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# THE DYNAMICS OF PROPULSION TECHNOLOGY ADOPTION IN THE MARITIME INDUSTRY: A SYSTEMS DYNAMICS MODEL OF TECHNOLOGY TRANSITION

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**Abstract.** As academics we seek to develop or refine enhancements to propulsion technologies, we look for energy efficiencies, but once found will those new efficient energy methods be used immediately? History traces maritime propulsion technology adoptions over decades and centuries. When new energy saving technologies are available, ship-owners are seemingly reluctant to adopt the new technology or embrace the new technology withskepticism, regarding available infrastructure and concern about investment in medium term developments. The reluctance may be completely rational as ship-owners will invest millions for a propulsion plant that will be in use for decades. Owners will look at the tradeoff between the benefits versus risk of the new propulsion technology – both have considerable uncertainties associated with them before adoption. Through causal loop and dynamic modeling the intent is to gain qualitative insight into the factors affecting of the adoption of a marine propulsion system in the merchant marine industry.

What is the tipping point that must be achieved before energy efficient technological changes will be adopted – overcoming the inertia of the international maritime community? A properly constructed model ofthe maritime propulsion industry will allow us to ascertain the adoption of an energy efficient system over time and varying external conditions. A systems dynamic model will allow for exploration of the interactions of the industry and allow for varying conditions to be reflected and the resulting behavior illustrated.

The maritime industry is complex and consists of a myriad of stakeholders all set in and impacting a global theater. The maritime industry faces accelerating economic, technological, social, and environmental challenges with respect to propulsion mode and energy efficiency. How will the industry and specifically the ship-owner react to these dynamic changes? The proposed research will serve to model this propulsion question.

**Key words:** maritime, marine propulsion, new technology adoption, dynamic modeling, prospect theory

## 1 INTRODUCTION FROM OARS TO LNG

The maritime transportation industry is century's old and truly global in nature. Marine propulsion is the system used to generate the thrust necessary to move the ship or vessel across the water. Propulsion modes developed from non-mechanized to mechanize over centuries in some cases and several decades in other cases.

The time line of adoptions from the 8th century to present, represent years of historical development that helped shaped the maritime enterprise. As propulsion technology developed, often it was not until significant factors, in many cases external to the technology itself, were achieved that industry fully embraced the propulsion concept and technological acceptance gained speed. What are the factors that affected the 8th century Gallery and the transition to sail vessels in the 16th Century? Are those the same factors that affected the sail ship transition to steam and similarly replaced steam ships with diesel propulsion?

## 2 EXTERNAL FACTORS AFFECTING PROPULSION MODE ADOPTION

Logic would follow, in an effort to run profitably, a ship operator would like to use the most efficient method of propulsion, the least expensive fuels suitable for that mode of propulsion and geographic operating area. Does data, with respect to adoption of new propulsion mode, support this statement or are there external factors not yet revealed?

The N.S. Savannah is an interesting case study challenging that question. The nuclear merchant vessel Savannah (N.S. Savannah) was constructed and operated commercially for 10 years. The Savannah was the first and only nuclear powered merchant ship developed. (Conner 2012) While operating, the N.S. Savannah ran safely for over 3 years without refueling. Understanding the high cost of fuel to operate merchant vessels, why did this mode of transportation fail despite its ability to run years without refueling? The US Navy currently operates several surface and submarine vessel utilizing nuclear propulsion. Why does this propulsion technology suit the Navy and not the US merchant industry? Currently LNG fueled diesel vessels are being adopted (Woessner 2013), while hydrogen fueled vessels are met with only cautious interest despite the economics of the fuel. (Armani 2011) Does the decision making for a propulsion mode starts and ends with economics? If the propulsion mode maximizes economics is the decision already completed? Or is this an over simplification of the decision making process?

## 3 START WITH ECONOMICS

The long life of the ship owner's principal asset – the ship – requires that that the propulsion plants have an equally long life. A typical ship will last 25 years (approximately) and the engine will need to be useful for the entire life of that vessel. Generally, vessel propulsion equipment is not replaced during its life due to prohibitive costs associated with such an endeavor. When a ship owner chooses a propulsion plan he/she

