On the conceptual design of large Cutter Suction Dredgers; Considerations for making choices

Jaap L. van Overhagen[1], Marcel Boor[2], André Kik[3] and Caspar H.M. Kramers[4]

Abstract: In December 2003 a milestone was reached when the first **Jumbo** self-propelled cutter suction dredger, "J.F.J. de Nul" was commissioned. This happened 17 years after the delivery of "Leonardo da Vinci", one of the last of the foregoing series of self-propelled CSD being delivered. As she is in all aspects larger and more powerful than all its predecessors, "J.F.J. de Nul" is called a Jumbo Cutter Suction Dredger. In the same year 2003 D.E.M.E. also ordered the design of a Jumbo self-propelled CSD. Although she should be very competitive with De Nul's Jumbo, she is in many aspects a completely different concept.

Of course there are more roads leading to Rome.
In order to make a distinction between the concepts, competing dredging Contractors want to search the outmost competitive design for future new building dredgers. Although she should be versatile, capable to perform well in a range of future, unknown, dredging jobs, she should perform best in one unique well chosen design point. This all is leading to a wide range of different design specifications.

This paper considers all the choices that are generally made during the specification and conceptual design phases of a large CSD, such as:

- Design aspects dependent on kind of soils and operation area(s)
- Dredging depth, capacities
- Degree of self-sufficiency, self-propelled or stationary?
- If self-propelled: which cutter ladder position (bow or stern oriented)
- Seaworthiness in sailing conditions, seagoing dredging capability?
- Type and stroke of spud carriage (flexibility required)
- Spud handling and hoisting system(s)
- Cutter type, diameter, speed, power
- Pump characteristics
- Diesel-direct or (semi or fully) diesel –electric
- Requirements related to noise and vibrations (incl. construction fatigue)
- Degree of automation

There is no doubt that all those aspects have their interrelations, which ask for tuning. Besides, a lot of developments are going on, which have to be balanced carefully in respect of pros and cons. And, of course, all solutions and choices have their impact on the building price as well as on the exploitation costs.

Keywords: Large cutter dredger, design aspects, cutter dredger development, workability, self-propelled, dredging work requirements.

[1] Design and Estimating Department, IHC Holland N.V. - Dredgers - Kinderdijk, - The Netherlands, jl.overhagen@ihcdredgers.com
[2] Design and Estimating Department, IHC Holland N.V. - Beaver Dredgers - Sliedrecht - The Netherlands, m.o.boor@beaverdredgers.ihcholland.com
[3] Design and Estimating Department, IHC Holland N.V. - Dredgers - Kinderdijk - The Netherlands, a.kik@ihcdredgers.com
[4] Development Department, IHC Holland Dredgers - Kinderdijk - The Netherlands, chm.kramers@ihcdredgers.com

1 INTRODUCTION

Recently the self-propelled cutter suction dredger "JFJ DE NUL" was commissioned. As it is in all aspects larger and more powerful than all its predecessors, "J.F.J. de Nul" is called a Jumbo Cutter Suction Dredger (CSD). Recently D.E.M.E. also ordered a self-propelled Jumbo CSD.

For trailing suction hopper dredgers (TSHD's) scaling-up of the equipment leads to a larger market for the ship-owners. Projects previously not feasible can now be executed economically due to lower costs per cubic metre of dredged material.
The recent developments in CSD design might lead to a comparable phenomenon?

The large cutter suction dredgers with a total installed diesel power of 10000 kW or more, which have been built during the last decade, are based on many different design philosophies resulting in a wide range of concepts.
In this paper design aspects of large cutter suction dredgers are highlighted in respect of the dredging work requirements.
In view of this various design choices are discussed, such as stationary, self-propelled, ladder position or rate of autonomy.

2 HISTORY

More than 100 years ago the first Cutter Suction Dredger (CSD) was developed and built. The size and power of the first CSD's were limited and these dredgers were used for inland waters. Nowadays the larger CSD are not only used for inland waters, but also for offshore dredging works and the capacity has increased enormously.

The first CSD with a total installed power of more than 10000 kW was built in 1968. This dredger "Sete 32" was built at the Merwede Shipyard and is still in operation in the Middle East.
In 1995 the largest stationary cutter dredger was built. This dredger, the "Mashhour", is owned by the Suez Canal Authority (SCA). The total installed diesel power of the "Mashhour" is 22400 kW.

In 1977 the first large self-propelled cutter suction dredger was built. This dredger, the "Aquarius", was provided with a total installed diesel power of almost 13000 kW. Six years later the "Taurus" was built. This self-propelled CSD had an 85% higher cutter power and a total installed power of 15600 kW. Until recently "Leonardo da Vinci" (Jan de Nul, 1988) was the largest self propelled CSD with a total installed diesel power of 20250 kW.
The new self propelled jumbo cutter suction dredgers are even more powerful with a total installed diesel power of approx. 27000 kW.

World's dredging fleet comprises about 40 large CSD's. Approximately 25% of these CSD's are self-propelled. The average age of the dredgers is more than 20 years.

3 INVESTMENT IN RELATION TO FUTURE DREDGING WORK

Considerations in regard of investment

An investment in commercial dredging equipment is risky. In the past dredging market appeared to be very cyclical and its future is quite unforeseeable. Therefore it may be clear that decision making for future investment in a large Jumbo size Cutter Suction Dredger will be ruled by uncertainty. Aiming for shareholders value at an acceptable level of risk, basically three main scenarios can be recognized. Mixed scenarios will also occur.

1. **Highly specialised niche market dredgers**. Such a dredger is designed fit for purpose. Additional functions for other type of dredging work will be left out. In many cases the duration of the project will be shorter than the technical life time of the equipment. Because future application of the dredger is too uncertain investment cost should be recovered for 100% during the project. Generally only long term projects are interesting. An example of highly specialised niche market equipment was found in the Netherlands when special equipment had to be built for the construction of the Eastern Scheldt Estuary works (Storm surge barrier).
2. **Commercial dredger with a life time high degree of utilization.** With commercial is meant that these dredgers are operated in an open market. High utilization will generally occur when the dredger is able to perform various kinds of dredging. This may conclude to a multi purpose dredger. This conclusion, however, is too easy. Besides its multi purpose character it should also be capable to dredge in various areas, weather and wave climates. It should be even capable to accept jobs in the middle of nowhere, without any support from shore. It should be economical for a mix of small and larger jobs. This results in a lot of transports between consecutive dredging work areas, which requires special provisions to reduce related cost. A recent example of such a dredger is the Self Propelled CSD JFJ DE NUL.
3. **Dredgers for a protected market** have their own rules of economics. These dredgers may be both specialized and general purpose dredgers. They should fit the mix of dredging work within that closed market. In case of dredging work contractor and customer – such as harbour authorities - are the same; there is in fact no market at all. An example of such a restricted market is found in Egypt where the Suez Canal Authority is operating the CSD “Mashhour”.

