

# Value based equipment selection

## Synopsis

Traditionally, equipment selection is weighted toward fulfilling the contractual requirements agreed to in the shipbuilding specification. Bollard pull and sea trial speed are examples of this. For today's common vessel types, we find that this design criterion often defines the entire equipment selection and at the same time only represents a fraction of the operational time for the vessel. A harbor tug is a good example - it will spend, typically, only a small percentage of its operating time in bollard pull conditions. Similarly, a cargo vessel is not likely to be crossing the Atlantic at sea trial speed. Ultimately, what this does is base equipment selection on a condition where the vessel spends only a fraction of its operational time.

Is this condition-based equipment selection the best choice or are there other conditions of considerable importance to look at for alternative equipment set ups?

## Selecting the optimal design criteria

The below example is for 150T offshore tug, (AHTS). The bollard pull condition is often considered the most important design condition, as this plays a major role in vessel contract qualification. Looking at the orange line, representing the time spent in each mode, we see that the expected time the vessel will spend in this operational condition is very low compared to other modes.

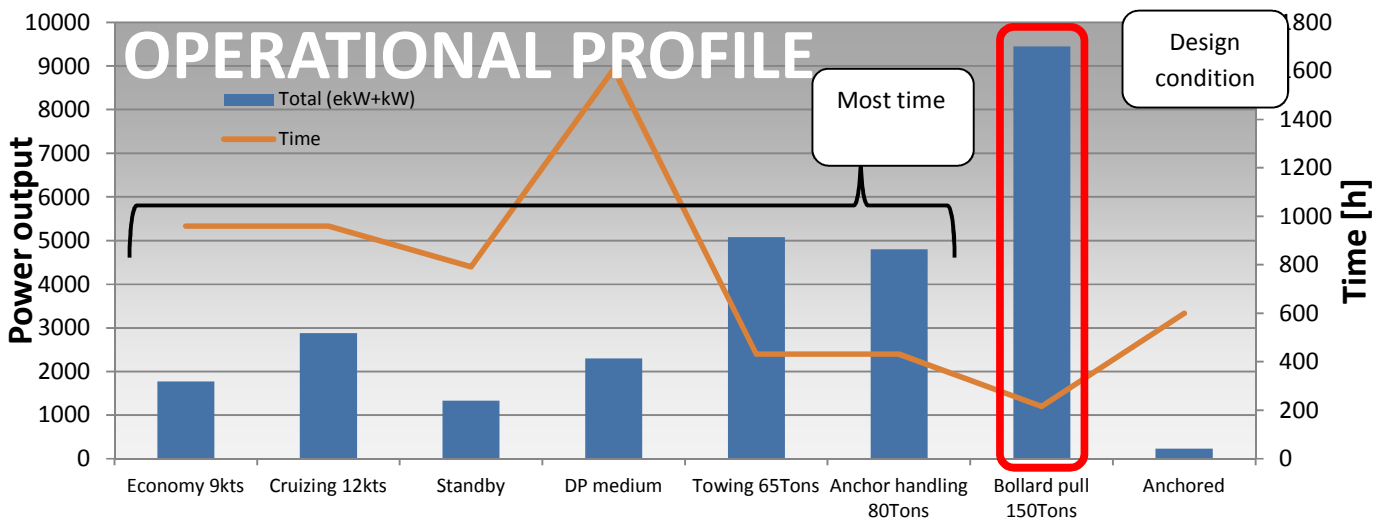


Figure 1: Typical operations profile for offshore tug

For these vessels, the equipment selection will often start with selecting either the main engine or the propeller diameter. With one of these defined, the other one can be selected so that the required bollard pull can be reached.

This design philosophy makes the engineering and risk manageable as the main design goal is to fulfill the one full-power condition using well established engineering rules and practices.

If we look further into the above example and how it performs over the entire operational profile, we see that this vessel would spend less than 4% of the time and 10% of the annual fuel consumption in the full power bollard pull condition. This means 96% of the operational time and 90% of the annual fuel consumption is spent outside of the primary equipment selection mode of operation. This doesn't necessarily mean that the vessel is inefficient in any of these off design conditions, or that they're not considered during the design process. It just means that they are often secondary to fulfilling the main contractual requirement within budget.

With this in mind, it might make more sense to shift the main propulsion design criteria to include the modes where the vessel spends most of its time and where the vessel aggregates most of the operating cost. The task of looking into and benchmarking different solutions against each other over an operational profile can be very tedious and time consuming, and a more experience-based approach is often adapted.

## Defining the operational profile

In order to do any kind of benchmark over the entire vessel operation, it requires an operational profile to be defined as a benchmark basis. This will allow concepts, designs and propulsion equipment to be evaluated against each other.

When building a new vessel for an already existing fleet, the task of defining the operational profile is manageable and can be referenced to the vessels already in operation. If, on the other hand, you're building a vessel with a certain capacity for a spot market or on speculation, this task might be more challenging.