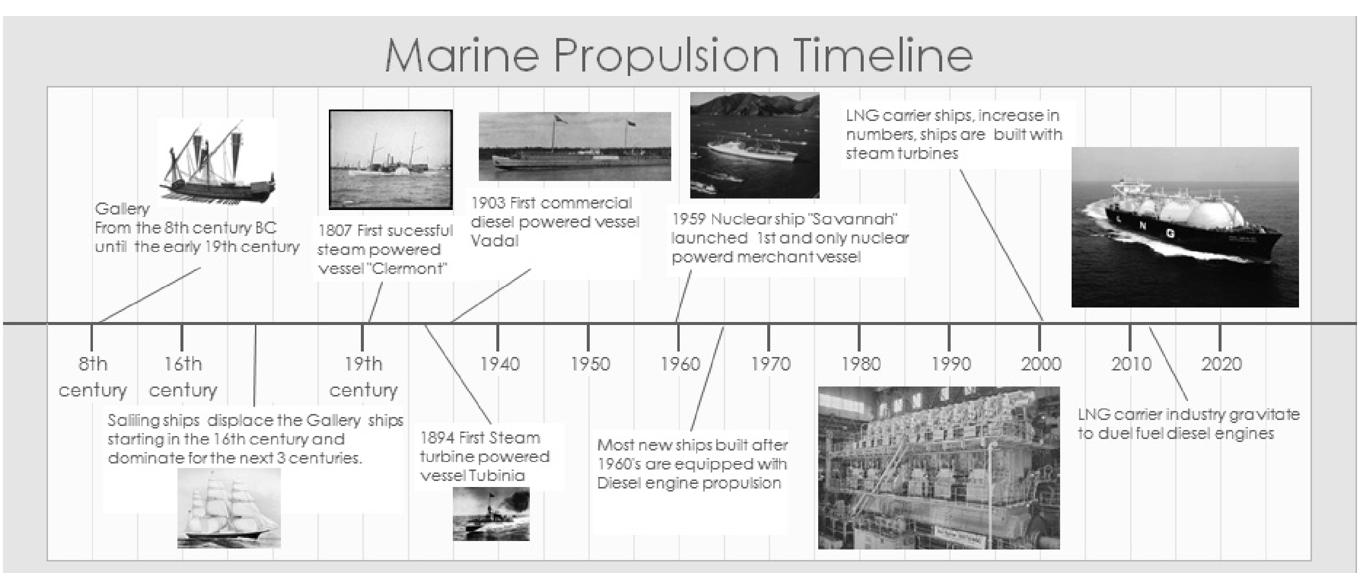


**Figure 1** Historical timeline for Marine Propulsion technology transitions.

| S65ME-C8 fuel consumption calculation |
|---|
| 164 g/kWh = .2696 lb/hp·hr |
| .2696 lb/hp·hr = 0.0001223 metric tons / hp·hr |
| 0.0001223 metric tons / hp·hr x 23,113 hp = 2.84 tons/hr |
| 2.84 tons/hr x 24 hr /day = 67.68 tons/day |
| 68.16 tons/day x 250 days per year = 17,040 tons per year |
| 17,040 tons per year x $282.00 per ton IFO 380 |
| Yearly cost for fuel is $4,805280 |

**Figure 2** Sample fuel oil consumption

does so with a 25 year planning horizon. Even if the ship owner is using the vessel as an asset play (buy ship low – sell high), the rational ship owner will maximize the value of the ship on the secondary market with a propulsion plant that is reliable, efficient & technically sound.

The operating costs of a vessel are comprised of fuel costs, crew costs and a host of vessel-specific overhead costs. It should be noted that fuel costs alone can represent up to 60% of the operating costs for a vessel. Therefore, the fuel efficiency of the propulsion plant is a critical factor in the operating costs of an engine. If the engine economy and fuel efficiency of the vessel are poor, then the cost for the ship's operation will be greater than for a more efficient comparable engine. Reduced profits for the ship owner result from inefficiencies of propulsion operation. Companies will often look keenly at the operation parameters to see where improvements can be made. Such evaluation often results in plans for alternative operations, such as change in speed (slower to reduce fuel consumption) or acquisition of better equipment to improve efficiency.

To this end propulsion costs are calculated to include specific fuel consumption calculations. These calculations involve lengthy formula to reflect costs for engine operation under way. The actual calculations are in figure 2 right.

The economics of the planning horizon can be modeled dynamically for most key aspects of ship operation. However, this is just a snapshot of the economics. To fully capture the long service life economics it would be necessary to incorporate, time value of money, interest on mortgage, mortgage, ship yard periods and end of service life disposal. The conceptual diagram of these aspects is shown in figure 3. Operating days or hours per year are reflected in figure 3 as the

