is no standard lane-width.

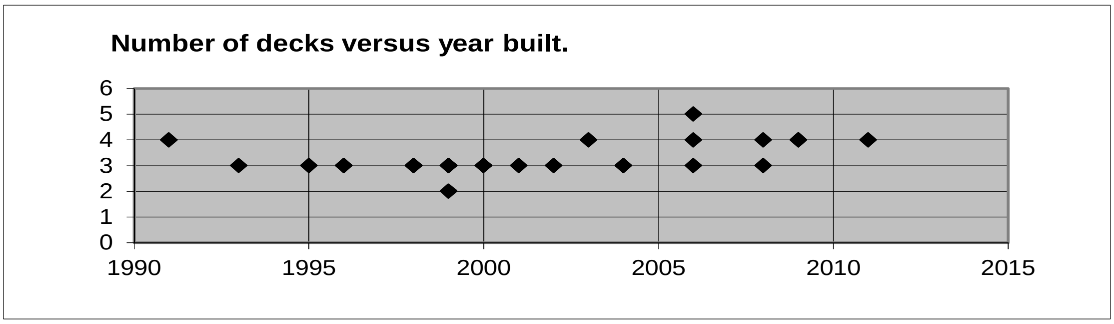

Figure 5. Number of trailer decks versus year built.

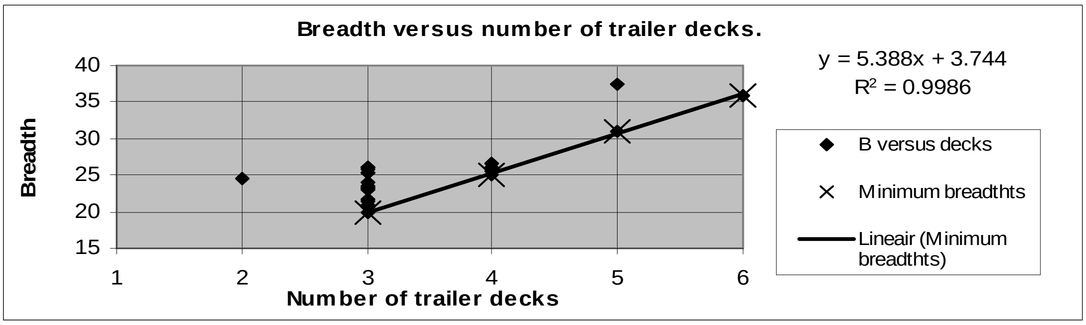

Figure 6. Breadth versus number of trailer decks.

So, the designers had to improve three areas in order to increase the cargo volume. At first the damage stability, secondly limiting the effect on the steel-weight by means of extensive finite element calculations and the application of High Tensile Steel (HTS) and last but not least, reducing the effects on the required power by computational fluid dynamic analysis (CFD). For example in Tobias Haack et al, 2009 a power saving is claimed from around 20 % by optimising the ship's hull and appendage configuration.

These new designs can be highly competitive for the existing vessels. However, when comparing RoRo vessels with container vessels one should realize that a RoRo vessel with roughly 3200 lane metres can carry around 850 containers, a comparable container ship of the same size, sizing based on Lpp x B x D, 2800 containers (Tobias Haack et al, 2009). The real competition is on loading/discharging times and loss of dwell time in the terminals. At sea a RoRo vessel will "lose" the competition against a container vessel. The cargo that has to be fast on its destination, is the cargo for a RoRo vessel.

In the last 10 years the following major design improvements have been made:

- A substantial increase in cargo per square meter of vessel, especially at the larger vessels, mainly by adding decks and using cassettes.
- A substantial decrease in power consumption in the order of magnitude of 10 till 30 % with relatively fuller ships.
- A slight increase in average size.
- An increase in number of decks per vessel, mainly from 3 till 4 partly driven by scale.

2.2 Basic technical judgement

Design Speed.

RoRo vessels operate typically in a liner service where speed can be important in order to compete and sometimes due to the shorter distance, or type of cargo, a slower speed is no problem. This spread in design speed is shown in figure 7.

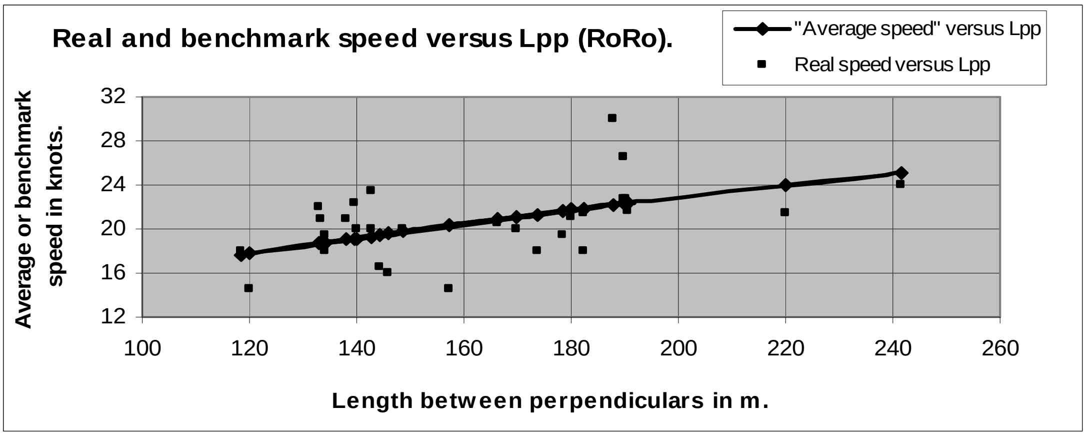

Figure 7. Relative design speed variation with trend per year vessel delivered.

