Reducing Fuel Use in the Southeastern U.S. Shrimp Fishery with Vented, Cambered Doors and Braided, Sapphire® Webbing

Texas A&M AgriLife Extension

TAA Trade Adjustment Assistance for Farmers Technical Assistance

Sea Grant Texas at Texas A&M University
TexasSeaGrant.org

Douglas L. Steele, Director • Texas A&M AgriLife Extension Service • The Texas A&M University System • College Station, Texas

Pamela T. Plotkin, Director • Texas Sea Grant College Program • Texas A&M University • College Station, Texas

Prepared by **Michael G. Haby, Gary L. Graham and Lawrence L. Falconer**

Reducing Fuel Use in the Southeastern U.S. Shrimp Fishery with Vented, Cambered Doors and Braided, Sapphire® Webbing[a,b]

Prepared by Michael G. Haby[c], Gary L. Graham[d], and Lawrence L. Falconer[e]

TAMU-SG-14-502

[a] This publication is supported in part by an Institutional Grant to the Texas Sea Grant College Program (NA10OAR4170099) from the National Sea Grant Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Specific work related to fuel conservation efforts in the shrimp-trawl fishery has been possible only through financial support provided by several grantors between 2005 and 2011. These funding sources include: (1) Award number 2005-48605-03347 from the U.S. Department of Agriculture to the Texas A&M AgriLife Extension Service, an agency of the Texas A&M University System (received in 2005); (2) Contract number CM725 / TAMU Sponsored Project: 0000421118 from the State of Texas Energy Conservation Office to the Texas Sea Grant College Program, a part of Texas A&M University (received in 2006); (3) Award number NA10OAR4170099 from the National Sea Grant College Program Office within the U.S. Department of Commerce to the Texas Sea Grant College Program (received in 2010); and (4) Award number H001344230 from the U.S. Department of Agriculture to the Texas Sea Grant College Program (received in 2011).

[b] The mention of a trademark or proprietary product does not constitute a guarantee or warranty by the Texas A&M AgriLife Extension Service or the Texas Sea Grant College Program, and does not imply its approval to the exclusion of other products that also may be suitable.

[c] Senior Research Associate / Professor Emeritus & Extension Economist – Seafood, Department of Agricultural Economics. Texas Sea Grant College Program and Texas A&M AgriLife Extension Service, Texas A&M University System. Mailing address: Texas A&M AgriLife Research & Extension Center, 10345 Hwy. 44, Corpus Christi, Texas 78406-1412. Telephone: 361/265-9203, Fax: 361/265-9434, E-mail: m-haby@tamu.edu.

[d] Professor & Marine Fisheries Specialist, Department of Wildlife & Fisheries Sciences. Texas Sea Grant College Program and Texas A&M AgriLife Extension Service, Texas A&M University System. Mailing address: P.O. Box 1125, West Columbia, Texas 77486. Telephone: 979/345-6131, E-mail: glgshrimp@embarqmail.com.

[e] Professor and Extension Economist, Department of Agricultural Economics, Mississippi State University. Mailing address: Delta Research and Extension Center, P.O. Box 197, Stoneville, MS 38776. Telephone: 662/686-3238, E-mail: larry.falconer@msstate.edu.

Table of Contents

Executive Summary

This report traces efforts to evaluate, modify, and verify more fuel-efficient trawl gear for the Gulf and South Atlantic shrimp fishery. This project began as the brainchild of Patrick F. Riley, the General Manager of Western Seafood in Freeport, Texas. Initial work began by evaluating off-the-shelf vented, curved, steel trawl doors used primarily in European mid-water fisheries. These doors showed promise during the proof of concept cruise. However, four engineering modifications created verifiable fuel-saving benefits while shrimp production remained identical to harvests made with traditional gear.