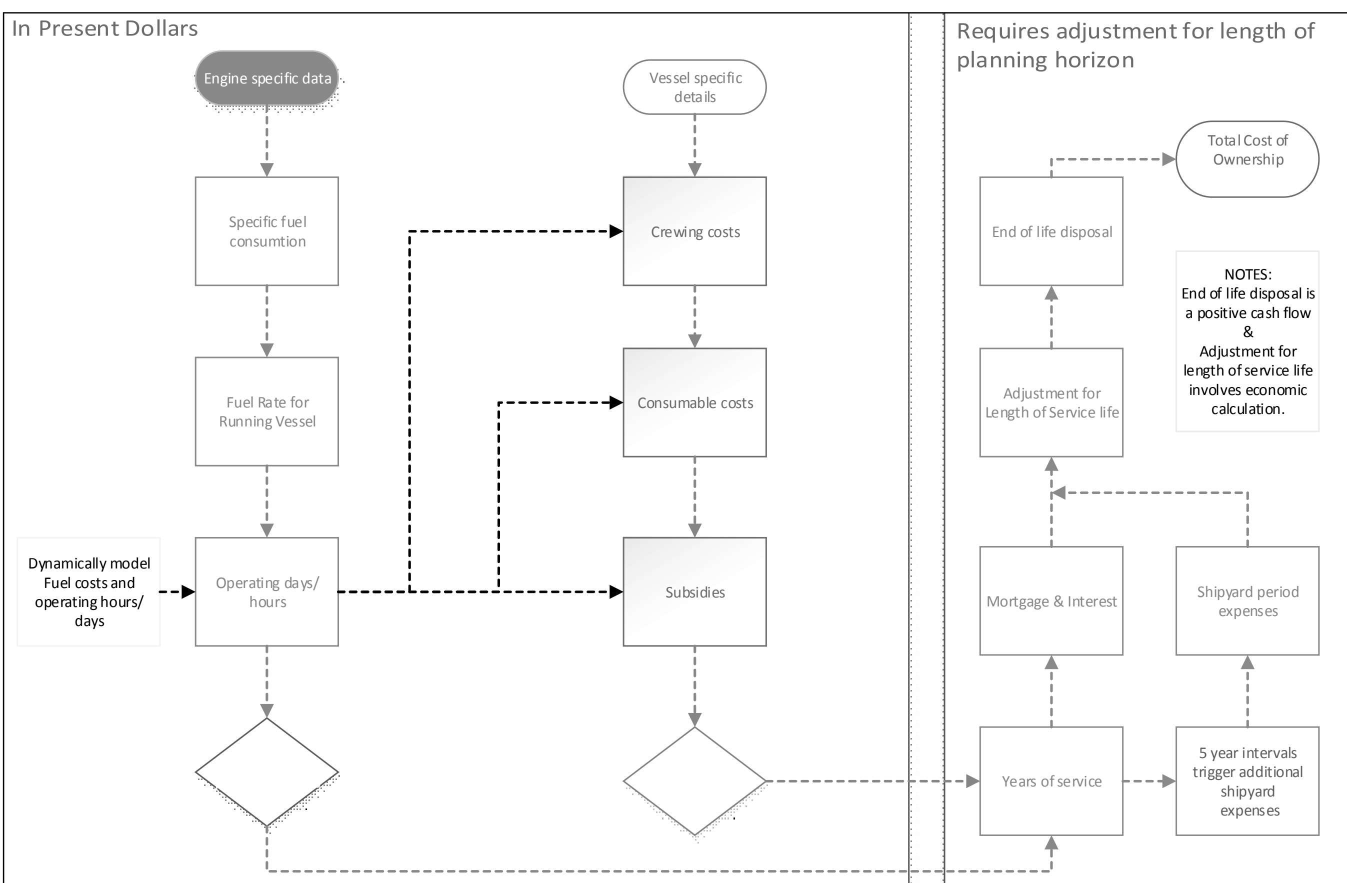


**Figure 3** Economic Aspects of Shipping Industry (Yearly and Extended Service life)

industry standards of 24 hours per day and 250 running days per year. However, these can figures be dynamically modeled to reflect higher rates of operation or lower rates.

Of note is the segregation of the day/monthly or yearly costs reflected on the right side of figure 3 – these costs are in present dollars. Consumable items container spare parts and are adjusted for prolonged operation to reflect wear and replacement. Equations are adjusted to reflect manufacturers specified running/replacement periods and frequency.

Expenses for the extended planning horizon need to be adjusted through economic values to represent the worth of those dollars in frame of reference. Adjustment is through sequence of economic equations (representing the time value of money) and a specified interest rate.

Figure 3 is a conceptual model that includes the propulsion related costs, running costs, extended life costs, and disposal payment. The left side of figure 3 represents costs associated with the vessel underway or in operation. Inputs to the model can be dynamically simulated to reflect changes in fuel cost or operating days. The middle section of figure 3 illustrates the running costs of the ship (minus subsidies - if any – which is a positive). These running costs (or subsidies) are attached to the ship whether it is propelled or not. The right side of figure 3 depicts the longer term nature of the shipping industry. The years of service will become a multiplier for the propulsion and running costs. Additionally the years of service will trigger expenses associated with mandatory shipyard period every 5 years. The green or right side of the conceptual model will be adjusted for service life using economic equations and interest rate. The conceptual model will result in a total cost of ownership for the ship.

The ship owner wants to maximize the profit from a voyage (low voyage costs < high voyage revenues) but typically profit margins are low and open trade. Voyage costs for a vessel consist of port costs and operating costs. Port costs are specific to the area where the vessel trades and are not controlled by the ship owner. Therefore, the ship owner will evaluate the operational cost from the vessel as it is under his/her control.

The conceptual model is deliberately segregated in yearly and longer term costs because it is necessary to evaluate the operation of the actual vessel in both long term cost of ownership and short term operation profitability. The daily/weekly/yearly expenses are monitored for areas where improvement can be made technically that add to a better performance or efficiency. On the other hand it is in this daily/weekly/