Figure 8 indicates the design speed deviation from the "average", being the design speed divided by a speed based on an average Froude number. Normally vessels will have a slightly higher economical speed with increasing length. To compensate for this, the Froude scaling number was used. The average Froude number of the database was 0.261. Based on this Froude number the benchmark speed as a function of the length is shown in figure 7.

Figure 8 shows a small tendency to increase the design service speed in the years, underlining the importance to be in time and the importance to deliver fast. It is too low to speak of a trend.

The quite large variation in differences shows the differences in design goals due to the business requirements per case. Originally these vessels are "one off" designs or small series made for one specific purpose with an eye on the possibility of selling the vessel after some time.

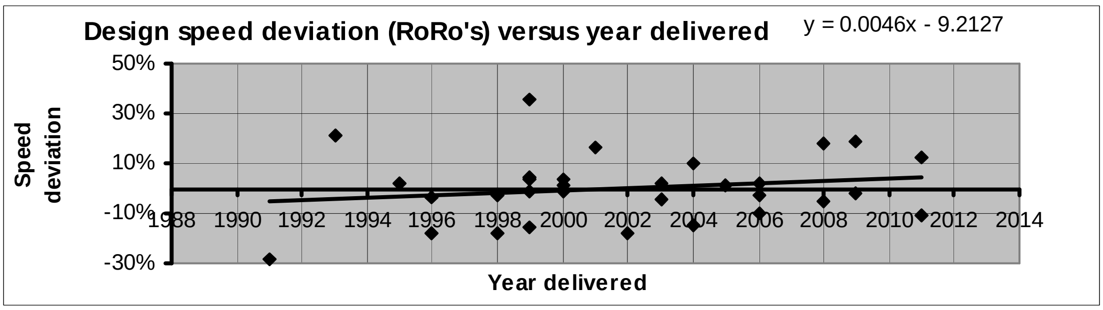

Figure 8. Design speed versus length and average design speed.

Deadweight/displacement ratio

In comparison to bulk carriers, ships within this “ship type family” have a large variation in deadweight displacement ratios. For example the vessel the Dongbang Challenger is specialized in carrying steel coils and has for that reason a deadweight displacement ratio of 0,633, in a range for RoRo carriers of 0,436 till 0,638. Also the block coefficient of this vessel is large, 0,701 in a range of 0,544 till 0,701, again for RoRo carriers. The result will be a low design speed, for obvious economic reasons because of the relative blunt shape.
The distribution of these figures in the database indicates a clear relation between these aspects and the type of cargo to be carried. RoRo vessels are designed for a specific cargo, in a specific service. Again, as such, more a “one off” design than a bulk carrier. More difficult to change from business.

Power ratio.

Figure 9 shows the ratio of real installed power / calculated required power using the design speed and main dimensions as input parameters. It shows the hydrodynamic “design quality” of the hull and propulsion system. Due to the fact that the main dimensions are used as input in the “benchmark power”, the impact of physically constrained main dimensions is ruled out.
The continuous line (a trend line based on all dots) indicates that the quality of the designs are improving. According this graph an improvement of 25 % in 20 years. The same trend was found in Bulk carrier designs as shown by Shun Chen, Frouws et al (2009) . The dotted line is based on ships from one specific yard, known for its good designs.