One common way to define an operational profile is to define the power consumption over a number of modes. This is an effective way if you've already defined your propulsion system and how it will operate. A good example would be optimizing a diesel-electric engine plant to a predefined propulsion system or reading data from an already existing vessel.

Example of power based operational profile:

Operational mode	Power consumption [kW]
Transit 9kts	1000
Transit 12kts	3000

Standby	800
Dynamic position	1200
Anchor handling	4000
Bollard Pull	9000

The problem with this kind of operational profile is that it really only works when benchmarking engines of approximately the same size and power against each other, or different diesel electric configurations. For cases where you want to benchmark complete vessel performance such as different propulsion systems, propeller diameters, engine solutions or running modes, it's better to take a more operational driven approach. The idea with this is to base the operational profile on the thing that matters - the operational requirement - and relate this to a hull design.

Operational mode	Requirement
Transit 9kts	9kts
Transit 12kts	12kts
Standby	2kts current, 5kts wind speed
Dynamic position	2kts current, 10kts wind speed, DP2
Anchor handling	2kts, 85T pull, 10T tunnel thrusters
Bollard Pull	150T

This, together with a hull resistance profile/data and the proposed propeller concepts, will give the power consumption per mode for the propulsion candidates. Using this approach makes it possible to benchmark total vessel performance while varying propulsion concept, engine configuration and running modes while still making sure that the propulsion system is able to fulfill all operating modes.

## Modern tools

New technology combined with advances in marine engineering science have made it easier to streamline the engineering process and allow more extensive studies before the equipment selection and vessel construction starts.

These tools can take many shapes ranging from Excel sheets to very sophisticated automated engineering software solutions. In this paper, the Caterpillar tool known as the **Efficiency Workshop** has been utilized. This tool allows you to input the hull characteristics such as resistance and hydrodynamic data and then apply an operational profile. With this you can then apply various propulsion and engine solutions to benchmark them against each other, comparing fuel consumption, maintenance consumption, load response as well as equipment cost.

This approach allows owners to quickly form an opinion about the general direction to go when evaluating propulsion concepts and make educated decisions.

## Design evolution

In the below example we will go through the design evolution for a 150T AHTS using the operational profile from the top. The study starts with a very basic design, moving forward by trying to eliminate the inefficiencies one by one. This approach has successfully been applied to many different vessels types and projects, and the 150T AHTS is merely an example.

### Varying engine rating and propeller diameter

Looking closer into the initial example of the 150T AHTS and how it could be improved, we start by varying the concept within the borders of a 2 engine installation. The base numbers are as follows: 2x MaK™ 9M32C engines each delivering 4500kW coupled to two 3.95m main CP propellers. Bow thrusters have been kept the same throughout the entire study, but could just as easily be varied as well.

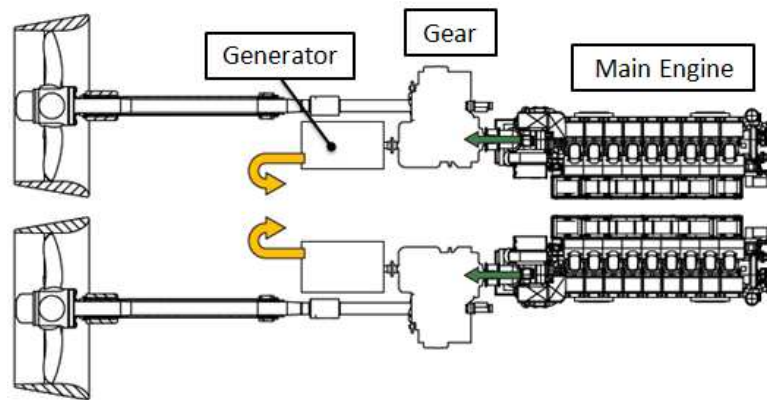


Figure 2: Reference configuration 1

An easy way to start studying how to improve the concept would simply be to try the next higher and lower ratings of the same base engines and consequently adapt the propeller diameter to achieve the same bollard pull. This would mean that the two alternative configurations would be:

Reference	2xMaK 9M32C – 4500kW	3.95m @ 150rpm
Higher rating	2xMaK 9M32E – 4950kW	3.6m @ 170rpm
Lower rating	2xMaK 9M32C – 4320kW	4.15m @ 135rpm

By applying these three alternatives to the operational profile for the vessel, we see that they behave differently.