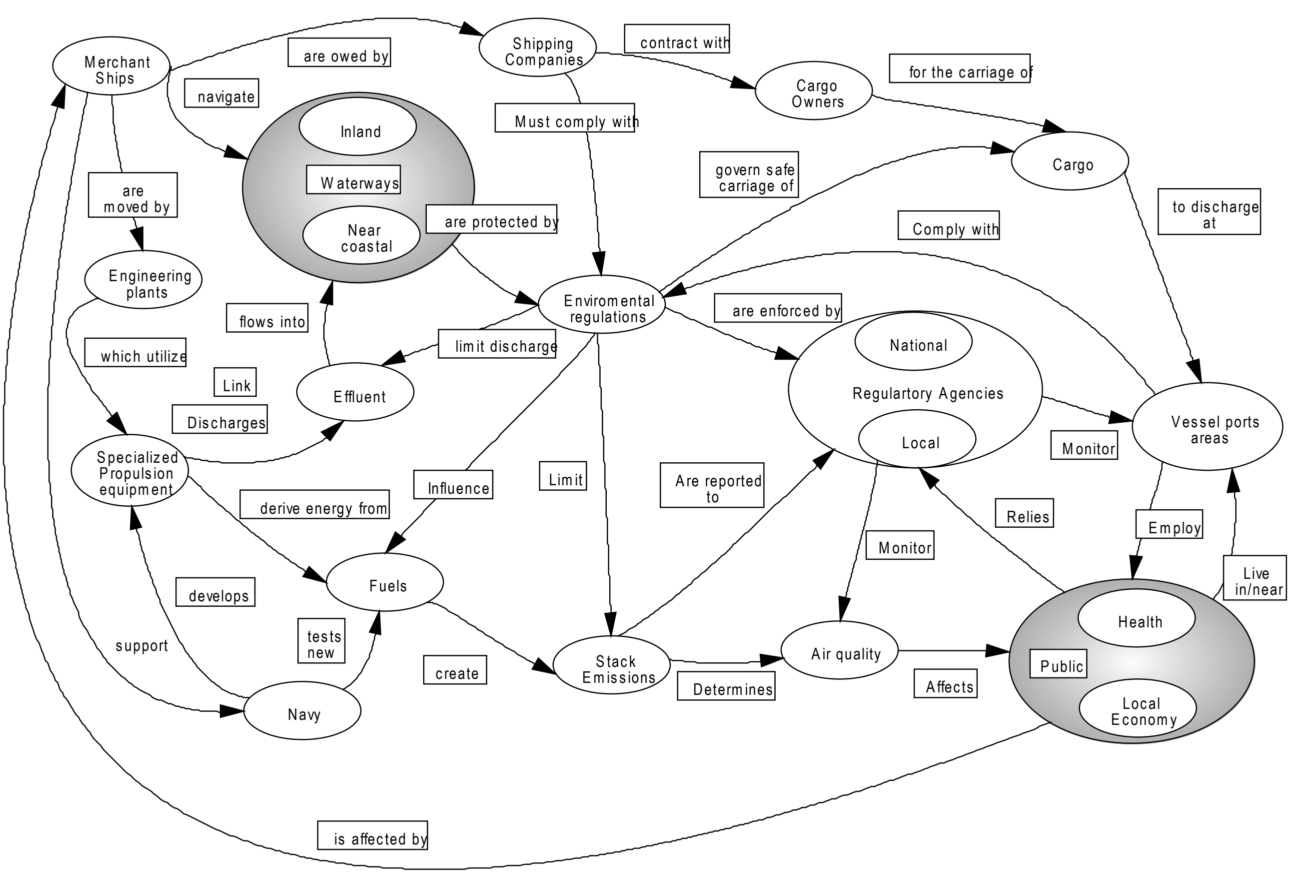


**Figure 4** The Systemigram of the Merchant Ship and industry in a day to day setting.

year expense area that operators seek reduced to lower costs. The ship owner often straddles the line between efficient and substandard operations.

The conceptual model reflects how the multi-level economics model will fit into the decision making for a new propulsion mode. The challenge is to develop a system model of the maritime industry; marrying the economics to the complex system itself. Then relate that structure to the dynamics of maritime propulsion. This will provide for an overview of the industry an illuminate exogenous factors that may influence technology beyond pure economics.

## 4 MARITIME PROPULSION WITHIN THE MARINE INDUSTRY, BEYOND THE ECONOMICS

While much of the costs for the ship operator stem from the fuel for vessel propulsion, pure economic models of the maritime industry fail to account for much of the underlying forces of the merchant maritime industry. Figure 4 is a Systemigram of the ship-owner within the maritime theater based upon the current merchant mariner industry (present day) and normal day to day operations. The Systemigram is an amalgam of a system description conveyed in a diagram. The pictorial representation of the maritime industry via the systemigram is helpful to visualize the relationships within the sector, but static in nature.

The Systemigram is read from top left to bottom right. The systemigram will illustration via nodes, links and words the purpose of the system. In general the Systemigram illustrates how the merchant ship-owner is linked to other nodes and what is the relationship between the merchant ship owner and the nodes.

What can be seen in this Systemigram is that merchant vessel carry cargo to discharge at ports. Commerce, from the carriage of goods by the vessel to the port, affects the local community. Further, those merchant vessels utilize engineering plants using fuels for propulsions. Those propulsion plants are monitored for discharge to the environment via the air and water. International, national and local regulatory agencies are monitoring stack gas emissions from the propulsion process, the emissions affects the air quality and the public in port areas. The communities are affected by the air quality arising from vessel emissions but are also affected by the goods brought into the local area for transport and sale.

As indicated, the Systemigram is read from top left to bottom right, however the center of the page holds a node that is highly linked to the others; namely environmental regulations. Many nodes are linked to environmental regulations and the output links from this node are declarative and forceful. It becomes apparent that in today's maritime industry the impact on the environment is significant. Other significant nodes affecting propulsion equipment adoption can be through the relationship between the merchant vessel and the Navy. The merchant vessel supports the Navy with logistics. The Navy develops specialized propulsion equipment and new fuels. What cannot be seen from the systemigram is the strength of each of the links or direction (reinforcing or opposing).

Why did the change from sail to steam engine and from steam to diesel take so many years given the obvious economic advantages of the competing alternatives? The answer is not simple, but the systemigram is a start. With the complex maritime theater mapped, we have better insight to who the stakeholders are and what are the links or relationship among parties that might affect the adoption for new propulsion technology. We will use system dynamics to model the interactions among the actors.

## 5 MARITIME PROPULSION AND SYSTEM DYNAMICS

To model the propulsion adoption process including the effects of the system and actors we will use a system dynamics model. Stocks, and flows along with feedback are the two central concepts of dynamic systems theory. Stocks are accumulations. These are the state of the system, for example the number of commercial merchant vessels. These are represented in a diagram by a rectangle. Flows are characterized by rate of increase or decrease to the stock, for example the rate of ship building or retirement. The flows are characterized in a diagram by a valve indicating a rate of change of the stock. Inputs and outputs to a stock are represented in systems dynamics as pipes with arrows indicating an outflow or inflow. Feed backs are an illustration of the interaction of the system players or actors. The actions of the players cause a change. The change triggers other actions or others to act. Thus a new situation is present which then feeds back to the system influencing our next decision. The feedback can be positive (+) or negative (-). The dynamics of the systems result from the feedbacks. Delays are also a part of the dynamic modeling and create instability in systems. The delay feature simulates the time delay between the initiation of a control action and its effects on the state of the system.