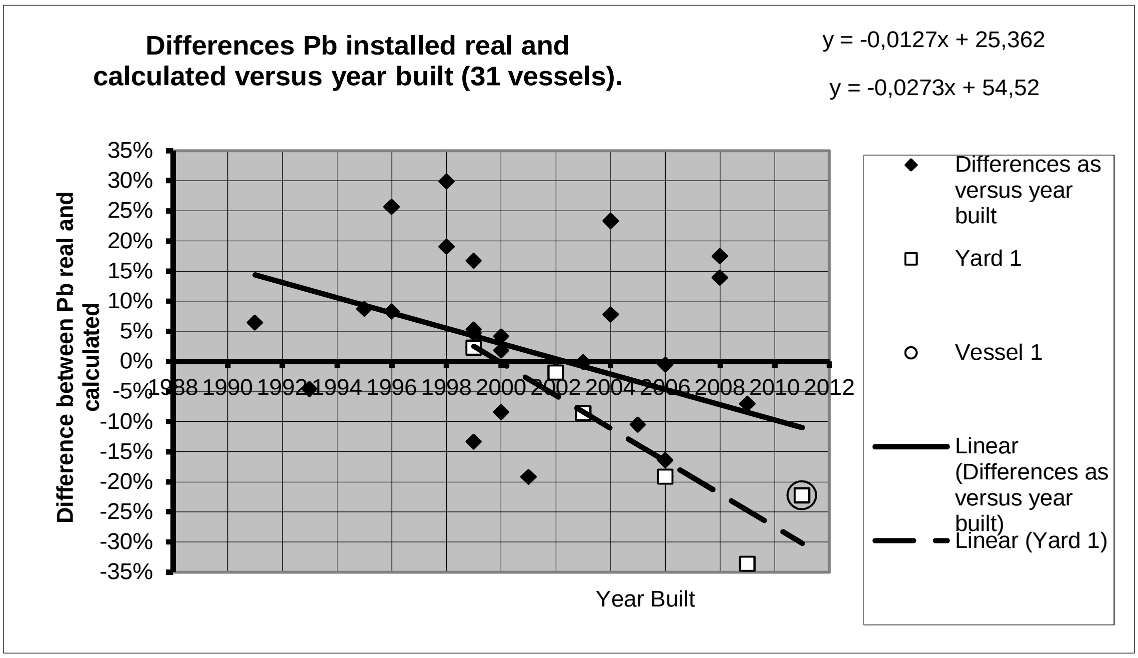

Figure 9. Benchmark ratio Pb installed / Pb calculated. Based on database author.

It teaches us very basic things, namely:

- The improvement of the last years is impressive and will challenge the designer.
- With dropping new building prices and new buildings with substantial decreased fuel consumption it can still be worthwhile to order a new vessel.
- The vessels from yard 1 perform excellent. However one, named vessel 1, is ok but not perfect.

Lightweight ratio.

The real lightweight / calculated lightweight ratio is also investigated. It is not shown here but indicated no clear trend since 1990 and has a spread of around 10%. It can be used to judge specific designs. In essence a spread of 10 % means a spread of around 10% in investment costs. However, in the case of an additional roof above the top deck, for example in order to keep paper rolls dry, it can be necessary. If the result from a wrong design, it can add some displacement and will result, as such in additional fuel consumption.

2.3 Suitability for a specific trade

Because the deadweight and /or lane-meters are not involved in figure 9 it tells you nothing about the performance of the vessel in the business. It just simply tells you how good the hydrodynamic performance of the hull and the performance of the propulsion system are. For that reason the following figures add a lot of information:

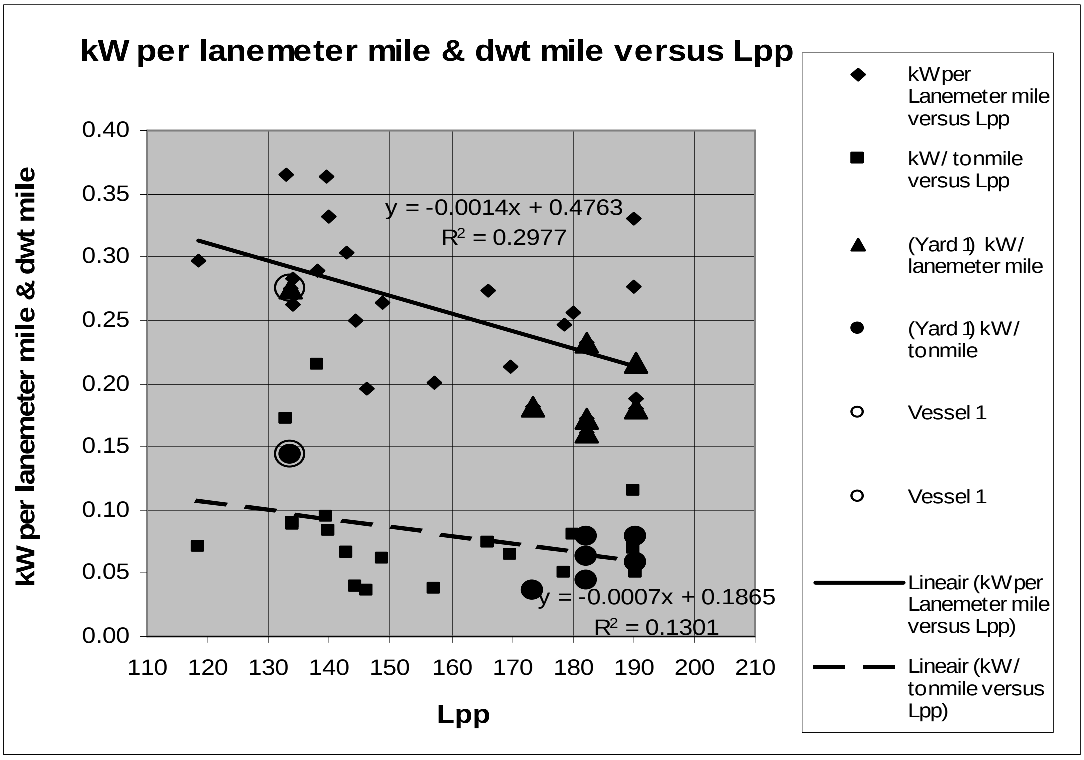

Figure 10. kW per lane-meter mile & dwt-mile versus Lpp.