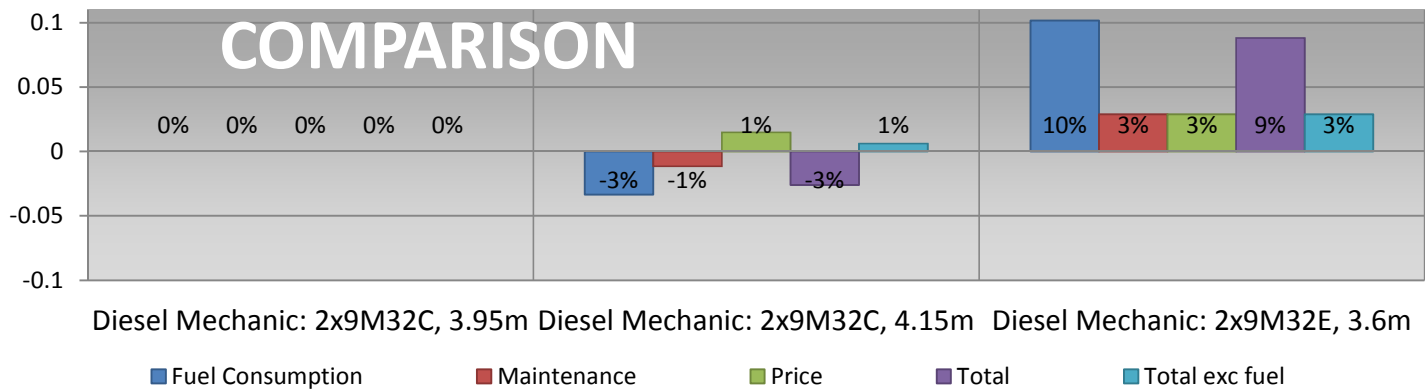
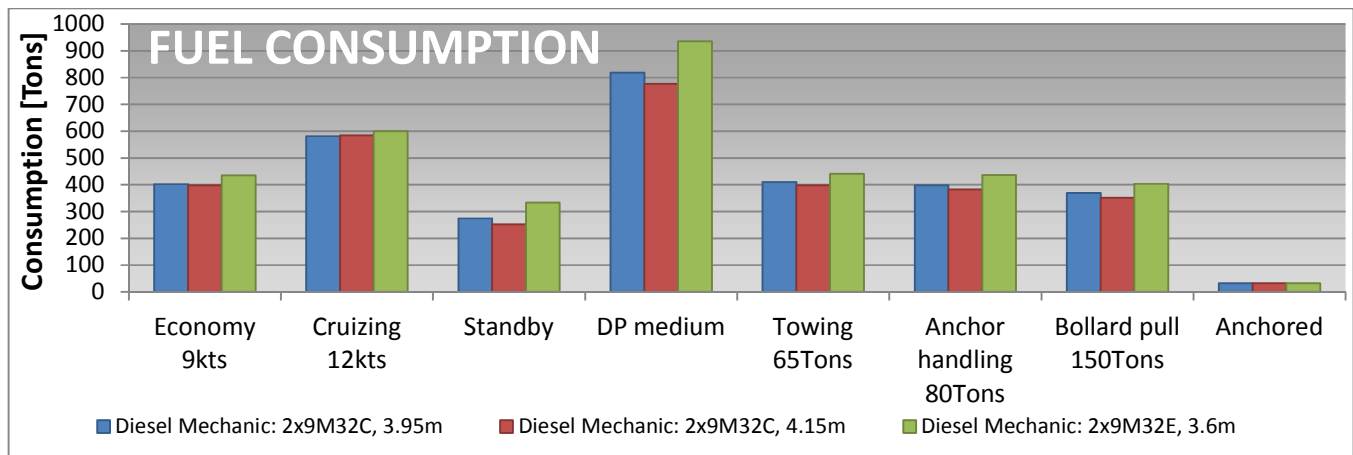


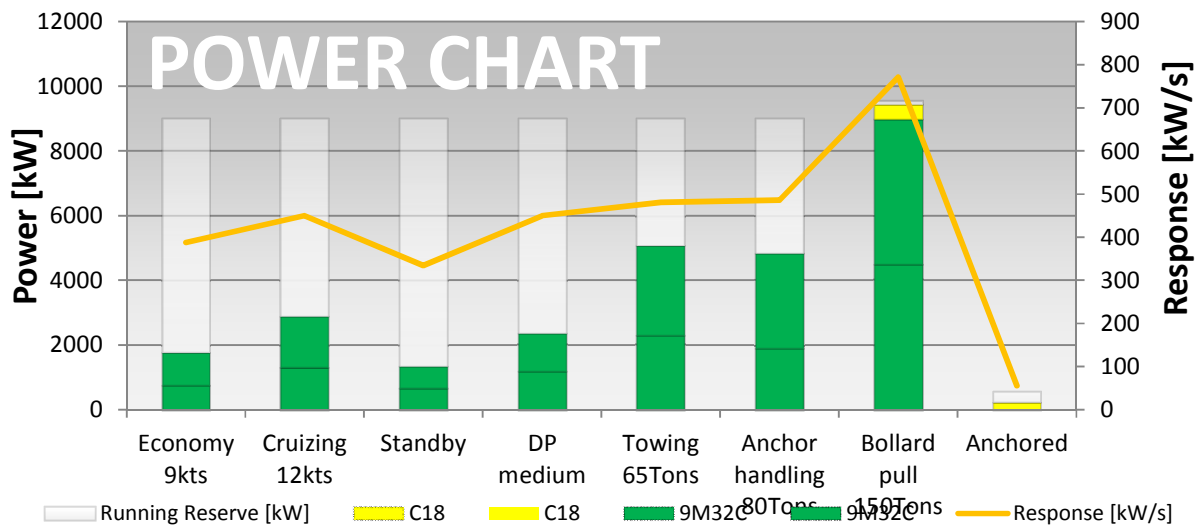
Figure 3: Comparison varying engine rating/propeller diameter