The spread of rumors and new ideas, the adoption of new technologies, and the growth of new products can all be viewed as epidemics in which the innovation spreads by positive feedback as those who have adopted it 'infect' those who have not. The concept of positive feedback as a driver of adoption and diffusion is

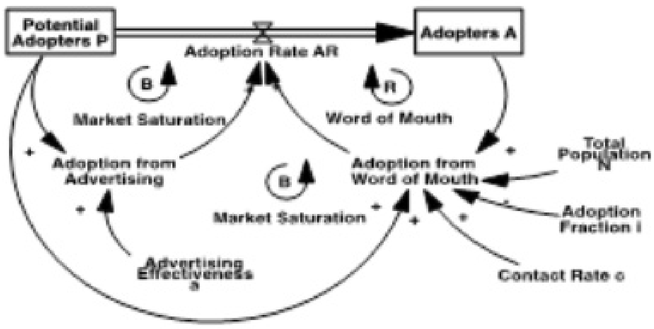


**Figure 5** The Bass Diffusion Model

very general, and can be applied to many domains of social contagion.

In 1969, Frank Bass developed a model for the diffusion of innovations; this has become one of the most popular models for new product growth and is widely used in marketing, strategy, management of technology and other fields. The Bass Diffusion Model is a system dynamic model using stocks, flows and feedback. Figure 5 (above) is the Bass Diffusion Model.

However, this model in its current form cannot respond in modeling the maritime case of adoption of new propulsion technologies; since the numbers of potential adopters are small relative to other types of technology adopters, very different dynamics, different set of variables, and different balancing and reinforcing loops.

Therefore, we use concepts of a diffusion model (like Bass) and modify the model to reflect specific variables of the maritime industry detailed in the systemigram. The Maritime propulsion adoption model is an adaptation of the Bass Diffusion Model.

The power of the systems dynamic model is that underlying the causal relationships are mathematical relationships. In the model figure 6, the population of ships is *N*. We also have the fraction of ships that have adopted *f*. As the fraction of adopters *f* get larger it limits the number of potential adopters *P* from the total population *N* of ships.

The variables and equations for the underlying mathematical relations ships are as follows:

Figure 6 System dynamics model variables are defined as follows:

| | |
|---|---|
| *P* = Pool of Potential Adopters | *f* = Fraction of adopters |
| *A* = Adopters | *n = Rate of Military interactions* |
| *N* = Total population of ships | *r = regulatory compliance policy* |
| *AR* = Adoption Rate | *c = Rate of port/commerce interactions* |
| *Ar* = Adoption from regulation | *s = social pressure/policy* |
| *Aw* = Adoption from waterfront word of mouth | *Av* = Adoption from value |

*v* = Value is an output from the prospect theory calculation of cost differential between the proposed propulsion mode and the existing or alternative modes and risk.

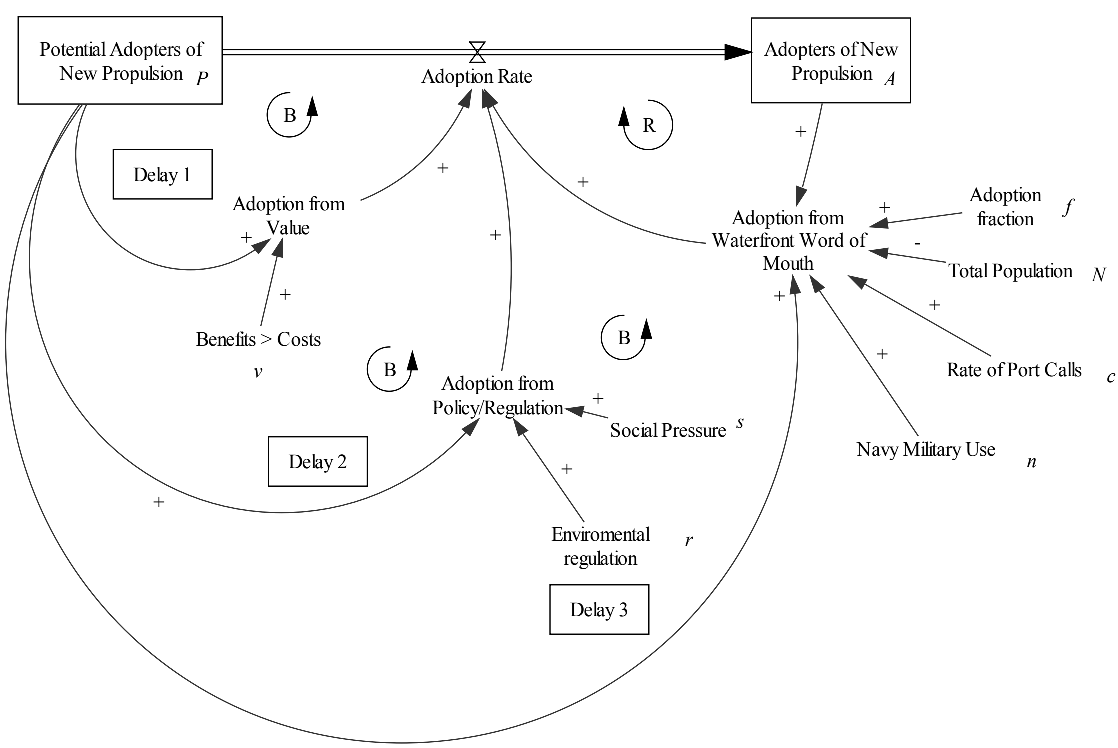


**Figure 6** Maritime Propulsion Adoption Model

Figure 6 System dynamics model equations are defined as follows:

$N = P + A$ where $N$ is constant, $P$ is the pool of potential adopters and $A$ is the adopters.