Figure 10 shows us that vessel 1 is a rather short vessel , on top of that this vessel is despite its shortness equipped with 4 decks which makes it rather heavy but creates space for an exceptional amount of lane-meters. This is clearly reflected in the kw per tondwt-mile which is high in comparison to the excellent kw per lanemeter-mile. This vessel was specifically designed to carry a lot of trailers in small ports, ports physically constraining the main dimensions of this vessel.

Some vessels seem to perform disappointing. However, it is very important to realize that the vessels are put in the graph with their design speed. This means that fast vessels will need more kiloWatts. A lot of vessels have a high design speed. When sailing at a high design speed it can easily double its fuel costs against the slower sailing competition. On the other hand the vessel itself could sail slower and as a result save fuel. To get a better view of this impact the same items are set out against the Froudenumber. See figure 11.

In comparison, vessel 1 performs less good in kW per ton-mile and excellent in kW per lane-meter. Indicating its steel required to build 4 decks on a short ship, which will limit its deadweight capacity. In general this graph shows the increase in required kiloWatts with an increase in Froude number.

It is important to notice that the vessels from yard 1 are relatively underperforming on the kW per Ton-mile but are excellent in the required kW per lane-meter. This can be an indication that the average cargo weight is over estimated by some competitors or the trade differs.

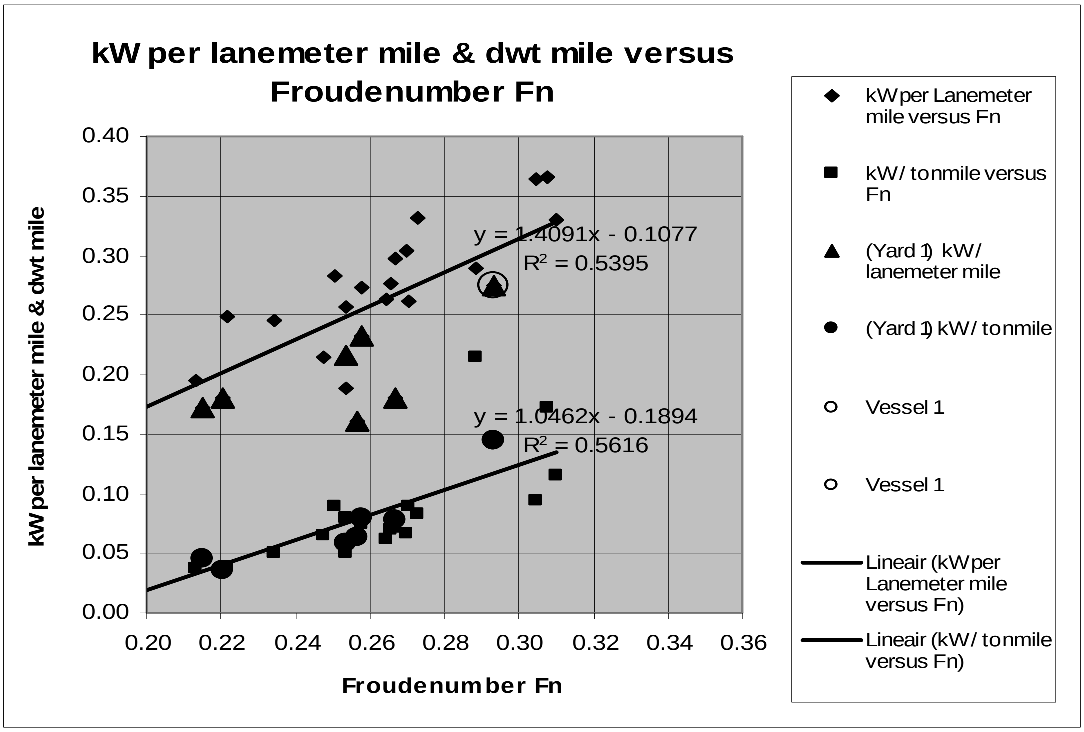

Fig 11. kW per lanemeter mile & deadweight mile versus Froudenumber Fn

Figure 12, shows the required gram fuel per ton-mile of the RoRo carriers based on the published fuel consumption in mt/day. This data is probably, because not expressively indicated, based on a full deadweight condition and the design speed. So, in reality they will be lower.
The fuel consumption figure of trucks is also shown and is based on an average of several tests described in Nicolas Hill (2011). These trucks from different manufacturers were loaded with on average of 28.4 ton cargo which is 68 % of their maximum cargo being around 40-44 ton. Their average speed was 76 km/hr on the tests.