From this simple run we see that varying the engine and propeller diameter together can have a big impact. There is a positive effect when increasing the propeller diameter and decreasing the engine rating. The equipment price for this alternative would of course increase, as the gear and propulsion becomes more costly depending on where you end up with your propeller and gear selection due to the higher torque in the slower turning propeller shaft. Going in the other direction - increasing the rating while reducing the propeller diameter - has a negative effect on the fuel cost as the propeller efficiency drops with the smaller, faster turning propeller. The below graph highlights the differences in more detail.



### Optimizing transit operation

In this example, 32% of the vessel operation time is spent in transit, amounting to ~30% of the annual fuel consumption. The below chart is known as a power chart and shows how the installed engines work together to deliver the requested power. The chart also allows you to see the running reserve, which is the power online but not utilized, and the load response.



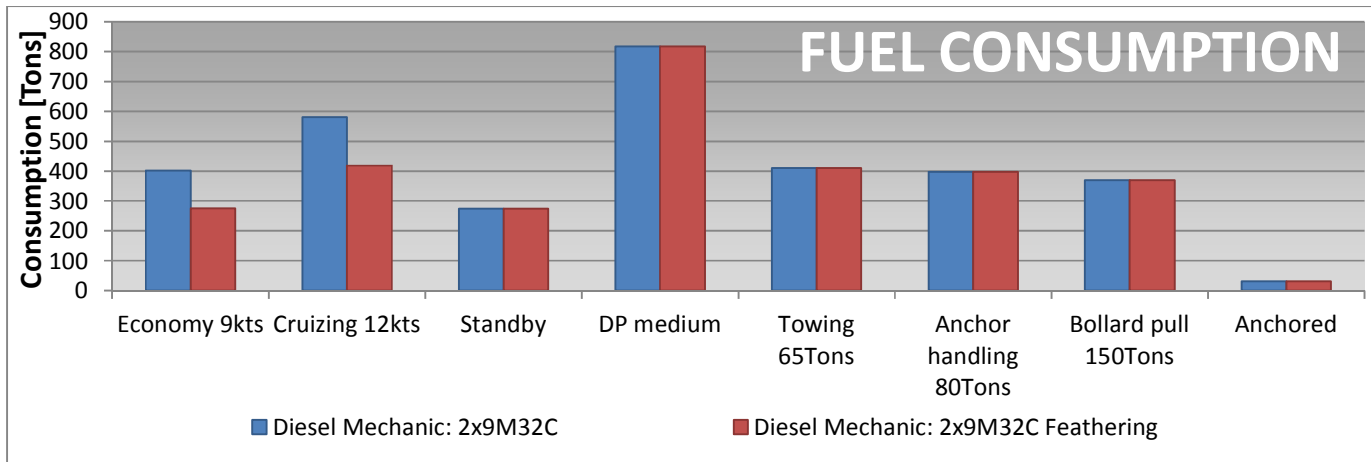
Looking at how the engines operate, we realize that both main engines are needed for every operational mode except anchored, and that the main engines are running at very low load utilization. Average load is only 30%, which is far away from the numbers where most engines are optimized to run. This will in turn drive up fuel and maintenance costs, as normally happens when having too much unused power capacity online.

What, then, can be done to increase average load on main engines? In transit, it seems like running one engine only and shutting the other down would be enough to propel the vessel. Doing so is nothing new and there's more than one way to do this: simply freewheeling one propeller, driving two propellers with one engine, driving one mechanically and the other one electrically via the shaft alternator/motor. In this example, we will attempt to increase engine load by installing feathering propellers.