$A = INTERGRAL\ (AR, A_0)$ where $AR$ is adoption rate and $A_0$ is the initial installed base.

$P = INTERGRAL\ (-AR, N - A_0)$ where $AR$ is adoption rate, $N$ is the population of ships minus the installed base)

*AR = Adoption from Value + Adoption from Policy/ Regulation + Adoption from Word of Mouth*.

$Aw = c \times f \times n \times P(A/N)$ where $c$ is the contact in port or commerce interactions, $f$ is the adoption fraction, $n$ is interaction/commerce with military or Navy, $P$ is the pool of potential adopters, $A$ is adopters and $N$ is the population of ships.

$Av = v \times P$ where $v$ is perceive value (benefits/costs) and $P$ is the pool of potential adopters.

$Ar = r \times s \times P$ where $r$ is required compliance, s is social pressure and $P$ is the pool of potential adopters.

## 6 INTERPRETING THE MARITIME PROPULSION SYSTEM DYNAMIC MODEL FIGURE 6

The stock of potential adopters would represent ship-owners evaluating new engine technologies. The adoption rate of new propulsion technologies is represented by a flow and would be as a result of inputs from the adoption from value, policy/regulatory requirements, as well as waterfront word of mouth variables. The eventual stock of Adopters represents ship owners that have chosen to utilize the new propulsion mode.

Starting with the adoption of propulsion mode due to value; simply stated this balancing loop illustrates how the potential adopter exercises their option to delay or wait until some of the uncertainties and benefits are more fully realized. Often this means a delay until the benefit is greater than cost.

In the case of Maritime Propulsion, the initial investment in the propulsion mode is costly. However, significant costs such as the training of employees on the new technology as well as any costs associated with changes to infrastructure to accommodate that new technology must also be considered. The auxiliary variable 'Adoption from Value' can be explained by a financial investing term "deep in the money"[1]. When the potential adopter is assured of value for investment (benefits > then costs with low/lower risk) this increases the Adoption Rate (AR).

The second balancing loop is a result of forced adoption from policy or regulation. Often regulatory agencies will pass policies limiting discharges into the environment for the greater good. The policies are authored; often there is a delay to the policy making due to politics and bureaucracy and eventually forced compliance is required. The second balancing loop is affected two auxiliary variables policy (regulation) as well as social pressure.

An example of this forced compliance is in emission regulations in the State of California. It is unlikely that a ship owner would voluntarily spend 30% more on fuel than necessary. However, policy and social pressure in the State of California required compliance with the policy or be banned from trade in that port. When the potential adopter is forced to adopt a new technology (or face economic consequences) this increases the Adoption Rate (AR).

The third balancing loop and only reinforcing loop is as a result of waterfront word of mouth. There is a saying in the Marine community, "It is not a small world – it is a small waterfront". This explains the third balancing loop. Ships come in contact with other ships in ports or during commerce, "exposing" themselves as in the epidemic example to other operators. The more frequent the contact, the more exposure. Exposure to adopters of the technology, either military or non-military will lead to word of mouth experience.

The third balancing loop is affected a delay and four auxiliary variables of port call frequency (contact), military use (adopted user outside of population), the number of adopters, as well as ships without the technology. The number of ships without the technology comprises a much larger pool than potential adopters. As the life of a vessel is typically 25 years, this ship will likely never join the pool of adopters but participate in the Waterfront Word of Mouth adoption. The adoption from word of mouth increases the Adoption Rate (AR).

As the pool of adopter grows, there is a reinforcing loop as part of the Word of Mouth adoption loop. This reinforcing loop results from Adopters actively participating in in a word of mouth exposure which is governed by the auxiliary variables increasing the adoption rate. Please note, the term word of mouth is used, but this exposure and contact could be from email, fax and casual observation. This does not necessarily have to be by direct contact.

When the propulsion mode is initially adopted, the adopter population is zero; the only source of adoption is from Value and to a lesser degree any word of mouth from military applications. The initial growth will be as a result of adopters perceiving a Value in terms of benefit and cost.

[1] DEFINITION of 'Deep In The Money' An option with an exercise price, or strike price, significantly below (for a call option) or above (for a put option) the market price of the underlying asset. http://www.investopedia.com/terms/d/deepinthemoney.asp#ixzz3ZEgfjBq9

The adoption resulting from 'Value' has several underlying variables that form part of a positive feedback. These positive feedbacks can the initial growth for a propulsion product. In the initial phase there is little 'Word of Mouth' awareness with the exception of Military use – which may be of some value but not a direct feedback. The initial growth of a new propulsion technology will be as a result of adopters seeking 'value' (Value loop) as well as regulatory requirements (regulatory loop). As indicated above 'value' indicates that benefits > costs with lower risk.

Initial growth will be in sectors where the existing network or infrastructure can be utilized. This lowers the costs to adopt the new technology and allows for the adopter to arrive at the benefits > costs more quickly than other potential adopters.

For example, ships carrying Liquefied Natural Gas (LNG) as a fuel are among the early adopters of new slow speed diesel engines using LNG as fuel source. This also illustrates a concept of complementary goods. The ships are loading LNG as a cargo, they are already at the port facility and the infrastructure is in place to load the LNG as a fuel. A benefit is achieved by utilizing existing networks (a new fuel terminal does not need to be constructed) as well as no deviation to a specialized fueling facility. The facility is built already and the capabilities present.