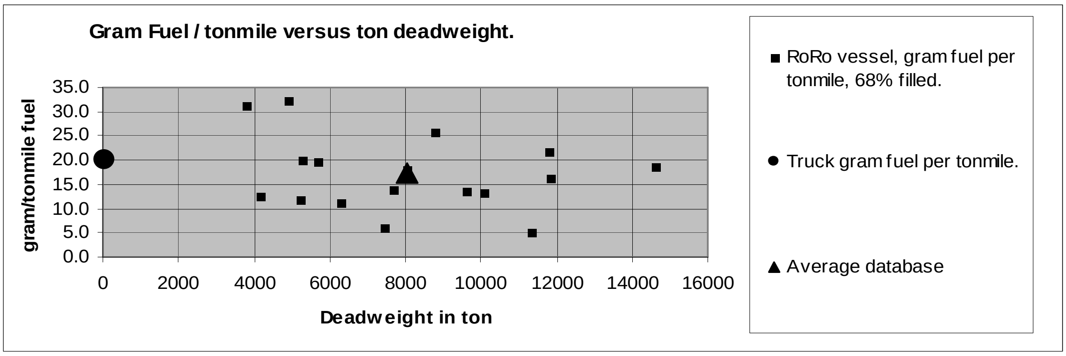

Figure 12. Gram fuel per ton-mile

It shows substantial differences in relative fuel consumption between the RoRo carriers. The very high figure is from the vessel carrying steel coils. Secondly it learns us that trucks can be a competitor from RoRo vessels.

Main conclusions.

- There have been substantial improvements in ship design the last 25 years, however, the spread in performance is large.
- Eventually RoRo carriers can only be judged correctly in their logistical role, taking into account their real operational profile and logistical constraints.
- There is a clear trend towards more volume at the price of deadweight.

2.4 The Economic evaluation

The basis of the economic model to determine the investment and the required freight rate is given in the chapter "methodology of benchmarking designs". All type of costs, like for example maintenance, dry-docking, pilots etc. are included and parameterised as a function of for example the vessel size or number of trips.
The input of the required freight rate calculations shown in this paper was as follows :

- The amount of cargo, with other words the deadweight, was set on 80 % of the maximum, which was regarded as a more realistic value than 100 %.
- The time spend in in the port was set on 10 % of the total time.

- The speed was set on the design speed, taking into account the fact that most of these vessels are active in a liner service.
- No pilot costs, no tug costs, no canal costs.
- Survey and docking costs will escalate in time

The financial values used in the calculations are shown in figure 13

Own capital	60%	
Interest rate	6%	
Depreciation time	15	yr
Duration project	30	yr
Internal rate of return	8%	
Scrap rate	385	Euro/ton Wsm
Escalation scrap value	3%	
Escalation fuel	4%	
Escalation rest voyage cost	3%	
Escalation crew	3%	
Escalation rest oper.cost	3%	
Escalation docking/survey	3%	
Escalation freight rate	3%	

Figure 13 Example from financial input used in the following graphs.

The results are as follows:
Building costs versus Wsm, Lpp and lane-meters, the latter is a common way to express the loading capacity and with the rather constant distance between the decks also a good indicator of the available cargo volume.

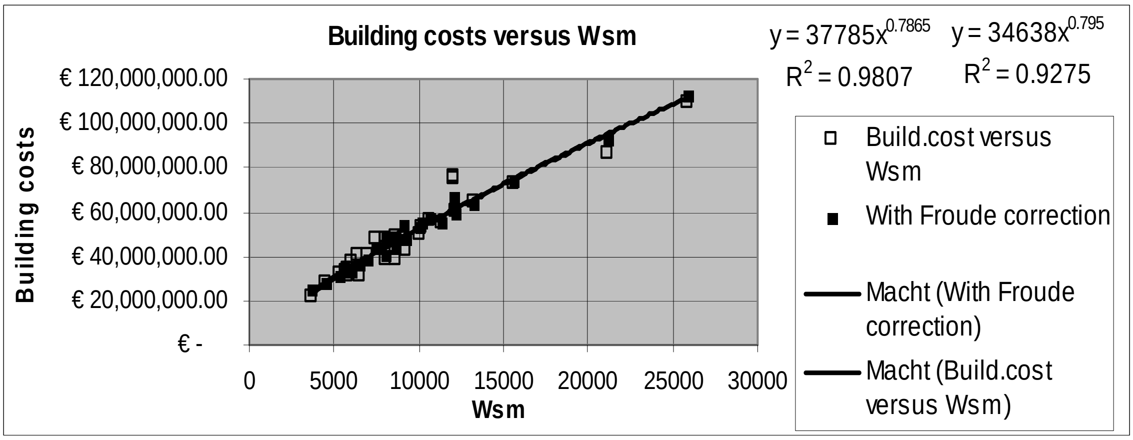

Figure 14 Building costs versus Wsm.

The correlation between the building costs and lightship of the calculation model is obviously good because this is one of the main parameters. Especially the installed power takes care of the deviations. The installed power varies a lot so a second set of dots was developed with a correction factor based on the Froude number which shows the impact of the installed

power. Take care, the real prices of new buildings are strongly dependent from the market conditions. This building cost model is roughly tuned on the average situation in the last decade.
For business purposes it is interesting to show the diversity in consistently calculated building costs per lane-meter.