There are many good reasons to choose for a heavy, high powered dredger. Considerations for these are discussed later in this paper. The larger the investment the more certainty about return on investment is required. Therefore a large CSD needs a high degree of utilisation and will generally be more versatile than a small one. In the mean time, in order to compensate for the investment cost of features that are only rarely used, but needed to be versatile, the dredger should have a high production rate, leading to low specific dredging cost per dredged unit.

From dredging work requirements to outline specification of dredger
Before the specifications can be formulated to which the dredger will be designed, the future market expectations have to be mapped and analysed. For the analyses following outline diagram may be useful.

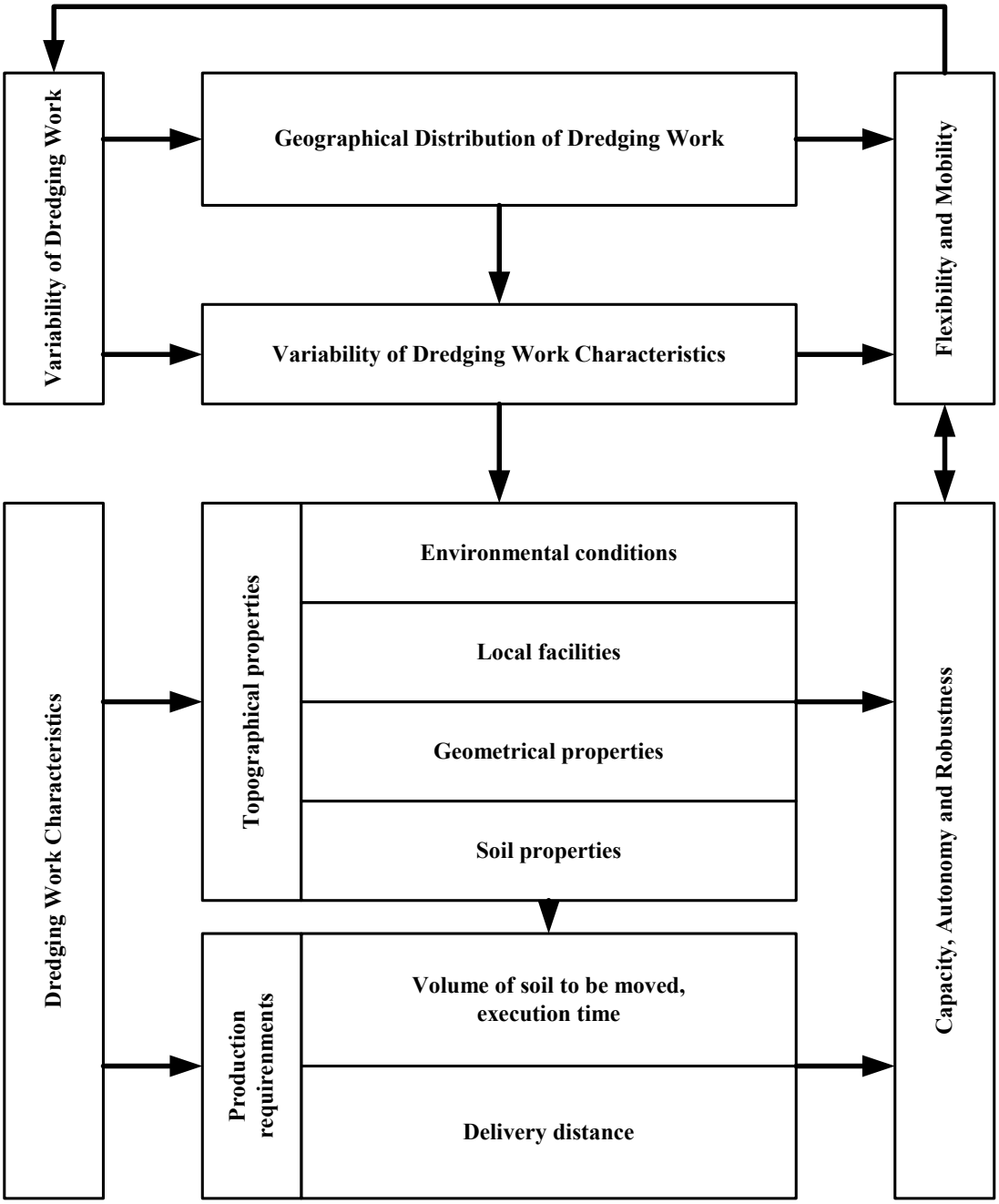

Diagram 1: From dredging work requirements to outline specification of dredger

Two main view points can be taken.
Looking from the left side a future dredging work can be characterized by both production requirements and topographical properties.
Looking from the top side the mix of future dredging work can be observed. Relevant information is then the geographical distribution of future dredging work and the variability of dredging work characteristics.
From the geographical distribution, together with the distribution of duration of various dredging jobs the required mobility can be determined. Mobility is meant to be the rate of ease (and cost) with which the dredger can be moved from one location to another.

The variety of dredging work requires flexibility of the dredger for operation in different environmental conditions such as weather and wave climate, to deal with restrictions from geometrical properties and (lack of) local facilities, and, last but not least, soil volumes and properties, delivery distance.

After mapping the future world dredging workload one will of course compare this indicative market expectation with the capacity and geographical distributions of the existing fleet of both the contractor involved and his competitors.
From this a scope of work for a new dredger may be derived, which will be the starting point for the outline specification. Choices have then to be made whether or not the dredger should be a specialized dredger, built for a restricted market only or versatile. Further it is important to know the frequency in which the dredger has to be moved and over which distances.

4 DREDGING WORK REQUIREMENTS

This chapter shows detailed definitions to explain the dredging work requirements in Diagram 1 and 2.

4.1 Environmental conditions

Environmental conditions consist of two major aspects:
- Weather climate
- Wave climate

Temperatures of air and water as well as humidity are defining in weather climate. Also the chance of violent storms blowing up is an aspect of the weather climate.
Wave climate is characterized by wave height, period and its distribution (spectrum). Also statistics in respect of wave appearance in time is useful.
Both climates are leading to workability. Workability is part of the dredger's overall capacity.
Violent storms can lead to autonomy when means of escape are required.