If there is a benefit to the LNG fuel in the new engine it will be gained by the vessel at lower costs (little or no infrastructure costs and compatibility with existing equipment) allowing for value to be realized more quickly. With value achieved at a lower threshold, the vessel may adopt the technology and become part of the reinforcing loop of adopted users.

The positive feedback associated with regulatory compliance will also help to spur initial growth. Ship owners seek to comply with regulations, non-compliance will likely adversely affect economics or result in punitive measures. If a product is compliant with new requirements it will be attractive or favored over other modes of propulsion that are not fully compliant. Once installed, the new technology adopter becomes part of the adopted pool and provides the benefits of Waterfront word of mouth reinforcement.

A negative feedback loop is self-limiting rather than self-reinforcing. In most cases the potential adopters are from new ship building, economics often prohibit the replacement of an engine. With the ship population essentially fixed. Ship retirements equal the number of new ships or very early so over a 25 year period 1990 -2015 for container ships. Therefore, as adoption occurs it increases the fraction of engine adopters in the population. This in turn, reduces the number of potential adopters from the population. The increase in the fraction of adopters will at a point retard growth since the population is nearly constant.

## 7 HOW DO WE MODEL THE SHIP OWNERS DECISION MAKING

The system dynamics model above has several auxiliary variables that represent key phenomena. These variables are critical to the function of the dynamic model and require additional modelling to capture the behavior and essence. Perhaps the most important of these variables is the notion of value. Value will be used as benchmark for how the potential adopter will make technical and economic decisions under risk.

Utility theory is the canonical approach to incorporating risk aversion into an economic decision model. In conventional utility theory, people are expected to make rational decisions that maximize their wealth or income (utility). Gains and losses are equally weighted for the rational decision maker.

People tend to be loss adverse. The ship owner is highly risk adverse as there is long term implications to a decision made involving propulsion choice. He/she cannot afford to be wrong and 'live' with a bad decision for the life of the vessel. The risk adverse ship owner may well reject opportunities that could increase their net income (gains) if possible losses (risk) are involved. A new/unproven technology would be such an example. If a new propulsion technology were developed the gains would have to be large enough to overwhelm the pain from suffering losses.

In prospect theory, people do not value losses and gains equally. Prospect theory puts greater weight on losses than it does gains (a dollar lost has greater value than a dollar gained). Prospect theory is appropriate for modeling the nature of the risk aversion of the maritime propulsion industry in that it seeks to maximize **value** not wealth. In maximizing value the people are willing to sacrifice possible increases in future income for less risky or safer economic prospects.

Utility theory is based upon decisions seeking to maximize utility. The ship owner instead displays characteristics of behavioral economics reflected in prospect theory. The maritime propulsion community is risk adverse. The ship owner would rather forego some efficiency (savings) related to the engine for the value choice with less risk. The use of Prospect Theory will capture overall risk as it better reflects the importance of risk aversion to technology adoption and the economic implications.

The key to modeling technical and economic risk with prospect theory will center on the concept of value. Value can be expressed as a positive and negative outcome. Prospect Theory will be used for this purpose as it expresses the ship owners tendency to reject opportunities that increase their income if possible losses are involved.

