MORE EFFICIENT DIESEL ELECTRIC POWER PLANT FOR DREDGES

Vinton Bossert, P.E.¹, Vassili Rozine, P.E.², and John Ockerman³

ABSTRACT

Diesel Electric (DE) power plants for dredges are commonplace, however new developments in DC power technology have paved the way for a completely new Diesel Electric application. To the operator it appears essentially the same, but to the dredge owner, significant efficiency improvements can be realized.

This paper compares the characteristics, efficiencies, operations and maintenance of a traditional Diesel Electric power plant to a DC power distribution plant. A typical DE AC plant uses isochronous paralleling generator sets, AC switchboards, and variable frequency drives for controlling the speed and power of the propulsion, thrusters, dredge pumps, and winches. A DC power distribution system uses variable speed generator sets, DC switchboard, and multi-drives for heavy consumers. DC also facilitates Energy Storage systems for peak power shaving, load ride-through or boost.

An AC plant requires a large footprint and infrastructure requiring many moving parts, with associated expertise to operate and maintain the plant. An AC plant typically needs power conditioning components to mitigate harmonic distortion. A DC plant requires less infrastructure, smaller footprint, no harmonics mitigation, and is easier to operate and maintain. DC distribution is made possible by new solid state short circuit protection devices versus traditional circuit breakers.

The DC technology has been applied recently to research vessels and fishing vessels, that have similar power plants to dredges, with some extraordinary results. It is proven technology, providing advantages of lower fuel usage, less maintenance, simpler operation and cost savings.

Keywords: Blue Drive Plus C, Direct Current, DC Grid, diesel-electric, efficiency, electrical, fishing boat, hybrid, multi-drive, power plant, propulsion, research vessel, thrusters, switchboard

INTRODUCTION

Brief History of Electrical Power For Marine Propulsion

Marine electrical power has evolved from the first light bulb on a ship in 1880, to an all electric battery powered ferry in 2015. The "war of currents," AC versus DC, for marine applications has evolved from AC to DC, to AC, and now back to a combination of DC/AC due to the development of power electronic building block technology and solid state DC "circuit breakers."

Electrical power in marine propulsion and large auxiliary applications is nothing new. Starting around the time of WWI, turbo-electric power plants developed. The development of turbo-electric ships continued through WWII. The T2 Tanker was a workhorse for the allies during WWII and some years after. The T2 used steam powered

¹ President, Bossert Dredge Consulting, LLC, 39 Cornwall Drive, Newark, DE 19711, USA, T: (302) 740-1841, Email: vintonbossert@comcast.net

² VP Engineering, I & M Engineering, 1004 Rochester Ave, Coquitlam, BC V3K 2W7, Canada, T: (604) 931-4403, Email: vassilir@IMEngGroup.com

³ President, Ockerman Automation Consultants, LLC, 916 8th St, Anacortes, WA 98221, USA, T: (360) 293-0206, Email: john@ock-inc.com
turbines driving AC generators, which in turn, powered AC Propulsion induction motors with DC excitation. It is interesting that the use of turbo-electric propulsion in T2 tankers was due to logistics (Skjong). It was difficult to obtain large marine reduction gears during WWII for merchant ships since all large propulsion reduction gear manufacturers were backlogged supplying gears for military ships. The turbo-electric system was designed and built to perform the speed reduction electrically. While the turbine would turn the generator at 3600 RPM, the number of poles of the propulsion motor was such that it drove the propeller directly, no reduction gear required.

Figure 1 - T2 Tanker

Figure 2 - T2 Tanker Propulsion Plant
With the development and continued refinement of power electronics, in particular the thyristor in 1956, a simplified conversion of AC to DC, with reliable speed control of DC motors, was enabled. From 1960 -1980 many dredge propulsion, dredge pumps, and winch drives were powered with DC motors from an AC power plant and AC distribution system. During the 1980's, marine DC motors powering large variable speed consumers declined in favor of AC power and control with the development of the variable frequency drive (VFD). A VFD converts a constant voltage AC source to DC, then, through power electronics, recreates AC at a reduced volts/hertz, and reduced speed of the load as required by the speed control. Though fairly large, complicated, and expensive, VFDs made it possible to reliably control speed and load of AC induction motors. AC induction motors had advantages over DC motors due to not having brushes or commutators requiring constant maintenance. AC power had other advantages such as being easier to transform to different voltages, and being easier to protect against damaging short circuits.