4.2 Local facilities

A wide range of local facilities can be stated. If few facilities are expected to be available then a high rate of autonomy of the dredger is required.
Examples of local facilities are:
- Repair area ashore
- Workboats or other supporting vessels
- Supply of spares
- Supply of bunkers, drinking water and other consumables
- Availability of shore pipelines and/or barges and passage of merchant ships
- Availability of shelter area

These examples are all related to autonomy.

Also water depth for spud tilting and ladder tilting are examples of local facilities which have to be taken into consideration. Restrictions in water depth can determine the way of tilting.

4.3 Geometrical properties

Geometrical properties are related to the dredging work itself. Examples are:
- Water depth at start
- Water depth to be realized
- Canal width, slope and quayside

Consequences of these requirements are treated in paragraph 5.1: "Capacities".

4.4 Soil properties

Soil properties of the material to be dredged strongly influence the production of the dredger. Examples are:
- Density
- Hardness, strength
- Grain size distribution

Soil properties can also influence the workability of the dredger. Hard soil means small allowance of wave induced ships movements.

4.5 Production requirements

Production requirements, as there are: volume of soil to be moved, execution time and delivery distance, speak for themselves. They are primary dictating the capacities of the dredger. However the capacity of the dredger is still to be seen in combination with topographical properties, like hardness of rock, water depth, etc.

4.6 Geographical distribution

With geographical distribution is meant the different locations of dredging work. The more locations are expected the higher the rate of mobility is required. Even more in case the distance between locations is great.
It can lead to variability and so ask for flexibility. A clear example of this is the weather climate, which is related to the location of dredging work, e.g. it can be desert, tropical or polar.

4.7 Variability of dredging work characteristics

Flexibility and variability of dredging work characteristics influence each other. A wide variability requires a multi purpose cutter dredger. A specialized dredger, design for less variability, is the opposite.

5 CAPACITIES, WORKABILITY AND AUTONOMY

Dredging work requirements result in different aspects of the cutter dredger design as explained above. This chapter goes fully into the aspects of the design, in respect of capacities, workability and autonomy.

5.1 Capacities

Primary aspects for the capacities of the dredgers are:
- cutter capacity
- dredge pump capacity
- swing length and speed
- spud carriage availability and stroke
- automation

But there are also some secondary aspects, which are influencing the capacity of the dredger indirectly. Examples of this are:
- reliability of the dredger
- canal width, slope and quayside configuration
- availability of a barge loading system

These items are explained more over below.

Cutter capacity
The cutter capacity mainly depends on:
- cutting torque
- cutter reaction force
- cutter speed
- swing winch pull
- spud reaction
- soil properties
- angle of the cutter(ladder)

Dredge pump capacity
The dredge pump capacities depend on the required flow rate and head. In regard to this an important factor is the discharge pipeline length, which can differ a lot if both pumping ashore at long distance and barge loading are possibilities. Furthermore, besides geodetic height, the capacity of the pumps is strongly influenced by the density of the mixture and so cutter production related to soil characteristics and suction mouth performance. Therefore a lot of scenarios have to be calculated to find an optimum design point of each pump, see also Flexibility.

Swing length and speed versus canal width
A great distance between cutter and work spud enables a cutter dredger to execute a wide cut per swing. This results in a high dredging efficiency (less loss of time in the corners, less need to advance and shift the swing anchors).

On the other hand it increases the minimum workable canal width, so small works may be more difficult or even impossible to execute. If dredging a canal with vertical quaysides or a slope in shallow water is expected, then special attention is required for geometry and appendages besides the cutter ladder.
Appendages below the waterline are rudders or propellers. The rudders and propellers of a self-propelled CSD may constitute an obstacle during dredging and should be properly protected when these are situated besides the ladder. A more drastic solution is to retract the propellers including rudders while dredging ("retractable thrusters"). Although retractable thrusters are not new it still would be an innovation to apply this type of propulsion on a CSD. Moreover it will be a challenge because available space in the ladder pontoons is very limited and loss of displacement (moon pools) in the same area is not favourable.
Appendages above the waterline are anchor boom pivots or the dredger's hull itself. Both may constitute an obstacle in case of vertical quaysides.

Spud carriage
The application of a spud carriage is common practise for large CSD's. This increases the efficiency of the dredger significantly. The larger the stroke of the carriage the more swings can be made without spud repositioning and consequently the higher the efficiency of the dredger.

Automation
Large cutter dredgers are complex dredgers. Also operating such dredgers is complex. Therefore process automation and monitoring instrumentation are relevant because they will increase the efficiency of the dredger. Of course automation can be executed to a lot of levels, which depends on the Owner's philosophy and the cost and skills of personnel.

Reliability of the dredger
Reliability is an important matter, because it is directly related to the employment rate of the dredger and therefore the total capacity and efficiency of the dredger on a yearly base. Dredging pipelines of wear resistant material is one example to reduce repair and maintenance time and so increase the employment rate. Availability of spare parts and/or repair facilities is another example.

Barge loading system
If the volume of soil to be moved is small in combination with short execution time and long discharge distance, then barge loading can result in the largest overall capacity. This can also be the case in swell (see also Workability).

5.2 Workability

The workability of a cutter dredger is based on two aspects, both related to environmental conditions:
- ability of working in weather climate
- ability of working in swell, related to the wave climate

Weather climate
This is in principle not special for cutter suction dredgers. Nevertheless, a lot of differences occur of related installations, from AC-unit to heating of deck equipment. This is a result of the great application differences of ship's equipment; from just local use to world wide operational. So this matter strongly relates to mobility and flexibility, see also next chapter. It may be clear that the extremer the environmental conditions are, the larger the related installations will be. Also the dimensions of cooling water units and thermal oil exhaust gas boilers may increase.

Wave climate (working in swell)
One of the main advantages of a cutter dredger is its ability to actively excavate the material to be dredged. Reaction forces are guided through the ladder to the pontoon and trough the spud to the bottom. High cutting powers can be installed in order to dredge materials of high strengths such as rock.
In order to absorb the cutting forces rigid constructions are required. This advantage for the cutting process on the other hand provides a disadvantage while operating in sea conditions. Especially long swell can exert high forces on the construction due to the inflexibility. Due to the alternating character of these forces they can cause severe fatigue and impact damage. This may lead to high maintenance cost in course of time.