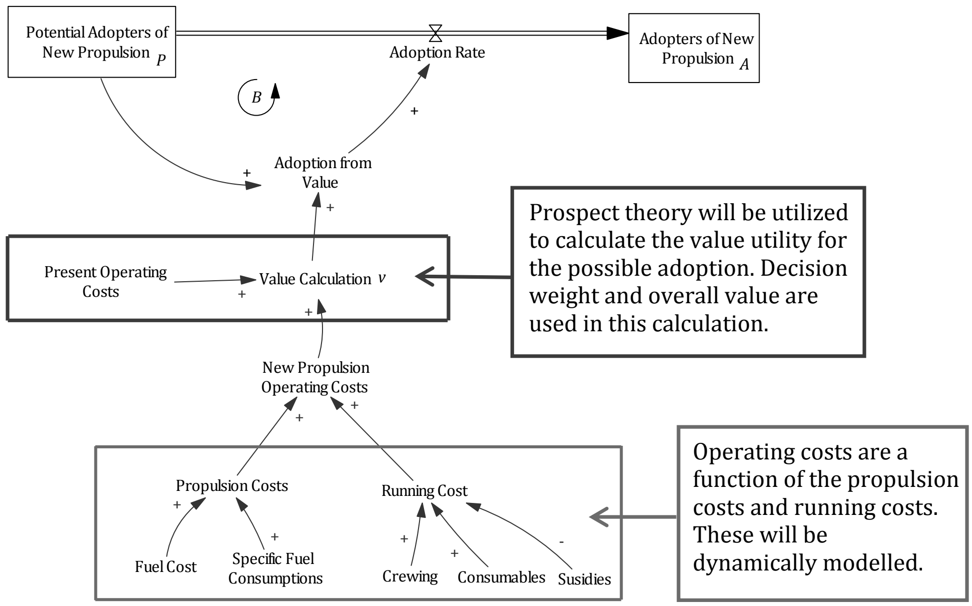


**Figure 7** Maritime Propulsion Adoption Model – question 6 modeling economic and technical risk

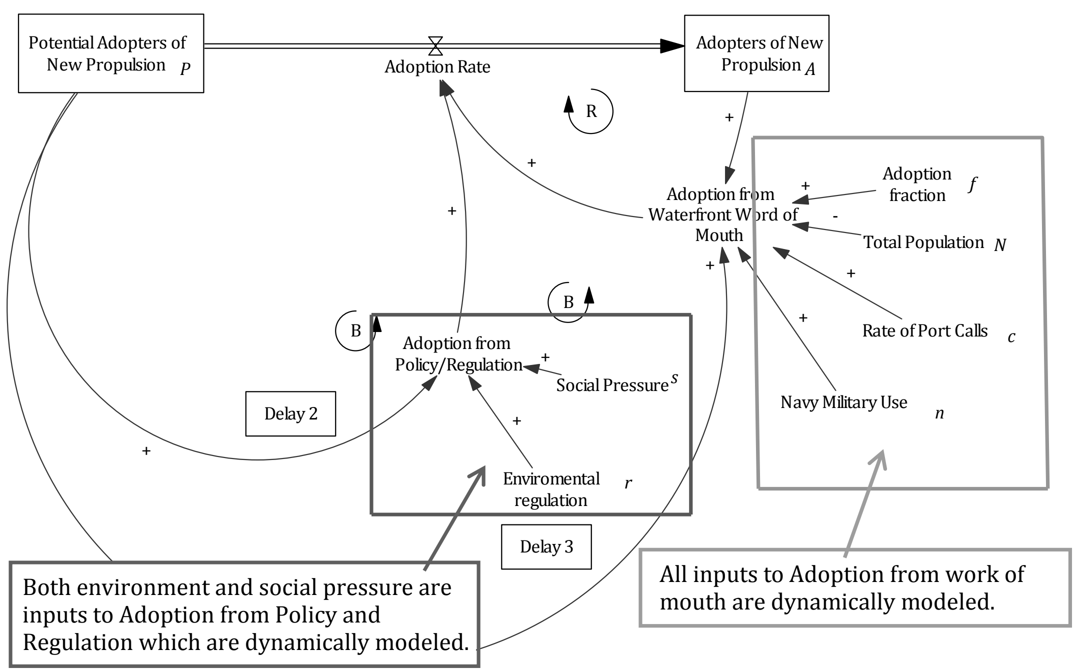


**Figure 8** details additional auxiliary variables that will affect new propulsion mode

Figure 7 shows part of the Maritime Propulsion Adoption model. For ease of illustration I have shown the conceptual model in pieces from the dynamic model built in a modeling software program called Vensim. This partial figure of the model shows the 'Adoption of Propulsion Mode Due to Value'. The operating costs are dynamically modeled so that specific fuel consumption, fuel costs, crewing, consumables and subsidies (if applicable) can be varied and simulated. The new propulsion mode costs are calculated. The potential adopter chooses between the options available to them ($new mode of propulsion or $traditional mode). This choice is based on two dimensions, the apparent value of each attribute or option, and the weight assigned to those values or options. These two features—overall value & weight—are then combined by the decision maker and the option with the highest combined value is chosen by the decision maker.

The output of the value loop will either be sufficient to convince the ship owner to adopt the technology or delay/ wait until some of the uncertainties and benefits are more fully realized producing a higher 'Value'.

In the case of Maritime Propulsion, the initial investment in the propulsion mode is costly. Added to this are costs of training employees on the new technology. Lastly, infrastructure costs (if any) to accommodate the new technology in port areas. The propulsion investment has a long planning horizon of more than 20 years. When the potential adopter is assured of value for investment (benefits > then costs with decision weighted risk) this increases the Adoption Rate (AR).

Technological risks are also reflected in the figure 7 model by 'Consumables'. Under the running costs there is a variable 'Consumables' – this figure represents maintenance required by engines for upkeep. Consumables can be dynamically modeled in Vensim and are represent parts for replacement and reflective of reliability. If new technologies parts are more less/expensive or require more/less frequent replacement it will be shown as increase/decrease cost respectively in this category.

Additional adoption factors such as the implementation of environmental factors, social pressure, rate of port calls and contact with military adopter will be modeled dynamically within the model. Figure 8 shows of forced adoption through regulation and social pressures. Figure 8 also included the loop noting the spread of the 'contagion of adoption' through word of mouth and other social interactions of the technology. The values will be variable so that effect of the variable can be noted. A built in slide bar is available in Vensim to vary the output of the variables and note the effect of those changes.

## 8 EARLY RESULTS AND FUTURE WORK

Using prospect theory, multi-level economic modeling and the dynamic model from figure 6 the early results confirm the intuitive thoughts on propulsion mode adoption. The model is still being evaluated using data from the steam to diesel technology adoption timeframe. Data collection is time consuming but early graphical results confirm the adoption curve for this technology transition. Several technological adoptions or failed adoptions must be examined before the model is fully vetted. Work is in progress to fully collect data, execute and interpret the output of the model with various propulsion technology modes both past and present.

## 9 CONCLUSION

The current system dynamics model is a work in progress. The relationships between the maritime propulsion communities are fully developed and modeled. Further work is needed to fully validate the model, and confirm that no significant factors have been overlooked.

Early results indicate that the use of behavioral economics in prospect theory appears to provide better insight into the behavior of the ship owner versus traditional utility theory. The length of time that the ship owner will use a propulsion engine as well as the impact to the operating costs of the vessel of the engine choice makes the ship owner risk averse. It appears that prospect theory in conjunction with system dynamic modeling could paint a more accurate picture of the average ship owners decision making behavior than conventional utility and economic theories.

Within the abstract for this paper I posed three questions regarding the adoption of a new efficient energy mode of transportation specifically would it be adopted immediately, what are the tipping points for the decision to adopt and how does the industry react dynamically to changes. The present system model is a significant step towards answering these questions. There is more work to be done to validate and fully support the initial results from this model.

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