With modifications completed, the next phase of the work put this newly modified trawl gear in the hands of cooperating fishermen across the Gulf and South Atlantic states. This cooperative research project was designed and managed by Texas A&M AgriLife/Texas Sea Grant faculty. A four-step research protocol for cooperators (a) benchmarked fuel use with their traditional gear, (b) measured the proportional contribution to fuel savings made by braided Sapphire® nets opened with traditional flat doors, (c) documented identical shrimp production during simultaneous trawling with their traditional rig and the new gear, and (d) measured fuel use while fishing with the new gear. Funds from the U.S. Department of Agriculture and the State of Texas Energy Conservation Office provided a complement of trawl gear and an indicating fuel-flow meter to each fisherman. These funds also supported two consultants who were the first adopters of the fuel-saving gear. Consultants assisted cooperators with adjustment issues in step three so the new gear would produce equally to their traditional trawl systems. This research effort verified the results generated aboard the *Isabel Maier*, the vessel used for the proof of concept cruise, and documented fuel savings that ranged from 10% to 39% with no shrimp loss! The first tier of fishermen who adopted the fuel-saving gear also noted that cambered, steel doors and braided Sapphire® nets had a much longer useful life than their traditional equipment.

In 2010, the complement of fuel-saving trawl gear necessary to replicate an operator's existing trawl system sold for $13,570 compared to $8,965 for a traditional trawl system. The $4,605 difference represented a 51% increase in cost. We believe that sticker shock was one factor responsible for slowing the changeover to the new gear. Of course, paying more for a consumable input like fuel when the same quality is available at a lower price elsewhere will always result in less income from a cruise, other things being equal. However, when faced with two choices for a durable input like trawl gear, a higher price may not have the same effect on income over time if the higher-priced option is more efficient and/or has a longer useful life. Thus, choosing between traditional trawl gear and fuel-saving equipment is a classic decision-maker's dilemma.

The question is whether production costs will be lower with the more-expensive, longer-lived, fuel-saving gear or the less-expensive traditional gear with a shorter useful life and no inherent fuel-saving capacity. This question was answered with a Net Present Value analysis that compared expected production costs generated by the two competing types of trawl gear. Over a 14-year planning horizon–required to account for differences in the useful lives of traditional trawl doors and the cambered gear–annual estimated production costs were converted to their present values across discount rates that ranged from 3% to 15%. Regardless of the discount rate used, the present value of production costs from the fuel-saving gear was consistently lower than those costs estimated with less-expensive trawl gear traditionally used in the Southeastern U.S. shrimp-trawl fishery. Because of a longer useful life and no annual costs to maintain Sapphire® nets, ownership and operating costs were lower when the higher-priced, fuel-saving gear was purchased. However, 80% of reduced production expenses were generated by using 10% less fuel each year, which was estimated to be 6,610 gallons. This 10% annual use reduction is a conservative figure since it reflects the lowest level of fuel savings experienced by fishermen who participated in the study. Therefore, operators who choose the new fuel-saving gear and reduce fuel use by at least 10% would see an increase in net cash flow over the 14-year time frame. Expressed differently, catching the same amount of shrimp, but doing so with lower input expense, generates annual cost savings, that fall right to the bottom line and positively impact the economic well-being of the shrimp-trawling enterprise.