In principle four main scenarios can be contemplated while trying to extend the workability of a CSD in waves:
- increase the main dimensions of the dredger
- shape the hull of the dredger
- make the relevant construction parts heavier (more rigid) to allow higher forces
- introduce flexibility to limit the forces exerted on the construction parts

The overall workability does not only depend on the dredger itself. Also floating pipelines and auxiliary vessels can be a limiting factor for the dredging operation. On the other hand, the dependency on local facilities decreases at a higher rate of autonomy and mobility (e.g. propulsion installation, barge loading facilities).If *barge loading* will be used in swell then heavy duty fendering is needed.

Increase of main dimensions
Increased main dimensions of the dredger result in significant lower movements of the vessel in waves.

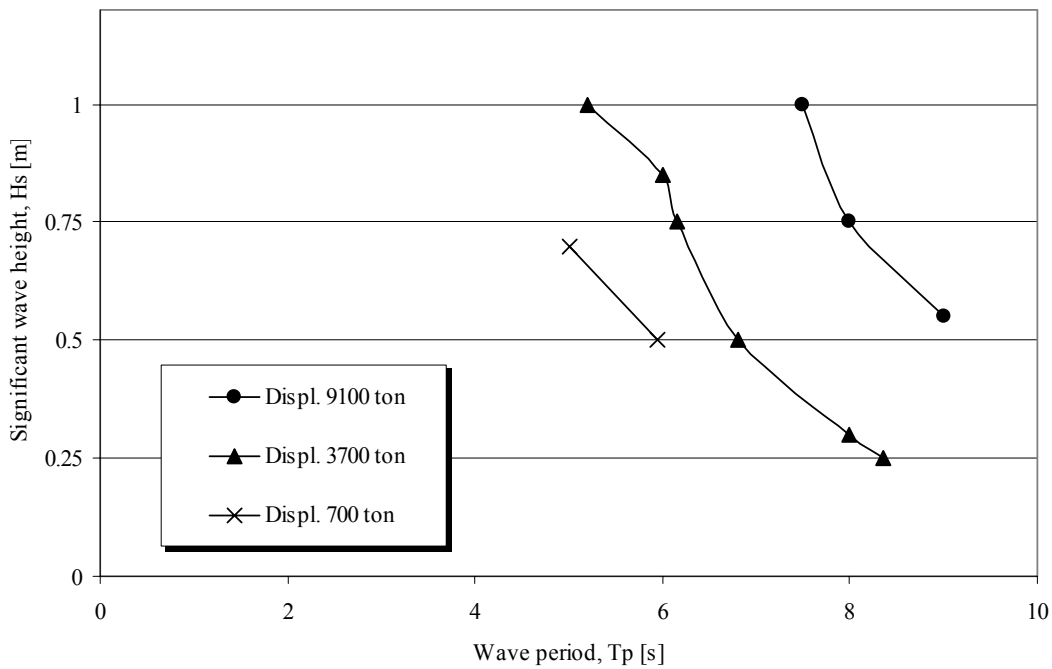

Figure 1: Equal cutter movement for different ship's size as a function of wave conditions (15 m water depth, wave direction 15° from spud side)

Another aspect is the workability in swell in respect of water on deck. This is related to the working freeboard of the dredger. Large dredgers have generally a larger freeboard.

Hull shape
Another way of reducing the movements, especially in short waves, may be by shaping the hull form. Stationary dredgers designed with a shaped hull, however, are very rare. Self-propelled dredgers are already shaped in respect of sailing.
The next figure (Figure 2) shows the difference in wave forces for a dredger with shaped hull and a rectangular pontoon. Main dimensions are approximately the same.
The shaped hull performs best at the specific conditions in Figure 2. There are, however, also cases known where the opposite effect occurs. Fortunately, calculation can be made to optimise the hull shape in respect of specific wave conditions.

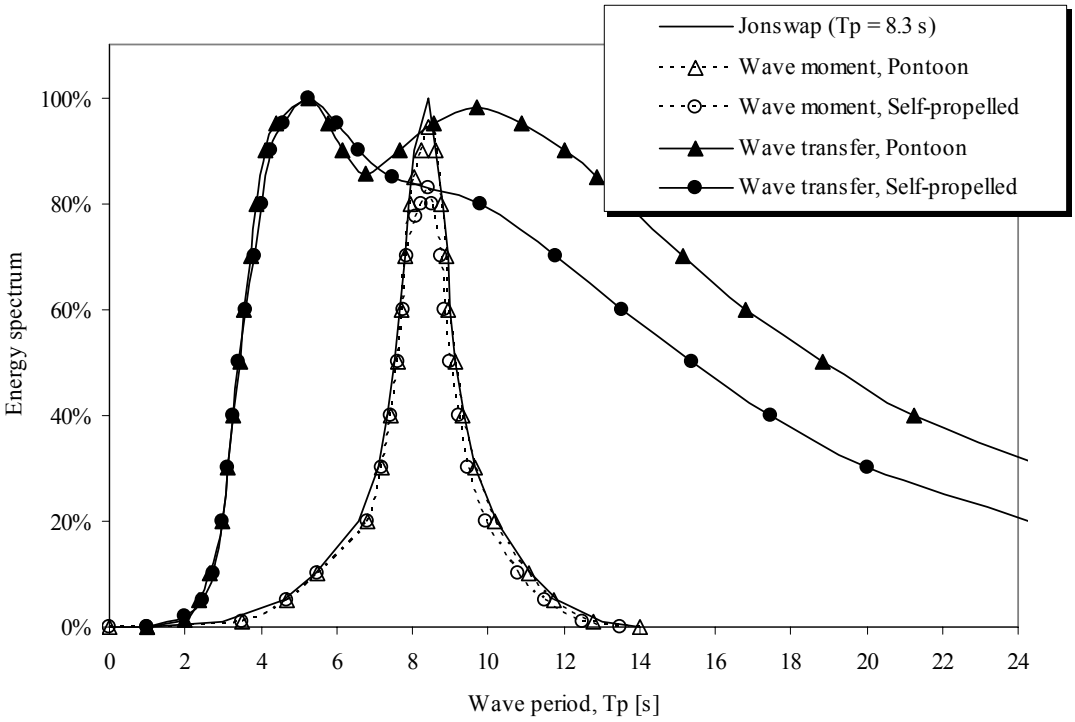

Figure 2: Energy spectrum for pitching of different hull shapes in waves.