Fairly recent developments in DC short circuit protection along with variable speed diesel electrical generation has propelled a resurgence in marine DC powered ships and hybrids. This is not your great grandfather’s marine DC electrical plant. These are state-of-the-art power electronics controlled Direct-Current marine microgrids.

Root Causes of Marine DC Resurgence

The comeback of DC power distribution can be best attributed to the efficient utilization of both AC and DC power components where each best fits in the marine power system:

- AC rotating machines are here to stay. AC Variable Frequency Drives are very reliable and an efficient method for controlling speed of any rotating load including propellers, pumps, thrusters, fans, etc... New DC motors are being built for retrofit, but practically none are currently being built for new marine applications, and that is not expected to change anytime soon. (Rozine, 2008)
- The development of variable speed power generation is becoming a game changer. By attaching an AC generator to a variable speed marine propulsion engine and converting the output of that generator into a useful form of power (in this case DC power), the best efficiency point of the diesel can be continuously matched to the load demand at any given time. Therefore the diesel engine can run at whatever speed that achieves the best specific fuel consumption (SFC) for a given load, and the power electronics converts whatever volts/hertz to DC volts for power distribution.
- Development of high DC fault current protection is another reason for the comeback. AC power had traditionally been easier to protect against large short circuits since AC power always crosses zero volts 100 or 120 times per second in its sinusoidal pattern allowing circuit breakers to more easily open. Once again, advancements in power electronics have facilitated the development of virtual DC circuit breakers. These "circuit breakers" can, through the use of semi-conductor technology (power electronics), very quickly interrupt or limit the fault current permitted to flow.

Summary of Hopper Dredge Design Comparison

The following will compare two power plants applied to medium size Trailing Suction Hopper Dredge designs of approximately 5500 cubic meter hopper capacity. A dredge of this type and size in the North American market would provide both channel maintenance and beach nourishment missions. The following objectives will be expounded herein:

- Combined potential for 20% in fuel savings, 15% from power management and 5% from Energy Storage/Regenerative power.
- Improved life cycle cost by reduced fuel consumption and maintenance intervals.
- Improved reliability and reduction of single point failures within the system.
- Better quality power by producing less harmful harmonics, and better power factor control.
• Good coordination and fault clearance characteristics where compared to conventional AC distribution schemes.

• Improved efficiency of energy due to optimization of loading of the prime movers in conjunction with energy storage and by utilization of an integrated power management system.

• Less space and weight intensive packaging of the power and control systems offering more flexibility within the machinery arrangements and allow more cargo carrying capacity for the same sized ship.

• Less propulsion machinery noise and less vibration due to fewer machines being on line, running at lower speed, and utilization of energy storage system.

The following particulars would be a typical AC diesel-electric dredge of this size:

Two different power plants will be compared - a modern hybrid DC power plant and a modern AC diesel-electric power plant. Partial General Arrangements and Profiles of the two powered dredges are shown along with simplified Electrical One-Line Diagrams. From a diagrammatical perspective there might not seem to be much difference...
between the DC hybrid and the AC diesel-electric. Those differences will be discussed in a practical way using vernacular that a non-electrical engineer can readily understand.

Figure 4 - Diesel-Electric Hopper Dredge Plan View
Figure 5 - Typical AC Diesel-Electric One-Line Diagram

The following particulars would be a duplicate dredge as in Figures 3 and 4 except with a hybrid DC electrical grid power distribution system. The arrangements and simplified One-Line Diagram for the hybrid DC concept are shown in Figures 6, 7, and 8:

- Length Overall: 103 m
- Breadth: 21 m
- Hopper Capacity: 5500 m³
- Cruising Speed: 12.5 kn
- Main Diesel Gens: 2 @ 2000 kw
- Propulsion Diesels: 2 @ 3000 kw
- PTO/PTI Gens: 2 @ 1700 kw
- Dredge Pump: 1 @ 2000 kw
- Jetting Pump: 2 @ 1000 kw
- Bow Thruster: 1 @ 600 kw
- Dragarm Winches: 3 @ 150 kw
Figure 6 - Hybrid DC Plant Machinery Inboard Profile