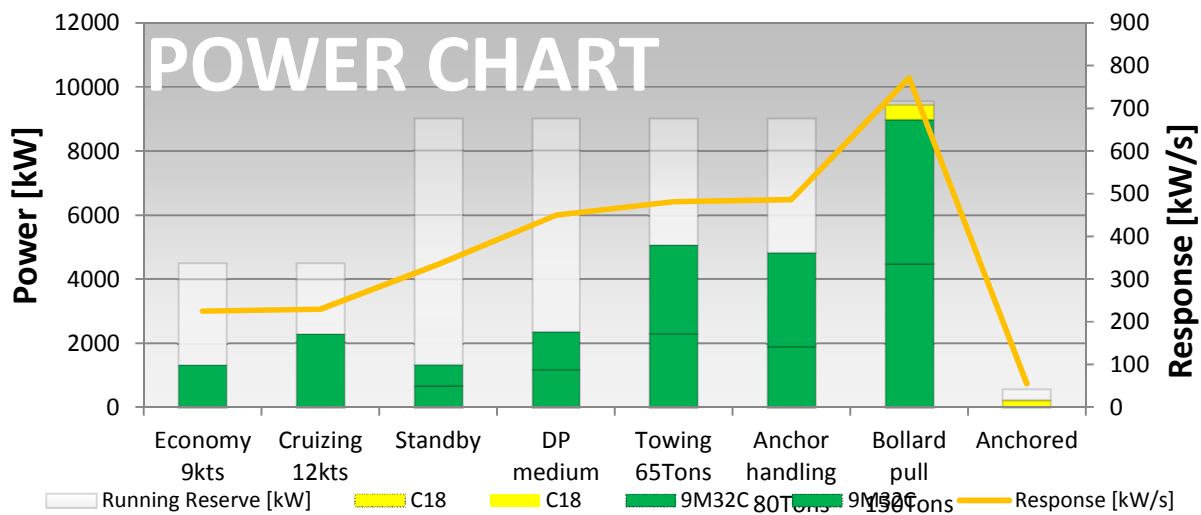


This technology allows you to run the vessel with only one propeller active while the other propeller is feathered and locked, creating a minimal amount of drag. The advantage with this solution over the other alternatives is the simplicity, very low drag, and that the active propeller will be running at a much higher load/pitch, meaning significantly increasing the propeller efficiency.

Applying the feathering feature to the propellers for this vessel results in a 9% fuel consumption reduction as well as a 17% reduction in scheduled maintenance, as the number of hours per year on the main engines is halved for the transit operation.



If we take another look at the power chart, the average engine load is now slightly higher at 35%, but still very low. Is it possible to have a different way to highlight the average load in the power chart?

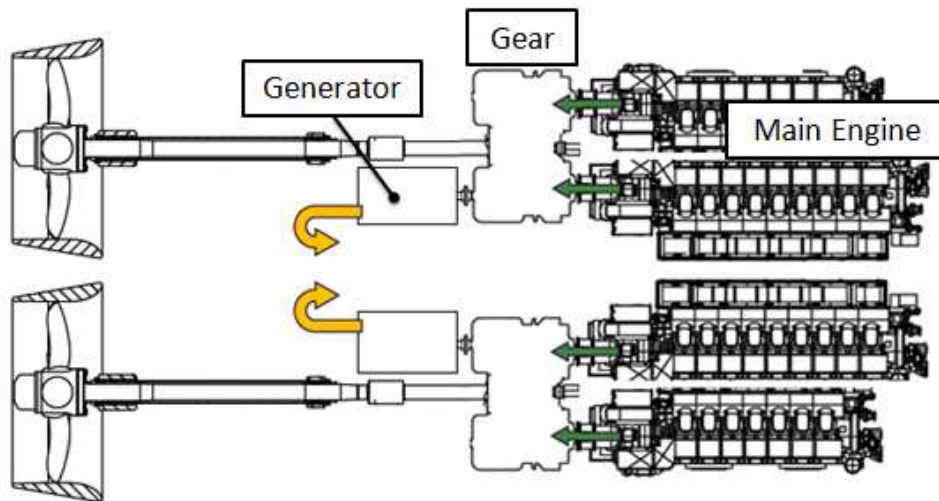


What can we do to further increase the engine load and thus reduce fuel and maintenance consumption? Looking at the chart above, the engine utilization still seems to be very low at many of the modes, especially during transit and standby/DP.