At the same displacement a shaped hull has larger main dimensions (Length x Beam x Draught) in comparison with a rectangular pontoon. As draught is generally a design criterion only length and beam can be increased. An increase of weight and so a further increase of dimensions, is caused by a larger bending moment. This is a consequence of taking away displacement at the ships ends where the hull is shaped, which is in opposite way compared to the weight distribution of the dredger.

Dredging in swell often takes place with the ladder in the direction of the shore (waves entering at spud side). Therefore a *bow at spud side* is an advantage for better withstanding and deflection of the incoming waves compared to a rectangular shape. As a result less fierce movements of the dredger may be expected.

There are, however, some technical consequences of creating a bow at spud side.
The construction of the guidance of the auxiliary spud will be part of the bow and has to be faired. Furthermore tilting of the working spud may be more complicated in a closed spud well. Nevertheless, if minimum water depth during spud tilting is already an issue, then the closed spud well is not a determining factor anymore.
An advantage of a closed spud carriage well is the barrier to oil pollution entering the well from outside the dredger, which causes troubles for friction bases spud hoisting. A similar advantage is the barrier to other pollution from the vicinity, like trash.

The best hull shape for a floating object, that is meant to undergo little movements in swell, is a semi-submersible one. Is that the innovation of the future? This will certainly be very expensive so feasibility must be doubted. It appeared not feasible at the time Simon Stevin was built.

Heavy construction
The "J.F.J. De Nul" is equipped with a rigid bogie type spud carriage, which is the same type as fitted on the "Leonardo da Vinci". The spud reaction is led via bogies at front and aft side of the carriage to the rails in the spud carriage well. Especially the carriage and spud of the "J.F.J. de Nul" are examples of heavy construction as a result of a large spud reaction in combination with a lot of finite element calculations. On top of that it is suitable to withstand the large spud reaction in any direction to the vessel, so 360° around.

Limiting forces by flexibility
In the past more flexibility in the anchoring system of the dredger was introduced by means of a Christmas tree installation. The spud is replaced by a system of three winches, wires and anchors. By placing the anchors spaced at 120 degrees the dredger can rotate around a more or less fixed point. The elasticity of the wires enables the dredger to move when forces are applied on the vessel. Disadvantage is that at every added force applied, whether these are wave induced forces or dredging forces, the wires will elongate, even when allowable forces are not yet exceeded. Especially when dredging in more compact soil, this flexibility is undesirable, because it will negatively influence the output of the dredger, and can introduce high forces on the cutter, the cutter drive, the ladder, and the ladder trunnions.
Flexibility can also be introduced within the spud carriage construction. An example of such a solution is used on the CSD Ursa (former Bilberg I). On the Ursa flexibility in longitudinal direction is provided by a spud carriage support system of crossed wires and sheaves. A new development is that these wires can be tensioned/adjusted hydraulically. Because of the hydraulic tensioners the system can now act as a (peak) load limiter. When using special wires the (undesired) elasticity of the wires themselves can be minimised.

Nowadays spud carriage systems are being developed which can be set rigid for cutting hard material in calm sea conditions or set flexible in swell; an innovation that combines the operational advantages of both systems.

The effect of flexibility in the spud carriage system is illustrated in Figure 3.

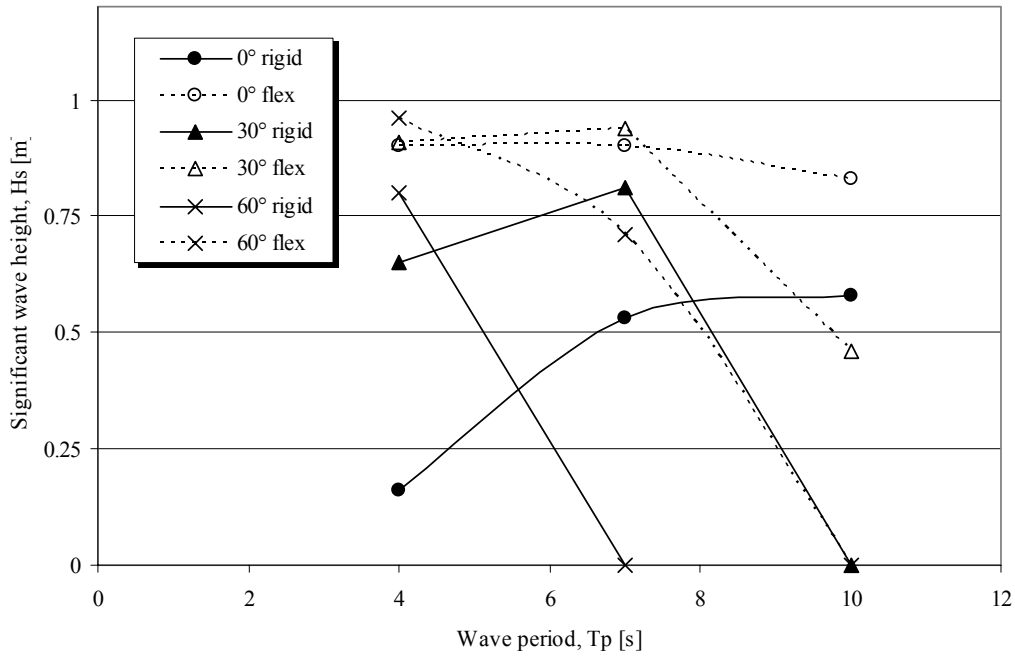

Figure 3: Comparison of a rigid and flexible spud carriage; limitations as a function of fatigue (indicated wave direction from spud side).

5.3 Autonomy

The rate of autonomy is a result of the availability of facilities at the dredging work location. Examples of facilities to increase the autonomy of a cutter dredger are:

- Deck crane and cutter changing equipment
- Cutter repair platform
- Spud tilting system (see Capacities, bow at spud side)
- Anchor booms
- Barge loading (see workability)
- Deadweight, tanks and store spaces
- Repair areas: inside and outside
- Tools and other repair/maintenance equipment
- Accommodation
- Means of escape

Most of these items do not need further explanation; a few are treated hereafter.

Deck crane and cutter changing equipment
It is obvious that a deck crane increases the rate of autonomy, especially in combination with one or more repair areas. The choice to be made is installing a travelling deck crane or fixed pedestal crane(s). The nature of travelling of the deck crane highly affects the layout of the dredger, because the crane has to pass from fore to aft end of the dredger and the rail has to be straight over the entire length. On cutter dredgers the deck crane is often multi purpose and used for cutter handling including cutter changing. This calls for extra requirements to the crane.