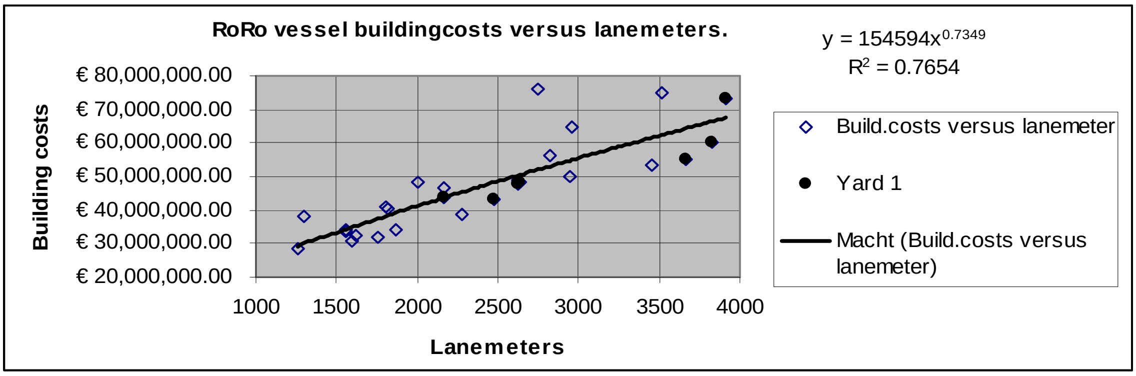

Figure 15 RoRo building costs versus lanemeters

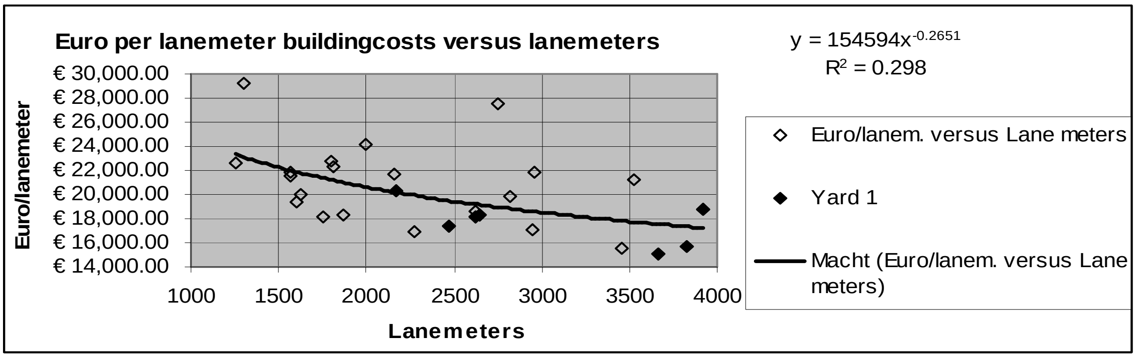

Figure 16 Building costs per lanemeter.

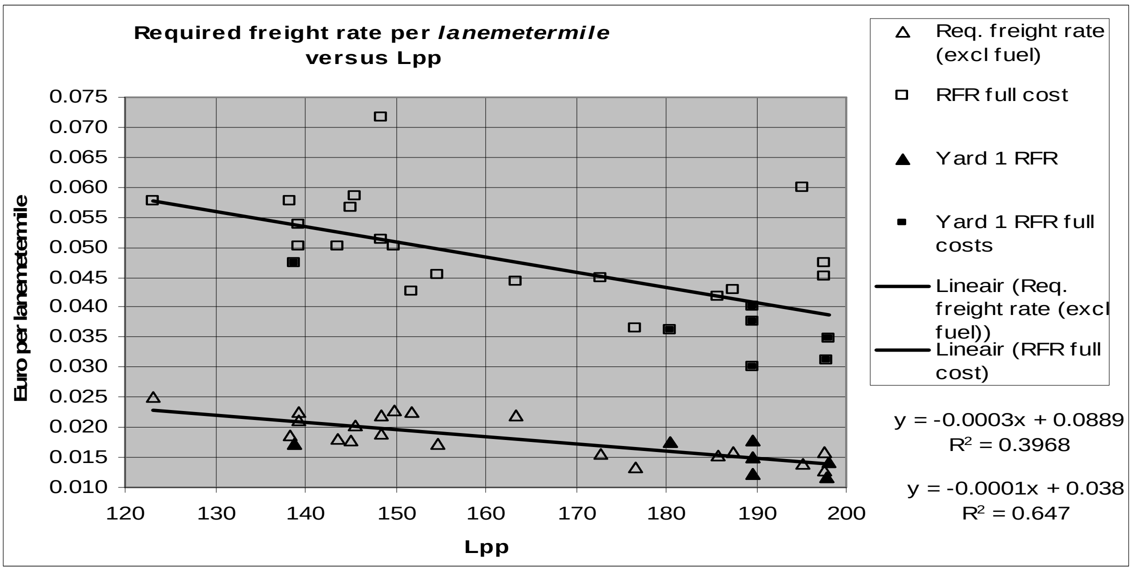

Figure 17 Required freight rate per lanemeter-mile full cost and time-charter rate versus Lpp