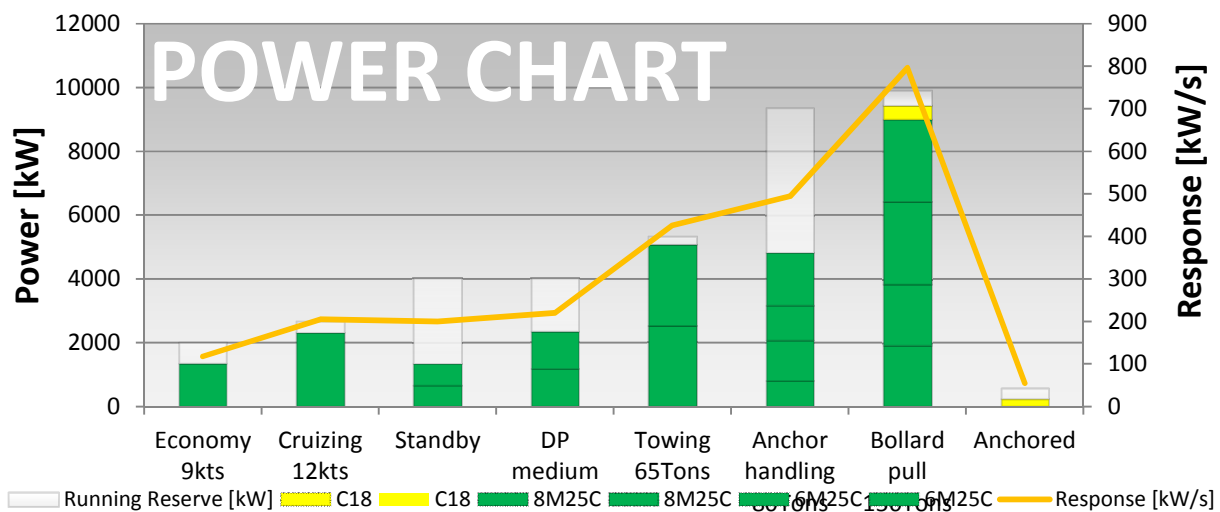
### Father & son arrangement

One limitation with the base configuration is that there are only two main engines, meaning that the ability to vary the number of engines running is limited. A popular way to build this kind of vessel is to utilize 4 main engines. A twist of this is the father and son arrangement which takes the concept a step

further, having 4 main engines where 2 are bigger than the other. This gives the operator more running modes and the ability to optimize the operation better.



If we apply 2xMaK 8M25C engines at 2666kW together with 2x6M25C at 2000kW utilizing the same 3.95m feathering propeller, we can now start varying the number of engines running.



In the above power chart, one engine is running with the other 3 engines turned off while in transit. In standby and DP, two engines are run as well as in Towing. For anchor handling, the power requirement would allow for running only two engines, but is not considered a likely way to run the vessel, as this is a mode with more dynamic loads and most operators would probably have all engines running.

The configuration running in the above way would increase the average engine load to 65% which is a very healthy and efficient load for this kind of engine.



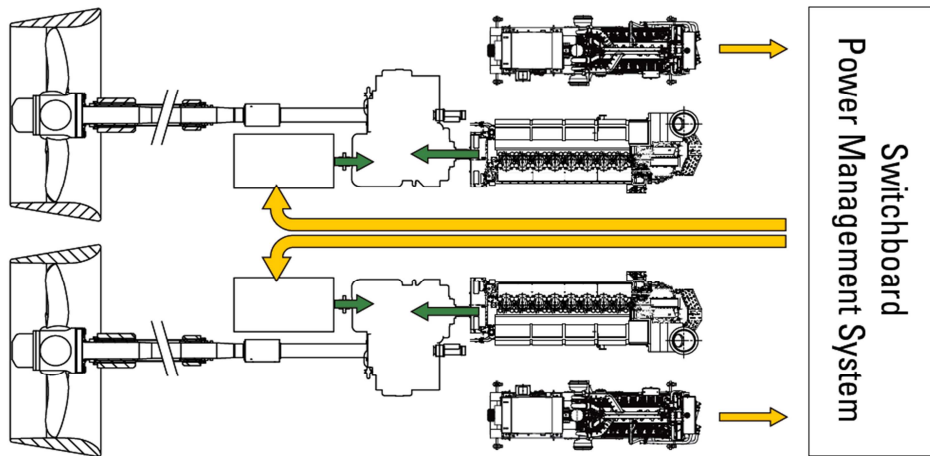
## Taking the concept further

If we look at how the engines are running in the father/son arrangement, we've already achieved a very good running condition and the return from the engines on fuel and maintenance is much improved. What can be done to further increase the propulsive efficiency and ultimately the power consumption from the main propellers over the operational profile?

In all modes except anchored, the shaft alternators require running at a constant speed. If we keep the constant speed operation in mind and look at the load on the main propulsion, we see that in many modes this is very low. For the transit modes, we have already significantly increased this by running only one propeller at a higher load while feathering the other. For the standby and DP mode, we're still turning two very big propellers designed to deliver 150T bollard pull in constant speed which, in zero pitch condition, will consume 15-20% of the design power.