Accommodation
Autonomy also means the capability to accommodate crew. This means not just accommodation space for the crew, but it also means a level of noise and vibrations in which the crew are able to live. In fact the crew will stay on board day and night.

Means of escape
The combination of main dimensions, hull shape, spud installation and weather climate dictates the escape requirements. The ability to escape on its own means contributes to the level of autonomy. The following means, subsequently increasing in level of autonomy, are possible:

- towing
- storm winch
- self-propulsion.

6 FLEXIBILITY AND MOBILITY

Flexibility and mobility are strongly related. In general a dredger with a higher mobility rate also requires a higher flexibility rate.

6.1 Flexibility

More flexibility sometimes results in a range of characteristics for the dredger. Examples: a dredger can be capable to discharge at a distance of 5 upto 10 000 metres or it is suited for -10°C upto 40°C.
On the other hand flexibility can result in a maximum capability. An example is autonomy. The dredging work with maximum required autonomy results in the maximum autonomy for the dredger. Other works are not decisive in this matter.
Another result of required flexibility is a concept choice (e.g. stationary or self-propelled).
Finally flexibility can be applied for all dredging work characteristics and geographical distribution. A few examples are mentioned hereafter.

Range of dredging depth
Jumbo dredgers are able to dredge on a large range of dredging depths (ca. 6 - 35 m). This is realised by fitting a low and high trunnion point and by applying a large cutter ladder angle to obtain maximum dredging depth.

In respect of minimum dredging depth and consequently minimum draught the trim conditions are very important. It is for that reason that the centre of gravity has to be accurately determined at an early stage. Regarding this matter it may be interesting to make a comparison with hopper dredgers. For hopper dredgers the ships weight is generally about one third of the total dredging displacement. The weight of Jumbo cutter dredgers can be ninety percent of the displacement at minimum dredging draught, so the impact of inaccuracy is considerable and know-how is important.

At the same time the spud is affected by the required dredging depth. The length of the spud is determined, but by increasing the length also the spud moment will increase and so the required strength of spud, carriage and other related constructions and equipment.

Types of soil
Diversity of soil requires flexibility of cutter types. Diversity of soil and cutters determine different cutter drive characteristics. This also leads to a wide range of excitation frequencies in respect of vibrations.

Range of shore pumping distance
Diversity of shore pipeline length asks for flexibility in pump characteristics. The range can vary from pumping a few metres away (barge loading) to pumping over ten kilometres. Flexibility of this order is not only achieved with pump drive flexibility but also with flexibility of the number of dredge pumps in use.

6.2 Mobility

Mobilisation costs can form a substantial part of the cost for a dredging contract. Large CSD's can be towed or be transported on a heavy lift / submersible vessel to the dredging site. Stationary CSD's are often designated to a geographical area in order to reduce mobilisation time and money. However this may lead to a decrease in utilisation of the equipment.
A self propelled CSD can be relocated to different areas more easily. The choice between a self propelled and a stationary dredger is based on:
- the added costs of depreciation and interest due to the higher investment of a self propelled dredger
- the added cost of transportation and insurance of a stationary dredger compared to the sailing time/costs of a self propelled dredger
- the anticipated number of relocations for the dredger
- the anticipated utilisation of either version (for a self propelled dredger the utilisation could increase because especially smaller jobs at different locations can still be dredged economically)
- composition of the fleet of the owner and the competitors' fleet

Creating a *self propelled dredger* in order to increase the mobility is not just a matter of adding a propulsion installation. It is much more as it must fulfil all the requirements for seagoing vessels. In order to really improve the mobility, the dredger should be more autonomic, which requires the availability on board of spare parts and auxiliary equipment. Consequently store space, e.g. containers, and deadweight will rise. In this respect even a barge loading system can be seen as a way of being more self supporting, as there is no need to mobilise large numbers of floating and shore pipelines when barges can be used.
It also means extra nautical outfit like life saving boats and nautical anchor equipment. Apart from extra investment, these items may have impact on the layout of the design. Seagoing also means extra requirements on the vessel's construction. A forecastle is required and the main section may be influenced.
The shape of the hull of a self-propelled CSD should be such as to ensure a minimum sailing resistance without neglecting the functionality of the ship as CSD. The main dimensions will increase due to the shaped hull (Workability). A further increase of dimensions is caused by a larger ship's weight, affected by extra specific parts (e.g. propulsion and nautical parts) and higher autonomy rate including deadweight.

One of the considerations for the design of a self-propelled CSD is the position of the cutter ladder: in fore ship as part of the bow (ladder bow concept on dredgers like "Oranje" and the "Ursa" (former "Bilberg 1") or in aft ship with rudders and propellers besides it (bow at spud side, like "J.F.J. De Nul", Leonardo da Vinci and Taurus).
Aspects of the bow at spud side are already mentioned in 5.2 Workability, item *Hull shape*. The ladder bow concept is explained below.

Ladder in bow
This is specifically a self-propelled variant with a hull shape just for sailing. The following aspects are related to this concept.

The shape of the cutter ladder is determined by working at the minimum dredging depth. At least it is required to be just free from the sea bottom when dredging in shallow waters. A larger clearance will give a reduced risk that the ladder will behave as a bulldozer and/or get jammed.
In the ladder bow concept the shape of the bow is directly linked to the shape of the cutter ladder, as the ladder, in hoisted position, is part of the bow. The more clearance is taken between cutter ladder and sea bottom the more fore ship besides the ladder has to be cut away. And that is just the location where displacement is most welcome in respect of vessel's trim conditions. It finally results in larger main dimensions, because at the other side of the dredgers also displacement has to be reduced to limit the trim.
Another way of solving this is by rejecting the need to conform the shape of the ladder to that of the fore ship. In that case the fore ship gets a kind of catamaran shape. That would be totally new in the cutter dredger branch.

Forces acting on the ship, especially on the cutter ladder, is another aspect. At rough sea the waves can lead to high forces on the ladder due to slamming. The accelerations as result of pitching of the ship are usually the worst in the foremost part of the ship. Consequently this requires a specially adapted rigid construction for the ladder including sea-fastening of the ladder. Especially the leverage of the ladder may result in high accelerations and big forces so a heavy locking system is required. In some cases model tests are needed to predict the forces due to slamming. On basis of experience with the former CSD "Oranje" and the recent IHC design it may be concluded that small details have a large impact on the result.