Introduction and Purpose

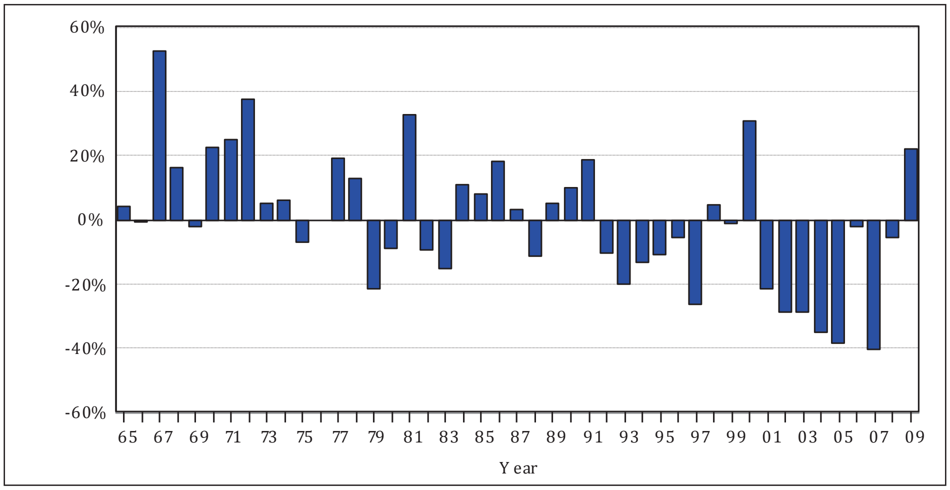
Introduction

Shrimp are a short-lived species that spawn offshore, mature in the coastal bays, and complete their life cycle by migrating back offshore, where they grow rapidly. Annual landings are influenced by short-term ecological changes in the coastal bay systems (nursery areas) brought about by meteorological events.

Annual shrimp harvests tend to fluctuate from one year to the next. In percentage terms, the chart shows how annual Texas Gulf landings compare with the 45-year average of 40.4 million pounds. In 16 out of 45 years–about 36% of the time–annual landings have been at least 20% above (7 years) or below (9 years) the long-term average. Thus, significant variation in yearly harvests has been the constant companion of shrimp producers.

How about seasonal variation? Between 1981 and 2000, 58% of annual Texas offshore harvests and 53% of real dockside value have been generated between mid-July and the end of September (roughly 77 days). During the other 9½ months catch rates were sharply lower, particularly after December.

In the business of shrimp fishing, there are few if any defensive measures an operator can use to offset year-in, year-out variation. Seasonal variation is another matter. During the summer season fishermen historically looked for ways to out-fish the competition. At the same time, experienced producers recognized that during most of the year, expected catch rates would be much lower and would require more operational inputs since shrimp were less abundant, farther from shore, and more dispersed. To succeed in both the peak production window and the remainder of the year, operators have continuously searched for various technological advancements that could squeeze the maximum amount of work out of a gallon of diesel. This drive for efficiency had two sides: (a) to increase output with the same input level or (b) to maintain historic output levels with fewer inputs. These two sides of efficiency meshed well with both a peak production window and the remainder of the 12-month operating cycle.



Percentage Change in Annual Texas Offshore Landings Compared to the 45-Year Average (0%=40.43 million lb.)

Increasing output with the same input level. Out-fishing the competition required investing in larger, more powerful vessels that could pull larger gear (when necessary) and support extended cruises. Upgrades to vessels and gear were undertaken to improve shrimp production, but astute fishermen also remained mindful of the consequences their upgrades had on fuel use. The propeller nozzle is an example of changes to the trawler. Surrounding the propeller with a nozzle provided the option of towing at a faster speed-over-ground rate with the same RPM used with an open wheel. In the late 1980s, webbing manufactured from high-tensile-strength, small-diameter fibers like Spectra® reduced the amount of webbing in the water, which, in turn, reduced drag. This combination enabled some producers to fish larger nets so more bottom could be covered. By pulling larger nets faster with the same engine speed, the efficiency of these enterprises increased as operators sought to assure an early, healthy contribution to annual revenues during the peak production window.

Maintaining output with fewer inputs. The same advancements that boosted production during the summer season also gave fishermen the choice of reducing fuel consumption during other parts of the annual cycle. For example, operators could switch back to the historic size of their nets, many made with strong, small-diameter fibers. Along with less drag created by the new webbing choices, extra thrust from a propeller nozzle allowed operators to maintain their historic speed-over-ground trawling rates in the off-season, but do so with a slower-turning engine that, in turn, burned fewer gallons per hour.