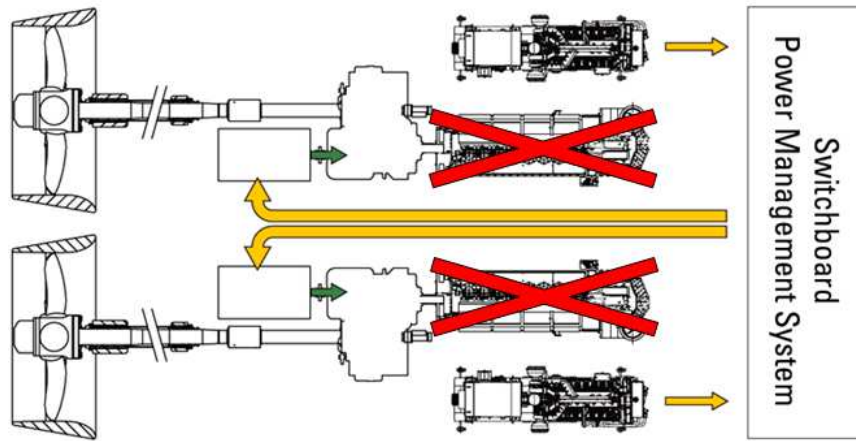
A better way to run the propulsion in those modes would be in combinatory or variable speed mode. This would require either to run the main engines in combinatory mode or driving the main propellers in variable speed electrically via the shaft alternator/motor. While both of them would require some additional electrical equipment, this has already been done on many vessels worldwide.

If we also look at the utilization time of the father/son arrangement, we see that 2 of the 4 main engines are not significantly utilized. What would happen if we replaced 2 of the main engines with generator sets and make the vessel a diesel mechanic/electric hybrid?

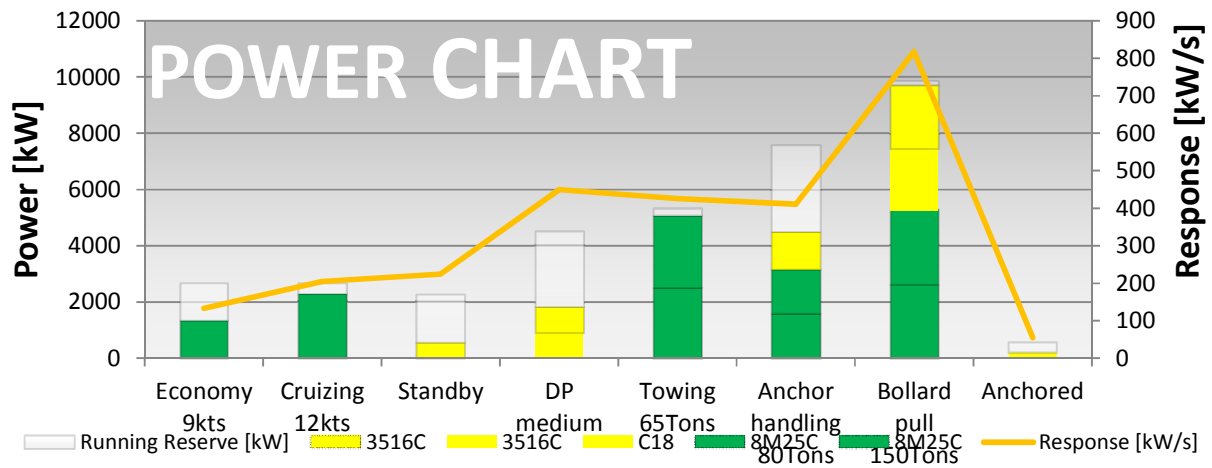


This would mean that the total mechanic power would be selected so that it's enough to efficiently propel the vessel during transit and modest towing operations. When in standby/DP, the vessel would switch over to diesel electric mode, running as a pure diesel electric off of the high speed generator sets.

When full power is needed the main engines and generators would all work together in a mixed speed hybrid mode.



This solution would maintain the efficiency gains worked up in the previous steps and reduce the power consumption in standby/DP. This would increase the propulsive efficiency and reduce the fuel consumption.