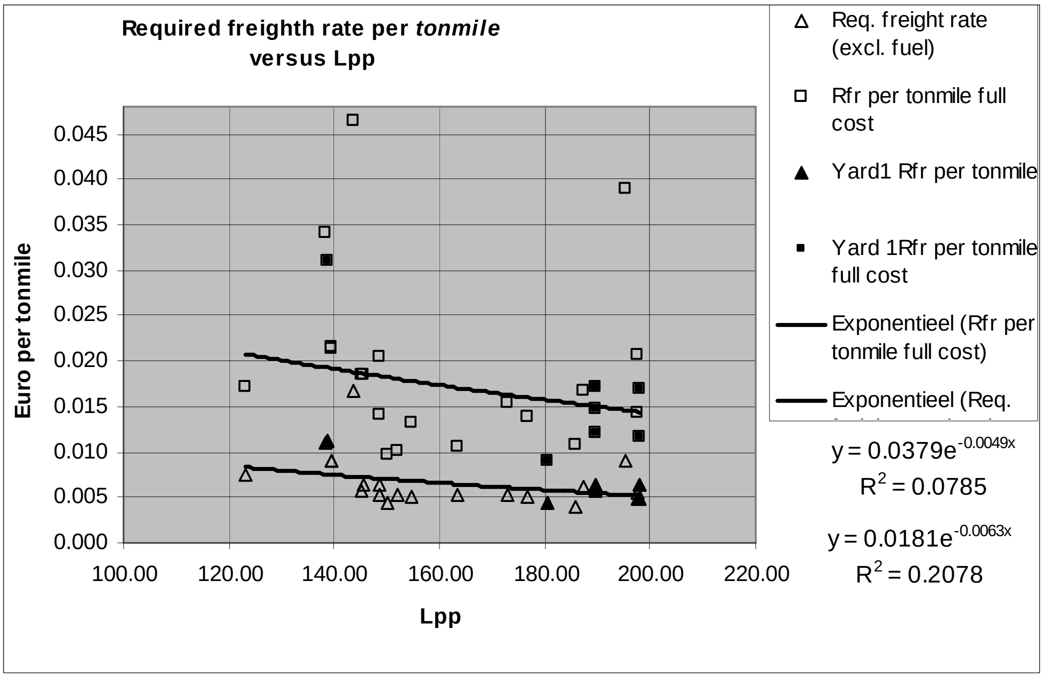

Figure 18 Required freight rate per ton-mile full cost and time-charter rate versus Lpp

One of the vessels of yard 1, the one with a length of just below 140 m has an exceptional large all in freight rate per ton-mile but more than acceptable per lanemeter-mile. This is the short 4 decked vessel described earlier. They managed to increase the lanemeters by applying a 4th deck on a very short vessel. This decision lowers the cargo carrying capacity in tons but increases the available volume for cargo. Its deviating L/B ratio is probably the cause that it is not as superb as its colleagues in figure 19 where the freight rates are set out against the Froude number. These figures, 19 and 20 compensate for the fact that speed can have a substantial influence on the cost level. So it adds value to look at both relationships.

There is a clear "economy of scale" All rates decrease with increasing length. This is not the case with the graphs versus the Froude numbers[3]. The time charter rate per lanemeter-mile (Rfr excl. fuel) is hardly influenced by the Froude number. This is the result of slightly lower Froude numbers at larger vessels on average. (graph not shown here) However these relative faster vessels do need smaller block coefficients which results in a lower ton carrying

[3] The Froude number, Fn, is the scaling factor for the ship resistance due to the produced wave system. With high speeds the most dominating part.

capacity which is reflected in the required freight rates based on a time charter contract in figure 20.