Purpose

Shrimp fishermen have always been concerned about fuel use because trawling is a fuel-intensive enterprise. In a Standardized Performance Analysis (SPA) of the offshore Texas shrimp fleet using producer information from the 12-year interval 1986 through 1997, the average quantity of diesel used by cooperating producers was 66,101 gallons a year [1]. The journey of investigating various upgrades to improve the operational efficiency of shrimp trawling continues to this day, but with a much greater sense of urgency. This sense of urgency exists because operators have encountered sharp reductions in dockside prices for their shrimp since 2001 and a simultaneous, rapid escalation in diesel prices that began in 2002. Today, identifying and reducing avoidable costs is critical to the fundamental business goal of surviving and thriving over time.

Beginning in 2005, Western Seafood and Texas Sea Grant began proof of concept work with curved (or cambered), vented, steel trawl doors as possible replacements for rectangular, flat doors that have served the industry for decades.[1] This report addresses the approach and analysis that ultimately demonstrated the effectiveness of these vented, cambered doors, which had never before been used in the Southeastern U.S. shrimp-trawl fishery.

Four elements are highlighted in this report. The first is a review of early trials and subsequent modifications to off- the-shelf cambered doors that made them a legitimate alternative for shrimp fishermen. Second, we describe the experimental approach used in a regional research program with selected fishermen. In their own backyards, producers measured fuel use with both their traditional trawls and the cambered doors with braided Sapphire® nets, while also verifying production equivalency between gear types. The third consideration highlights replacement, adjustment, and periodic maintenance requirements. Finally, the economic effects of the fuel-saving gear are explored.

This report shows that investing in fuel-saving trawl gear can simultaneously accomplish three key objectives: (a) reducing the use of a major input, which (b) increases operating income, while (c) providing more capacity to absorb economic shocks like large jumps in fuel prices, below average annual production, and fluctuating dockside prices. This work is no different than the migration made from double to quad rigs that occurred more than 40 years ago. It is just the next, logical step in a decades-long journey for greater efficiency in a fishery that experiences significant variation in annual harvests.

---

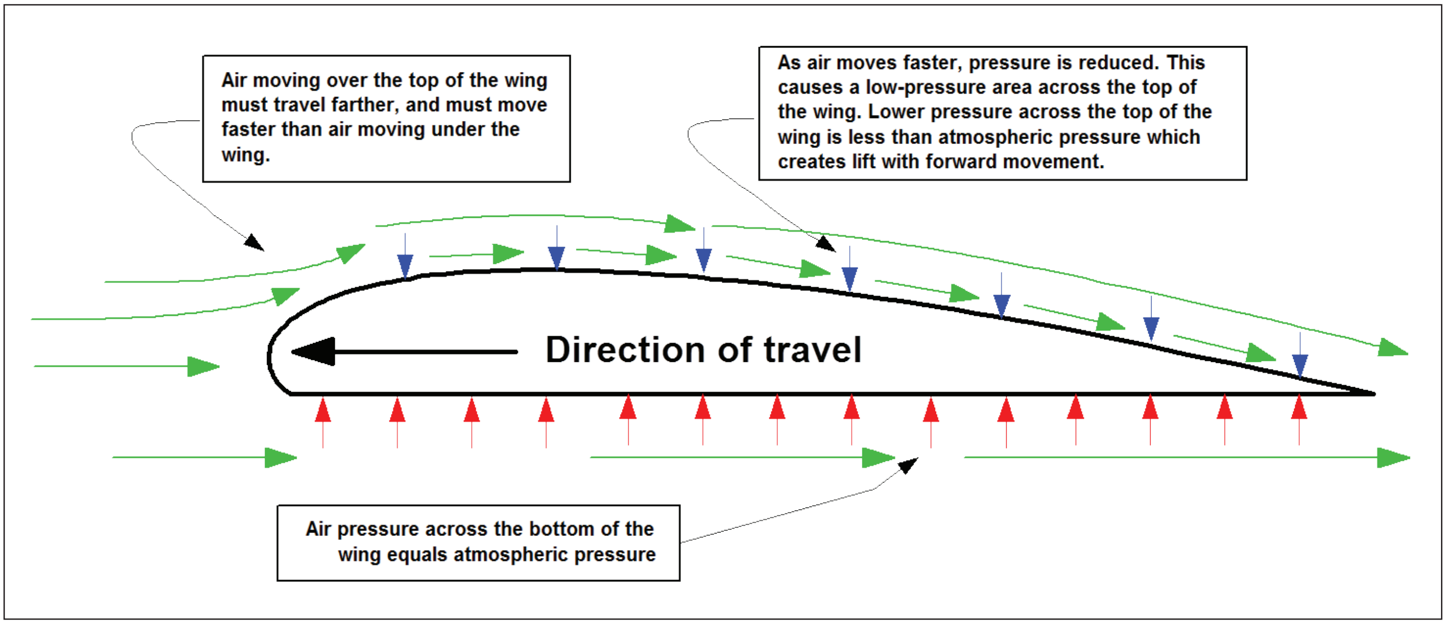
[1] Patrick Riley, the General Manager of Western Seafood in Freeport, Texas, and a second-generation shrimp fisherman, began searching for ways that could sharply reduce production costs across the Western fleet. With sky high energy prices, finding ways to reduce fuel use while taking advantage of current, record catch rates became a priority for Mr. Riley. In fact, Patrick's search for ways to reduce fuel use was just as important to the economic success of Western Seafood as work undertaken by his father, Captain Mike Riley, years before as he looked for ways to out-perform his competitors.