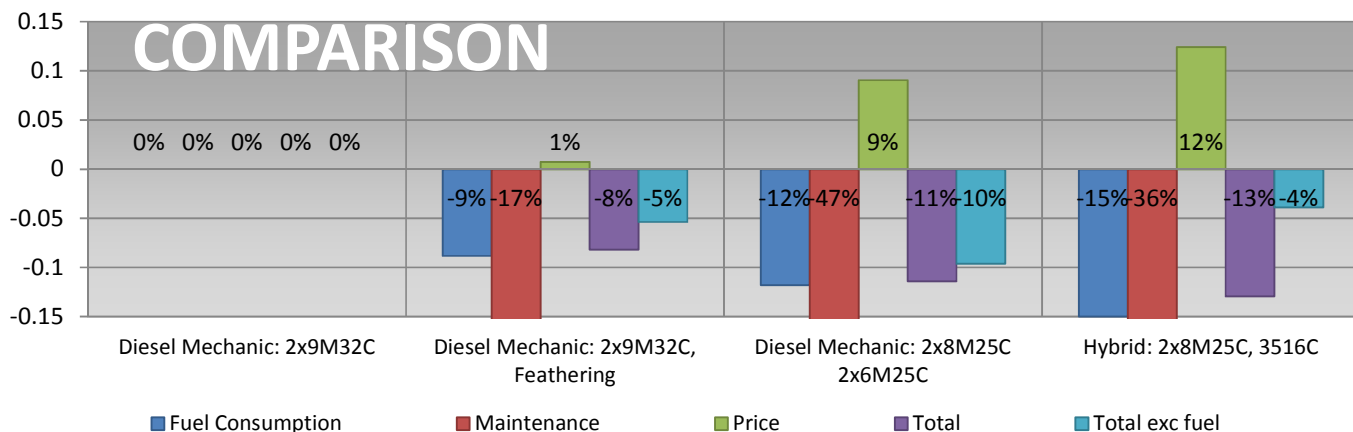


Looking at the power chart, we see that transit and towing modes are unaffected. Standby and DP are now diesel electric modes with the main propeller in a more efficient variable speed mode. Anchor handling and bollard pull now require main engines and high speed generator sets to work together.

Looking toward the engine loads, the average load for the main engines has now increased to 75% and the generator set average load is at 45%.

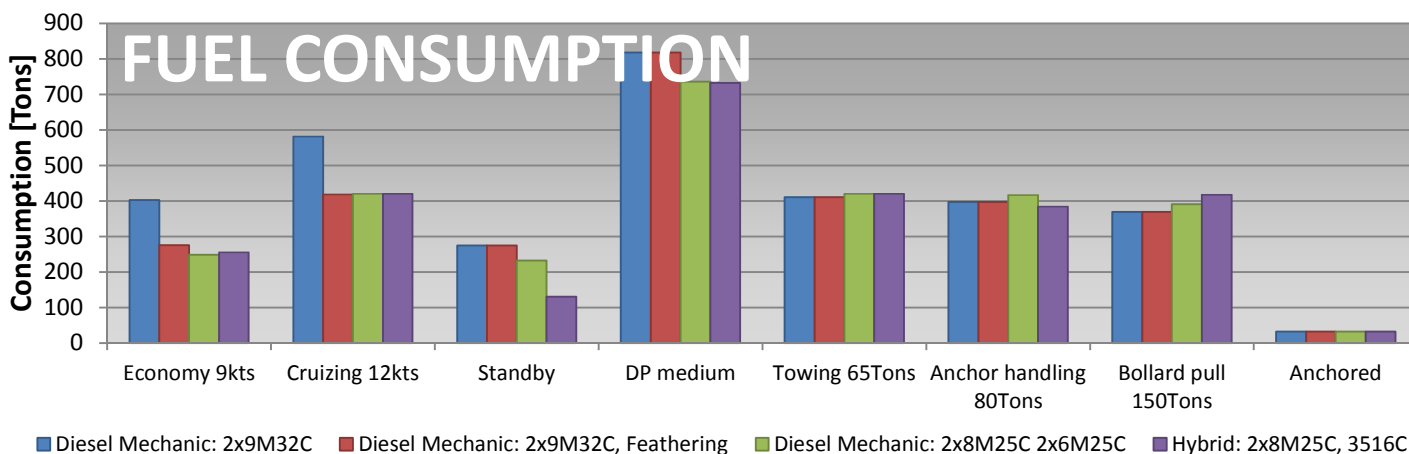
## Result

The above steps have taken the vessel in focus from a very conventional two engine design, added feathering propellers, added the father/son concept, and ultimately made the vessel a hybrid. All of these steps have eliminated the inefficiencies over the operational modes, using solutions that account for various factors such as simplicity, efficiency and cost.



The above chart uses the result from the enclosed study and allows us to follow the design evolution and how the financial factors come into effect. As we can see, each step improves the fuel and maintenance consumption. This is of course only valid under the benchmark condition chosen, meaning that if you change to a different hull or different operational parameters, this could all look different.

The below chart is a good source for doing further evaluation of the concepts. What we see here is the fuel consumption per mode for the concepts. One striking thing is that all solutions have at least one mode where they are the most efficient. A good example is the hybrid which is very efficient in most modes, but had the highest consumption during bollard pull. One could argue that this design would never be considered if no off-design condition study like this one was done, as the benefits lie outside the bollard pull condition.



## Summary / conclusion

Technology is moving on and the industry is getting better at performing these kinds of studies in a time efficient manner. In this paper, all info and data comes out of the Caterpillar tool known as the **Efficiency Workshop**, and is the result of a substantial development project on both the propulsion and engine sides.

The enclosed paper discusses equipment selection based on a benchmark methodology where different concepts, delivering the same basic vessel performance, are evaluated against each other to discover optimal solutions. While the viewpoint here is focused on fuel and maintenance consumption, in an actual project, aspects such as load response, electrical complexity, and crew requirements might weigh very high among the selection criteria.

The study also illustrates that doing additional homework before equipment selection begins, opens up the door for significant improvements in fuel and maintenance performance, which could bring significant reductions in total cost of ownership. Even a small study on how to match main engines to propeller diameter might reveal as much as a 10% difference between a good and a poor choice.