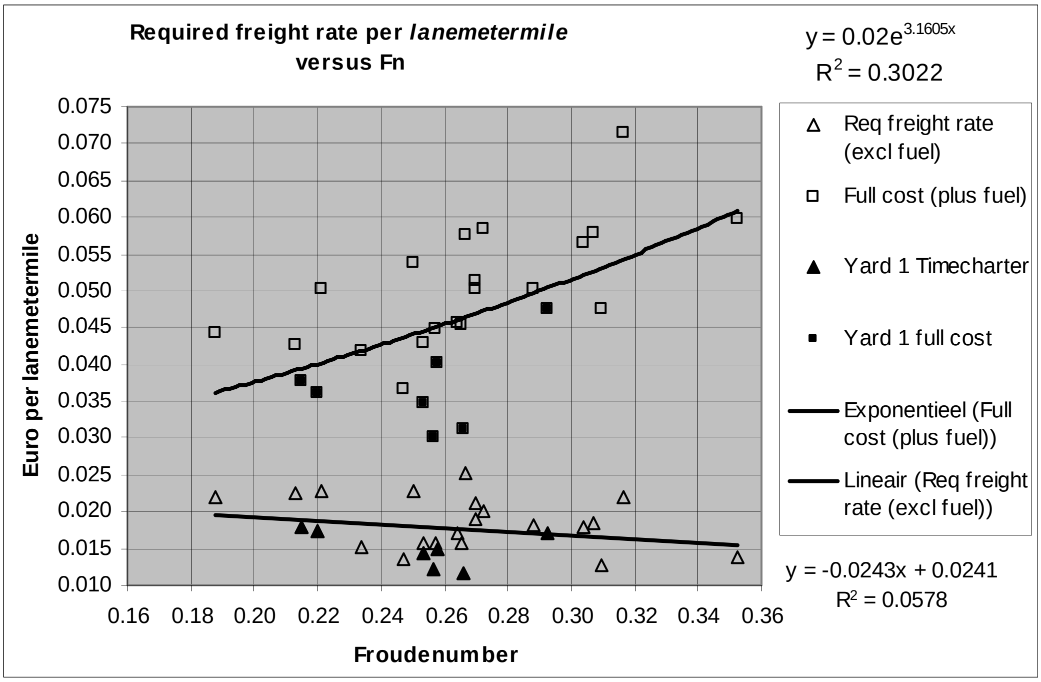

Figure 19 Required freight rate per lanemeter-mile full cost and time-charter rate versus Fn

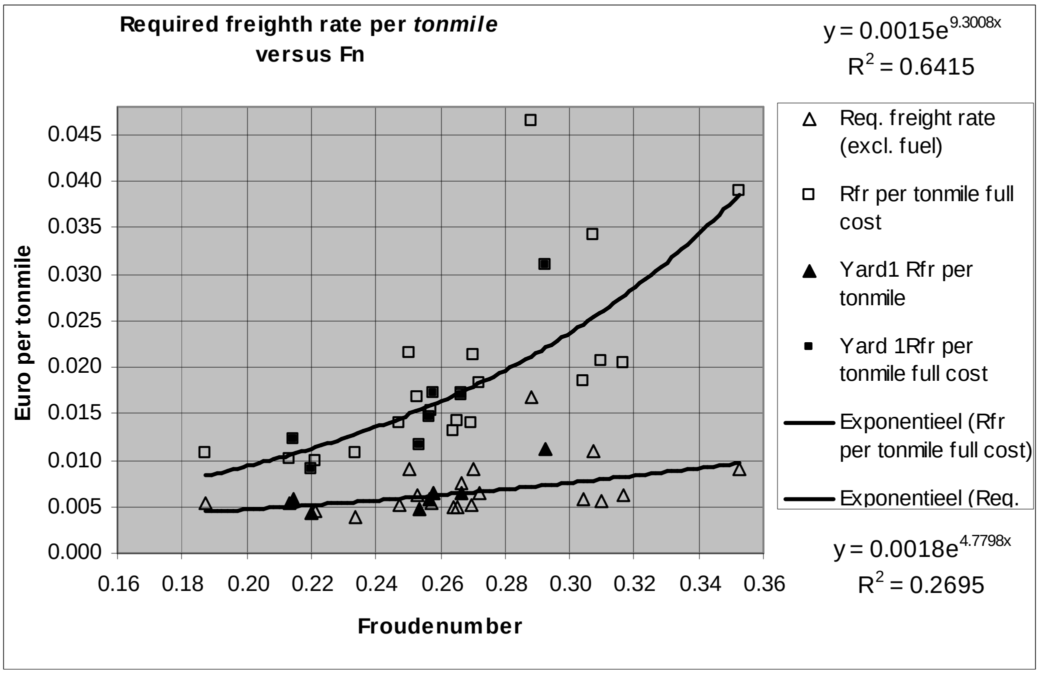

Figure 20 Required freight rate per ton-mile full cost and time charter rate versus Fn

2.5 Conclusions

The main conclusions which can be drawn based on the previous graphs are:

1. The designs from yard 1 are totally focused on medium speed, relative much lane-meters and a relative low deadweight in combination with low building costs due to a moderate lightship and smaller engines. The latter because of two reasons, medium speeds but also excellent hull shapes. This leads to exceptional low required freight rates compared with the competition. 0,03 in comparison to the max of 0.055 euro per lanemeter-mile at a Froude number of 0,258 in figure 19. However per ton-mile they are not exceptional.

2. The spread in required freight rate results shows the lack of attention towards good design and/or the lack of qualitative good methods to judge designs.

3. It could be worthwhile to investigate the impact of the technical improvement in time on the second hand prizes of vessels. The decreasing fuel consumption in combination with the increasing fuel prices can have devastating effects on the economic life time of vessels.

4. Building vessels for relative high speeds in order to attract business will increase the investment, decrease the deadweight, increase the displacement relatively which also increases the fuel consumption. The result is a vessel difficult to operate in other businesses where lower speeds prevail.

5. By placing the design or targeted second hand vessel in the graphs one can get a good impression of the competitiveness of the project. If the required power on lower speeds is known, the same vessel can also be introduced with lower speeds checking its ability to compete at that speed.

Of course further modelling and research work can be done with this model like:

- Although the economical speeds are not yet calculated, they will add interesting information. It enables the user to really compare vessels at their best economic performance point within the proposed sailing profile.
- The model as such seems to work well. Further research of cost figures can certainly increase the ability to compare the results with market situations. The first goal, a consistent comparison between designs and/or existing vessels seems to be achieved.
- All vessels are treated as new buildings in order to get a first consistent comparison. Calculating the second hand prices at constant freight-rates per lane-meter corrected for economy of scale could be an interesting exercise for all vessels, in order to position new designs and/or candidates in the real world.

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