Proving that Cambered Doors Could Work

Background Information about Cambered Trawl Doors

Rectangular, flat doors spread nets through resistance. A four-chain bridle system establishes both an angle of attack and cut (or backward lean) in the door. While the vessel is under way, the angle of attack serves to pull the doors apart and open the nets, and cut forces the doors to remain on the bottom. By design, the angle of attack creates more drag in the water and along the sea bottom. In a 1984 publication, Louisiana State University researchers noted that 30% of total drag is due to trawl doors [2]. Once this traditional gear is deployed, greater resistance requires additional RPM from the main engine to maintain the necessary speed-over-ground towing rate so the doors can fully open the nets. Rectangular, flat doors have served the industry very well. However, with the escalation in diesel prices that began in 2002 and averaged $2.124 a gallon by 2006, investigators looked for a type of trawl door that would spread shrimp nets through a pathway other than "designed resistance."

Compared to flat doors, cambered doors open nets using a pressure difference created between the outside and inside surfaces of the door. In fact, cambered doors create spread with the same principle that airplane wings use to create lift. As shown in the diagram below, an airplane wing creates lift when forced air rolls over the top of the wing, which is curved. Because the top of the wing is longer than the bottom, air has to move across the top of the wing faster. This faster air movement reduces air pressure on top of the wing, which lifts the plane off the ground.



Cambered doors are towed at a smaller angle of attack than rectangular, flat doors, yet they achieve the same spread in the trawls. The smaller angle of attack creates less resistance. Less resistance requires fewer RPM to reach desired speed-over-ground towing rates. It is this reduction in main engine speed (RPM) that directly translates into reduced fuel consumption.

The Proof of Concept Cruise – Initial Sea-Trials

The proof of concept cruise began with curved, elliptically shaped off-the-shelf trawl doors used primarily in European mid-water fisheries. During the proof of concept cruise aboard the *Isabel Maier*, the team encountered as many difficulties with the cambered doors as pioneering fishermen found in moving from double to quad rigs in the 1970s, but they were still able to report three essential findings: (a) the doors could get to the bottom, (b) they remained upright in the water column, and (c) they spread the nets. This all sounds pretty basic, except for the fact that each door was connected to a towing cable with a single attachment point instead of the four-chain bridle customarily used with traditional trawl doors. The proof of concept cruise demonstrated the possibility for success, but much more work was required before this new design could become a legitimate option to the flat, rectangular doors used for decades.