Figure 7 - Hybrid DC Hopper Dredge Plan View
EFFICIENCY IMPROVEMENTS

How Does a Dredge Owner Measure Efficiency

Dredge owners all measure efficiency in cost per cubic meter of dredged material ($/m^3). As in most businesses, capital expense, fuel, labor, and maintenance costs make up the large majority of the cost to operate a dredge. The following design features and success criteria of a new hopper dredge are listed irrespective of mission (size and application) of the new dredge. The collective result of these features and criteria are to facilitate achieving the mission at the lowest cost per cubic meter of dredged material. For a given size of hopper dredge, the dredge with the most production and the least cost will be the most efficient, as defined above, and should theoretically underbid the competition. The relationships between these features are often conflicting and the subject of trade-off analyses during design. The factors affecting each of those two criteria are listed below (IDR, Sep 2015):

Maximum Production
- Largest Hopper
- Most Maneuverable
- Highest Density Excavation
- Most Efficient Hopper Loading (least overflow losses)
- Fastest Loaded Speed to Disposal Site
- Fastest Unloading
• Fastest Speed Returning Empty

Least Cost
• Least First Cost
• Least Maintenance Cost
• Most Efficient Hull
• Most Efficient Propulsion System
• Most Efficient Pumping System
• Crew Size Matched to Automation

The following discussions only address the cost side of the equation except where cost decisions indirectly affect the dredge production. One such decision is Z-drive propulsors (see Figure 3). Z-drive propulsion and podded propulsion each have their own advantages and share a few advantages. Z-drives and pods (and Voith cycloids) are the epitome of maneuverability. Z-drives can often be removed from the ship for repair without dry-docking, which is a significant maintenance cost savings. Z-drives and pods each put all the torque where you want it, rather than divert the stream as a rudder would, adding efficiency to weather-compensating angle-orders, especially where a bow drive is available. They enhance dynamic positioning and tracking allowing the ship to stay on station or on track using less fuel and in worse weather. For maneuvering, Z-drives and pods can mean avoiding tug escort fees and assist fees at docking and passing under bridges. (IDR, Sep 2015)

Fuel Savings With New DC Power Plants

Any technology that reduces fuel usage should be reviewed very seriously. Fuel costs will go up in the future, perhaps in the near future, which will affect the business case for inclusion of hybrid technologies. Environmental regulations may also force more reliance on marine hybrid technologies.

A Hybrid DC grid power distribution plant can use variable speed diesel power generation. Since the AC output is converted to DC, no synchronous speed is required. The generator's speed is adjusted based on load to optimize specific fuel consumption (SFC). See Figure 9.

From 80% to 100% load there is no difference in fuel consumption between a fixed speed generator and a variable speed generator. Below 80% load, the speed of the variable speed generator can be reduced according to the fuel map to achieve the highest SFC. This is particularly beneficial for vessels operating in Dynamic Positioning (DP) mode, where average power demand is low, but extra generating reserve must be kept spinning and available.

![Figure 9 - Fuel Consumption for Fixed & Variable Speed Diesel Engines](Väskä, 2012)
Figure 9 illustrates that at an average generator load of 50% a variable speed generator would save approximately 10%. The actual savings would depend on the load profile of the ship, the size of the generators, and whether the operators would allow the plant to run automatically.

**Space Savings With New DC Power Plants**

A DC grid power distribution plant does not have a traditional Main AC Propulsion Switchboard, although it does have a Ship Service Switchboard for hotel loads and an Emergency Switchboard. As seen in Figure 8, the output from the AC generators are converted to DC prior to connecting to the grid. Several major advantages result:

- Synchronization and paralleling of generators is not necessary. Only DC voltage of multiple generators need to match to share load. No synchronizer section is required in the switchboard.
- Harmonic distortion is completely prevented from migrating to the ship service AC bus and hotel loads. As a result there is no need for harmonic mitigation or power factor correction equipment which is usually heavy and expensive.
- Major variable speed drives connected to the main DC grid are less complex due to the direct connection to the DC voltage source which makes them smaller and less expensive.
- The DC switchgear line-up is fresh water cooled resulting in higher power density and reduced space requirements.
- Traditional large AC air circuit breakers are not required. Only simple disconnects are needed for maintenance purposes.
- Energy Storage System (ES) can be easily integrated.
- Renewable energy sources such as solar and wind can be easily integrated.