Vessel's resistance and propulsion can be quite different for both ladder positions. The resistance at similar main dimensions is higher with the ladder in the bow. Especially for the ladder bow concept details of the bow construction, including the cutter ladder, can affect the ship's resistance.
Besides the position of the spud well is of large influence on its added resistance. This is substantial less in case the spud well is situated in the bow.
All this is based on the ladder in its low trunnoin point. The resistance is larger at high trunnion point, in particular with the ladder in the bow.
The efficiency of the vessels propulsion system is another item. An advantage of installing the ladder in the bow is the possibility to apply diesel direct propulsion. This enables a higher propulsion power at low investments and less efficiency losses than using an electric drive. However for a clear comparison on efficiency the difference in ship's resistance has to be considered as well. Finally the delivered diesel power to obtain a certain speed results in an objective comparison.

View from the bridge is also related to sailing direction. As a result of installing the ladder in the fore ship the forward view during sailing is very limited by the ladder gantry and the anchor booms. With the ladder in highest trunnion point it gets worse. The backward view however is better. In case of the ladder stern concept the funnel(s) hinder the forward view.
Sailing and dredging in the same direction is an advantage for the arrangement of the bridge and the orientation of the crew.

Last but not least, the distance between the spud keepers will approximately be divided in two in order not to obstruct the propeller. This results in a significant reduction of the permissible auxiliary spud load. For dredgers with the ladder in the bow the spud carriage well may be open (identical to stationary dredger). This increases the number of technical solutions of tilting the working spud if water depth during tilting is not limited.

7 JUMBO CUTTER DREDGER CHARACTERISTICS

In the last decade major steps have been taken in the development of materials, diesel engines, numerical calculations, design techniques, production techniques and automation. Driven by a market demand the trailing suction hopper dredgers (TSHD's) were the first dredging vessels to profit from these developments. An enormous growth in scale in TSHD's has taken place with as climax the Jumbo hopper dredgers. In this new decade a similar trend has born for the CSD's.

The Jumbo trailing dredgers were mainly triggered by economy of scale in transport and dredging capacity. The main trigger for the Jumbo cutter dredgers is to increase their capabilities for special operations like cutting rock and working in swell.

But how is the performance of Jumbo cutter dredgers judged in respect of the main diagram? The conclusion will be that self-propelled Jumbo cutter dredgers have:
- large capacities
- large autonomy
- large workability
- large flexibility
- large mobility

Although the dredging depth did not change much the main dimensions did grow significantly, as shown in Figure 4, resulting into more workability.

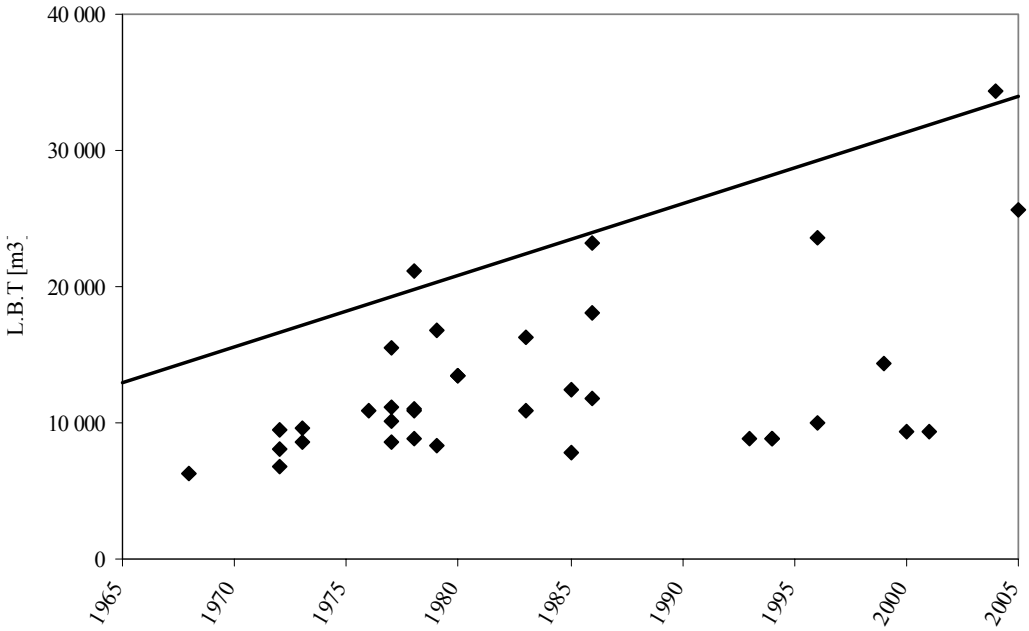

Figure 4: Increase of CSD Main Dimensions.

The same can be told by increase of total installed power (see Figure 5).

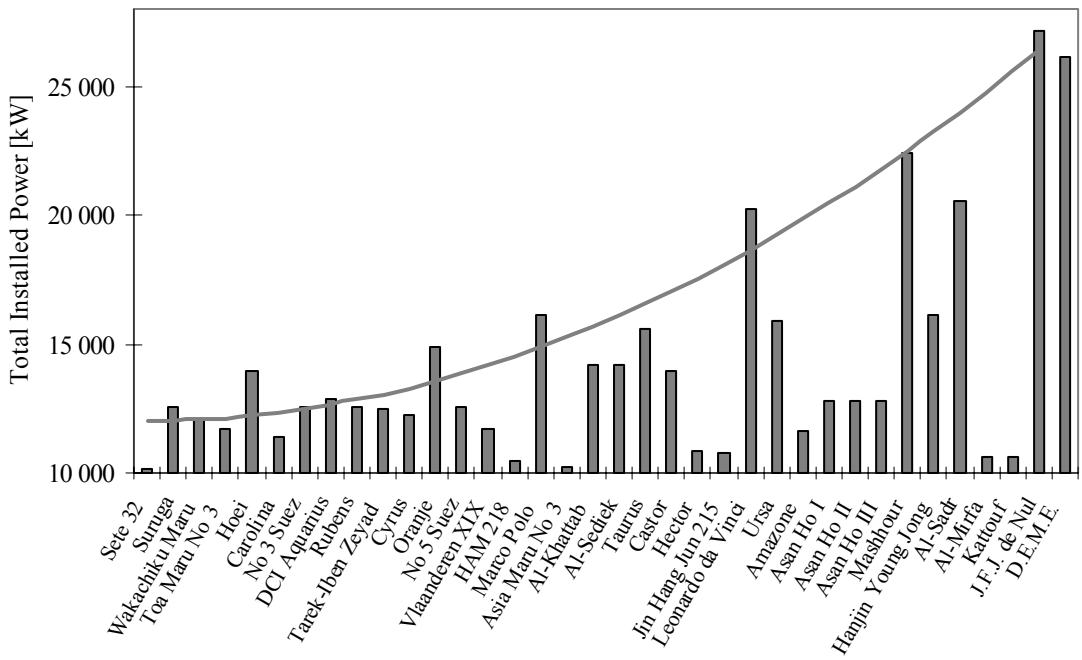

Figure 5: Increase of total installed power.