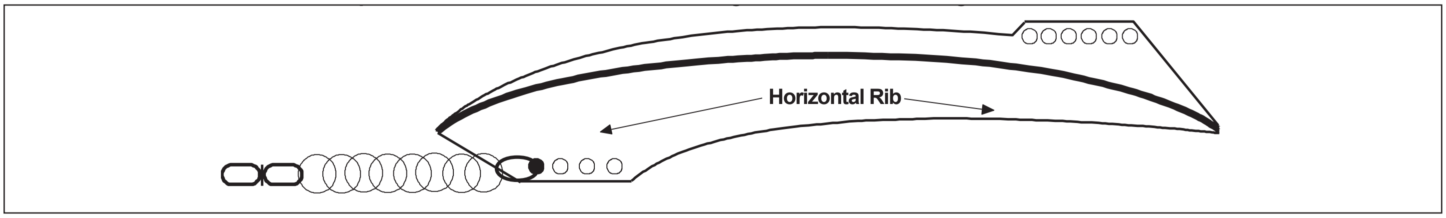
Observations and Subsequent Modifications from the Proof of Concept Cruise

The initial sea trials demonstrated the promise of the new doors. However, the more important results from the proof of concept cruise were the clues provided that would be instrumental in modifying a door originally designed for mid-water, pelagic species so that it could be used on the sea floor.

Door-sizing considerations. During initial trials, the team selected a cambered door that was roughly the same area (2.1 m^2) as the 9′ x 40″ (or 2.79 m^2) rectangular door historically used aboard the *Isabel Maier*. Investigators found that equivalent-sized cambered doors generated much more spreading power than rectangular, flat doors with about the same area. Specifically, the size of cambered doors initially chosen overspread the two 47½ ft. two-seam nets constructed of Spectra® webbing. As shown in the photo (right), when replacing a flat, rectangular door with a cambered model, a 50% reduction in door area is required. In this case, the 9′ x 40″ flat door was replaced with a 1.4 m^2 cambered door.

Re-designing the shoe. Off-the-shelf cambered doors were oval-shaped, with a curved shoe that maintained the oval form (left photo, below). When used for bottom trawling, the curvature of the original shoe held the footrope and tickler chain off the bottom. This resulted in a 19% shrimp loss in side-by-side production comparisons with rectangular, flat doors. This unacceptable shrimp loss ended when the curved shoes were replaced with re-designed flat shoes (right photo, below). Note that the new shoe design maintains the oval shape across the leading edge of the door.

Attaching a door to the towing cable. One of the unique features of off-the-shelf cambered doors was how the towing cable attached to the door. As the diagram (below) shows, in most applications worldwide, a cambered door connects to the towing cable at a single point along the horizontal rib. The rib is located along the inside of the door and follows the outward-most part of the door's curvature fore to aft. The diagram also shows a horizontal set of holes found in the horizontal rib that provides several choices for connecting the door to the towing cable via a length of chain, a few shackles, and a swivel. Each of these attachment points changes the angle of attack. The sea trials demonstrated that this single connection point was **not** an acceptable approach because the back bottom of the door had a tendency to kick out.