**Energy Storage (ES) Systems**

ES systems take several forms:
- Battery banks are the most common.
- Capacitor banks
- Flywheel

ES Systems can perform the following functions:
- Spinning Reserve - Reduce the number of gensets on-line, improve fuel efficiency, and reduce engine operating hours.
- Peak shaving - Level the power seen by engines, offset the need to start additional engines.
- Strategic Loading - Charging and discharging ES media to optimize the operating point of the generator sets, power is produced at peak efficiency.
- Enhanced Ridethrough - ES behaves as a UPS for all or portions of the power system, instant backup for running generator sets until next generator can come online, less dependent on engine load ramps.
- Reduced Emissions - ES eliminates high particulate matter discharge from stack due to engine load applied too fast. Quieter engine room. (Nergård, 2015)
- Take the place of dynamic braking.

The cost of ES Systems are constantly reducing, while the life expectancy (number of recharging cycles) and depth of discharge ratings are constantly increasing. Therefore the size and weight of ES Systems to perform the same function will reduce and, if current trends continue, battery cost will also continue to drop.

**Regeneration Fuel Savings**

Most repetitive duty cycle loads such as winch loads, have a haul-in powering mode and a pay-out regenerative mode. On standard diesel-electric plants, the regenerated energy created by driving a motor as a generator is usually unusable and wasted through dynamic brakes (choppers) that simply burn off the excess power via resistor banks.
Conversely, on a DC Grid, this regenerated power can be converted, integrated, and managed to reduce the load of the diesel or PTO generators. Hopper dredges have large dragarm winches and swell compensators that continuously haul-in and pay-out wire rope. The payout cycles of these loads can now be harnessed and the power regenerated can serve to reduce fuel consumption. Also, if the grid is equipped with ES, the excess energy regenerated can be routed into the ES System, and not wasted.

PTO/PTI Off Main Reduction Gear

A diesel-mechanical hybrid DC power distribution solution has been selected to compare to a standard AC diesel-electric system. The diesel-mechanical hybrid arrangement consists of a medium speed, Tier IV diesel engine driving a Controllable Pitch Propeller (CPP) through a reduction gear. The reduction gear, in turn, drives an AC shaft generator through a Power Take-off (PTO). The output power from PTO generator is converted to DC power and connected to the grid. This type of arrangement was selected for the following reasons:

- PTO Shaft Generator provides high efficiency through the entire power range.
- Simple arrangement
- Easy to maintain
- Very reliable, proven application over many years
- Lowest capital cost hybrid propulsion installation
- CPP provides flexibility for power management to select wide range of prop and gen speeds to meet many operating profiles.
- In an emergency the PTO can also serve as a PTI. In the event of a main engine failure, the diesel can be declutched and the shaft generator can take power from the auxiliary generators and drive the propellers.

Though not shown, steering would be provided with flapped rudders. Flapped rudders provide less maneuverability than azimuthing Z-drives, however, the cost savings of direct drive diesel with flapped rudders provide an overall simpler and cost effective propulsion solution.
Less Downtime = Increased Revenues

Downtime is the dredge owner's nemesis. Operations managers scour the logs to determine what caused production to stop. Weather, maintenance, repair, safety incidents, and accidents all cause dredge operations to stop. When production stops, costs continue to be incurred. Labor is still on the job, capital is still being expensed, maintenance still needs to be done. Shoreside crews are still waiting for dredged material to come through the pipeline to the beach. Costs per m³ go up, and average dredge efficiency goes down.

Dredge owners, production engineers, and project engineers are constantly on the lookout for technologies, products, and services that reduce downtime. A Hybrid DC grid power distribution system will result in less downtime, less maintenance, less space and weight resulting in flexibility in locating machinery and/or more cargo deadweight, and less complexity for the operators and maintainers. The operators will then have more time to focus on improving the efficiencies of the subsystems of the dredging process.

The hybrid DC grid power plant described herein will be easier on the diesels running, resulting in less wear and tear on the engines, and less moving parts. This results in longer time between maintenance periods and more production time which, in turn, results in greater efficiency.

OPERATION AND MAINTENANCE IMPROVEMENTS

AC Rotating Machines - Generators and Motors

As stated in the introduction, AC electromagnetic rotating machines are unlikely to be replaced with anything having compatible performance characteristics in the near future. AC generators and motors require little maintenance and are extremely reliable. However, when converters are used in distribution systems, often phase shift transformers, reactors, active front ends, or filters are necessary to mitigate the harmonics that are produced. All of these components add significant space and weight to the ship.