The increased power results in higher productions (see Figure 6). For this aspect economy of scale is relevant. The increase of power is affected by the growth of the dredging installation. This has led to an enormous increase in weight of dredging components like cutter ladder, spuds and spud carriage.

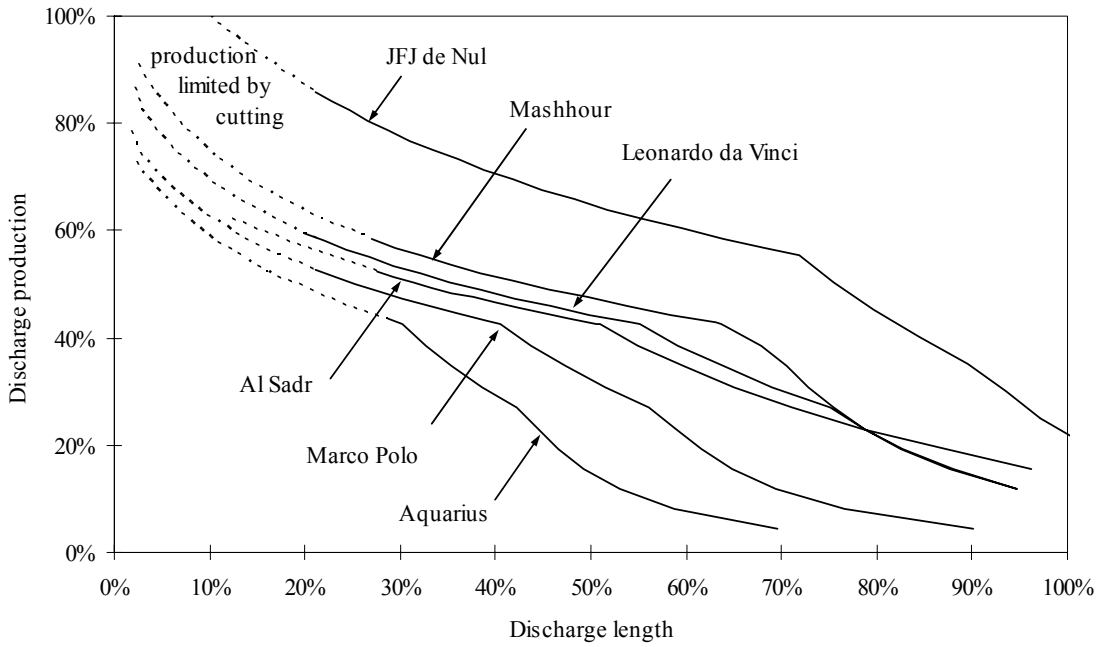

Figure 6: Comparison of production of large CSD's working in sand.

It may be no surprise that the investment for a Jumbo cutter dredger is large, as well, even more of it is self propelled. However:

- Transportation by third parties is very expensive for large vessels (Jumbo dredgers). A few large trips are enough to compensate for the investment (see Figure 7 and 8).
- More flexibility in combination with better mobility might generate extra work (e.g. work on sailing route) and even more variety of dredging work (e.g. rock or sand, sheltered area or in swell). And so the utilization rate of the dredger will be relatively high.

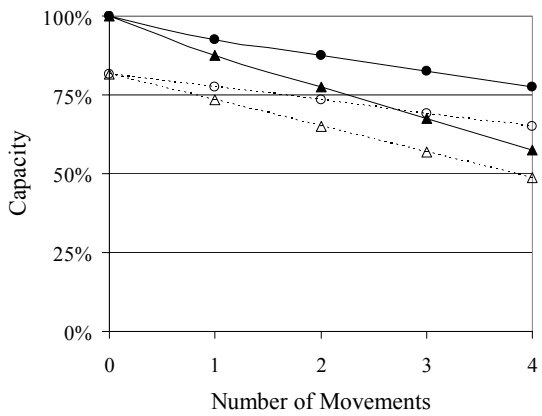

Figure 7: Capacity versus mobilization

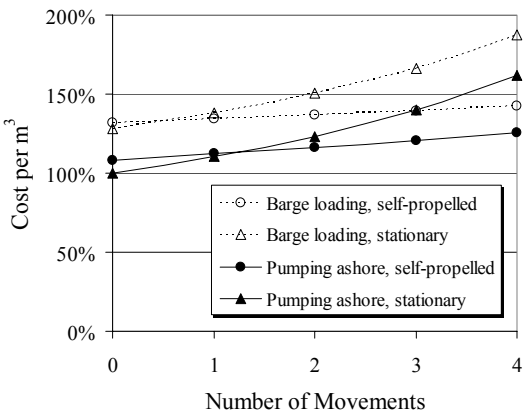

Figure 8: Cost versus mobilization

The recently built CSD's taught us that with the increase in scale new challenges arise. Because of the increase in scale many state of the art techniques can not be applied anymore. This also concerns production technology. The development and integration of all these new technologies and the actual implementation in a production process require a lot of effort.

8 CONCLUSION

Recent developments show a tendency to Jumbo cutter dredgers. These dredgers are large in all design aspects. Most significant characteristic of these Jumbo's is their large production as a result of large dredging installation in combination with high installed power.
Another trend is the development of hopper dredgers to make them capable to dredge in more compact soils and the improvement of workability in swell of cutter dredgers. This joins even more the performance and working area of hopper dredgers and cutter dredgers. The result may be new markets or dredging projects that in the past were not feasible.

The design and engineering (and construction) of a Jumbo CSD is very complicated because there are many possible design configurations and a lot of design aspects are interfering with each other. Many of these aspects cannot be treated in the common way, because they highly depend on the playing field and organization of its future dredging company. So, there are many ways leading to Rome.
To find the most optimum solution, it is very important to make a well-considered analysis of the type of future work. New techniques, more insight due to research and new calculation methods enable optimizing a CSD design nowadays.

Because the investment for a large CSD is for many years, it is necessary to make well considered choices. These choices are best made and considered in all aspects, when Owner, Yard and its subcontractors are working in close cooperation.