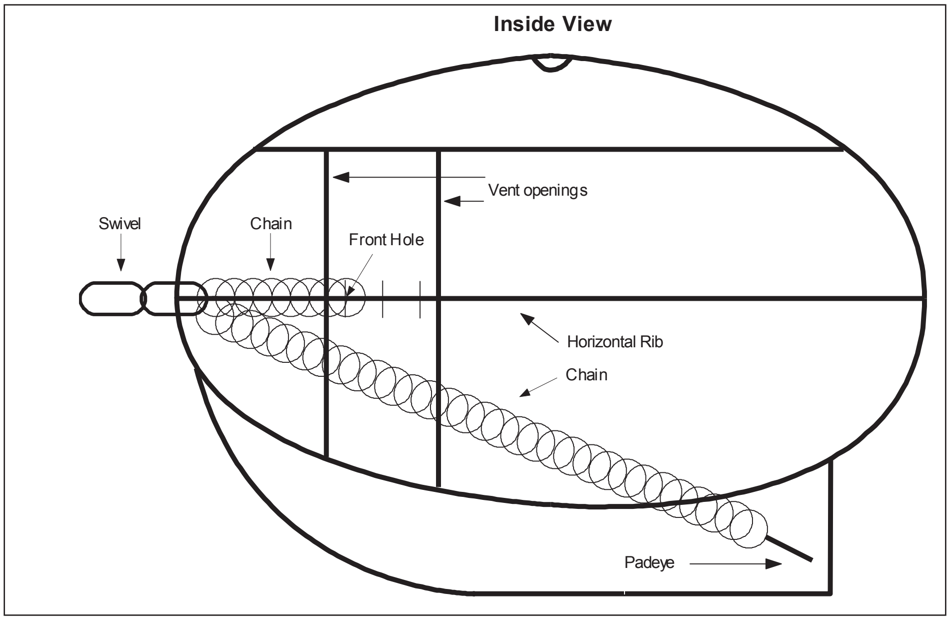


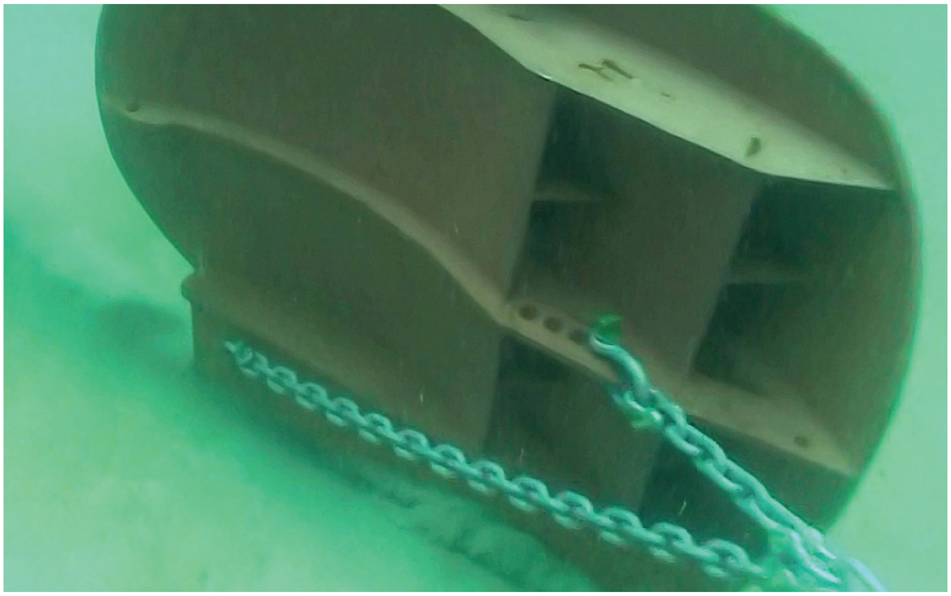
Top view of the cambered door with original attachment configuration.

To solve this problem, investigators engineered another attachment point on the bottom-aft part of the door. This required adding a pad-eye to the back-bottom of the door (shown in both the diagram (right) and the photo on the previous page). This second attachment point stabilized the door, and ultimately a two-chain bridle array became the standard approach for connecting cambered doors to the towing cables.