In a DC distribution system, the induction losses and harmonic issues are absent (Rozine, 2008). Generators do not need to be synchronized, which greatly simplifies the switchboard arrangement. Also, a generator can be run as a motor, if necessary, similar to the PTO Shaft generator described earlier. This is now a common application on swing winches for cutter suction dredges. On cutter dredges one swing winch is constantly hauling in while the other pays out. The winch paying out can regenerate power back to the grid. At the end of a cut the winches reverse.

Variable Speed Diesel Generators

From an operational and maintenance perspective, variable speed diesel generators are typically run at lower speeds than the speed associated at MCR, which usually results in longer life of the consumable components such as bearings, rings, liners, etc... This also results in less noise and vibration in the engine room, and a more comfortable environment for the operators.

Variable speed diesels significantly reduce NOx emission which is defined as being almost 300 times as bad as CO2 because of its radiative effect and the time taken to break it down.

Repairs

The multi-drive concept employs a philosophy of Power Electronic Building Blocks (PEBB). No matter what load is being driven, the drives use multiples of the same PEBB IGBT bridges. The model is always the same for all of the loads on the ship. The crew becomes adept at troubleshooting. Inventories are less because the same components are used for each drive. Human error is reduced in diagnosing and accomplishing repairs. With some practice, a standard IGBT bridge for a multi-drive can be replaced in 20 minutes.
In addition, with improvements to semi-conductor technology, a previous 12 year life cycle can now be 16-20 year life cycle.

**DC Fault Current Protection**

A major problem with DC distribution until recently has been with circuit breakers. Marine electrical distribution systems must be coordinated, meaning that in the event of a fault (short circuit), the circuit breaker closest to the fault must open first. This is so that the rest of the electrical system will continue to operate normally. In other words, the ship cannot have a blackout because of a short on a lighting panel. Steering, fire pumps, bilge pumps, and all control and safety systems must continue to operate.

Since AC voltage crosses zero volts 100 or 120 times per second, AC breakers can readily open at zero voltage and extinguish the minimal arc that is created. DC voltage does not cross zero. Over the last several years the major electrical system manufacturers (Siemens, ABB, etc...) have all developed methods and components to interrupt high DC current during a fault. Siemens uses the term Intelligent Load Controller (ILC) in their BLUEDRIVE PlusC™ system for their fault current interrupting components. ABB's version is called Input Circuit (IC) in their DC Grid system. While the individual recipes from each manufacturer are slightly different, the end result is the same - a regulatory body approved, safe marine DC electrical distribution system.

**COST COMPARISON**

**Capital Cost**

There is very little data regarding actual cost information for new hopper dredges built in North America. If new trailing suction hopper dredges were regularly built in American yards, and this information was accessible and accurate, it would facilitate accurate forecasting of capital expenses and build more realistic economic models.

Both designs compared herein have very similar power levels, hopper sizes, and intended missions. Both designs are considered diesel-electric. The major differences are summarized below:

<table>
<thead>
<tr>
<th>AC Diesel-Electric (Figure 5)</th>
<th>Hybrid DC Diesel-Electric (Figure 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Distribution with VFDs</td>
<td>DC Distribution with multi-drives</td>
</tr>
<tr>
<td>Electric driven Azimuthing Z-Drive Propulsion</td>
<td>Med Speed Propulsion Diesel, CPP, Flapped Rudders, &amp; PTO Gen</td>
</tr>
<tr>
<td>Fixed Speed 1800 RPM Generators</td>
<td>Variable Speed Generators (2 shaft gen, 2 high speed)</td>
</tr>
<tr>
<td>Strong Potential for Harmonic Filters</td>
<td>Potential for ES and Regenerative Load Reduction</td>
</tr>
</tbody>
</table>

The capital cost of these two designs would be practically equivalent. The medium speed engines for hybrid DC design would be more expensive than the high speed diesels. However, the CPP shaftline is less expensive than the electric-driven Z-Drive design.

**Operating Cost**

There is no typical dredging project. Each dredging project is unique, with any combination of the following variables:

- Dredging depth
- Time to fill the hopper
- Dredged material composition (soft mud, clay, sand, gravel, rock, etc...)
- Sailing Distance (time) between dredging site and discharge site.
• Time to discharge (bottom dump, pumpout, rainbow)
• Power to discharge (jetting pump power only, high power discharge with long pipeline, high pressure rainbow
• Amount of vessel traffic interrupting the dredging process.
• Harbor or channel configuration (able to dredge both upstream and downstream, vessel able to safely turn around or must vessel backup to make next cut?, are two dragarms needed?, etc...)

Some of the above variables probably will even change during the course of a project.

The design of any particular dredge will be best suited and most efficient for only a small subset of dredging projects. Dredge owners and operators are constantly modifying dredges to more efficiently perform on any particular project. A dredge that is designed to be versatile will likely pay a price in efficiency - jack of all trades is master of none. As stated in the introduction, every design has features that are advantages or disadvantages for a given project. For instance, a dredge designed with two dragarms will be heavier and will have double the complexity and maintenance of dragarm handling equipment and wire rope, but may be better suited to a project with severe channel restrictions. A dredge having a booster pump on board may be better suited for beach nourishment projects with long pipelines than a dredge with one dredge pump that requires mobilizing a barge-mounted booster pump to accomplish the same beach project. All dredges convert fuel to mechanical work and electrical power. A fairly versatile, reliable, durable, and efficient dredge design, that is best suited to a particular market will consistently win bids, and provide a quicker ROI than the competition.

Experience from the last three years of construction of research, platform supply vessels, and fishing vessels with hybrid DC distribution systems yields fuel savings from 10% to as much as 20%. These savings are due to variable speed generators, direct drive propulsion, and savings due to ES.

Another way is to look at typical inefficiencies of power systems. Below are typical transmission losses of various propulsion components:

AC Diesel-Electric
• Generator 3%
• Switchboard 0.2%
• Frequency Converter 1.5%
• Electrical Motor 4%
• Z-Drive (two right angles) 3%
  11.7%

Direct Diesel Drive
• Gearbox 1%
• Shafting 1%
  2%

The total difference using the above values yields a savings of roughly 9% from just transmission losses for the direct-drive diesel propulsion system. If another few % could be gained from ES and regenerative load reductions, the total maximum fuel savings (similar to instantaneous gas mileage) could approach 20% (10% for variable speed gensets, 9% for propulsion dive train, 2% for ES and regenerative load reductions). The average fuel savings will be less than the maximum savings possible. Also, the average fuel savings will be greater for a dredging project where the dredging site is a long distance from the discharge sight, since the above inefficiencies are applicable to the propulsion system. While dredging, the difference in fuel savings between DC Hybrid and AC Diesel-electric would be smaller than transiting at full speed.

Maintenance costs, both parts and labor, will be greater over time with the AC Diesel-electric system due to lower maintenance costs of medium speed diesels versus high speed diesels, and the complexity of the AC diesel-electric system.
SUMMARY AND CONCLUSIONS

Ship's begin the journey to obsolescence the minute they are launched, sometimes before launching. A Hybrid DC Micro-grid is the best marine power management and power distribution technology currently available for ships with large auxiliary loads, such as dredges, factory trawlers, offshore support vessels, etc... Its adoption and implementation into new dredge designs will result in:

- The most efficient power distribution system that will continue to pay off year after year.
- The least space requirement for the amount of power distributed due to no generator synchronizers, no line reactors, and less large circuit breakers.
- Less maintenance and single point failures than an AC diesel electric distribution system.
- Less harmonics and insulation degradation from heat associated with harmonics.
- Simpler operations compared to AC diesel electric distribution system – no generator synchronization required.
- Least fuel usage due to variable speed generators, ESS, and captured power from regenerative loads.

A hopper dredge is not simply a cargo ship hull with dredging equipment inserted. A hopper dredge is a dredging system, from stem to stern, with every component integrated to do one thing as efficiently as possible. Every pound of piping, wire, machinery or steel that is not optimized for this one purpose, contributes to inefficiency, with the cumulative effect of the commercial weakening and potential failure of the dredge.

Efficiency is everything. Efficiency represents the amount of fuel used and the amount of fuel wasted. Personal injuries are inefficient. Environmental impacts are inefficient. Emergency repairs are inefficient. Environmental fines contribute to inefficiency. Over-crewed vessels contribute to inefficiency. Antiquated practices and legacy equipment contribute to inefficiency.

Improved dredging efficiency through system design optimization, automation, and environmentally-responsible energy management will lead to more cubic meters of material moved for less money (IDR, Sep 2015).
REFERENCES