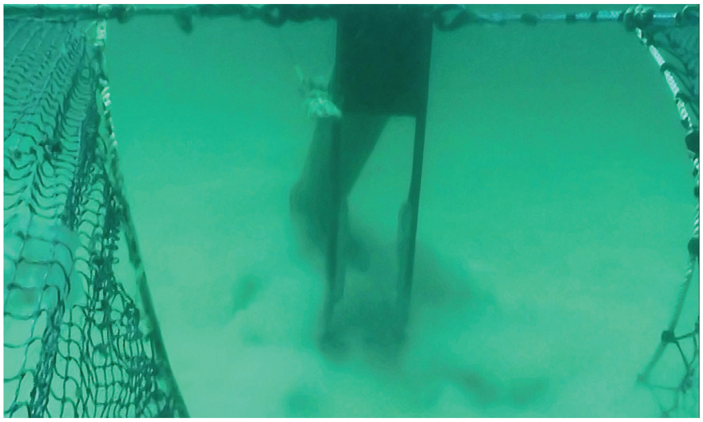
The underwater photo (right) shows the two-chain configuration during trawling operations. While the major towing point is still through the horizontal rib of the door, the photo shows a second chain that attaches to the back bottom of the door and greatly stabilizes it. This is a very unusual connection compared to the four-chain bridle system traditionally used with flat, rectangular doors in the Southeastern U.S. shrimp-trawl fishery.

Note the relatively small angle created between the chain bridle and the front of the door. The cambered doors are purposely rigged to tow at a smaller angle of attack than flat doors. Recall that because of the curvature of these doors, pressure along the outside surface of the door is less than the pressure along the inside surface. This pressure difference pulls each door outward.

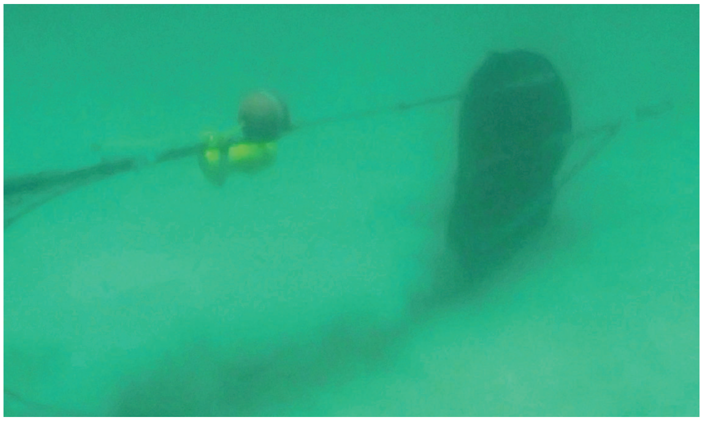




Re-thinking sled design. Finally, the sled used with quad rigs had to be modified. During the proof of concept cruise, investigators found that the sled sank much faster than the vented, cambered doors. This created a major problem during gear deployment. The final modification addressed how to prevent the rapid sinking of a traditional sled. In the left photo (below), a new sled is being fabricated with a floatation chamber. This flotation chamber slowed the descent of the sled to the sea floor. In the right photo (below), the new sled is shown during exploratory performance work off Panama City, Florida. Using a flotation chamber for the diagonal part of the sled solved the problem, but later a more economical sled was designed with a wider shoe fabricated from flat bar. This new design relied on a wide foot and allowed the sled to ski to the bottom in harmony with the doors. This improvement eliminated the need for a floatation chamber, and made the sled less expensive.



Summary of the observations-to-modifications process. The cambered doors, modified as a result of observations made during the proof of concept cruise, fished properly in subsequent performance evaluations off Panama City, Florida, in 2007. Note in the photo to the right that the footrope and tickler chain are in contact with the bottom as a result of the flat shoe (modification 2). As well, the door stands perpendicular to the seabed while trawling. The two-chain bridle adds the stability necessary to prevent kick out, and the door is spreading the nets using a relatively small angle of attack (modification 3).



A Preliminary Comparison of Fuel-Use and Engine Performance Between Flat, Rectangular Doors and Vented, Cambered Doors

Once all four of the design modifications were completed and investigators understood the adjustment logic required with the cambered gear, engine performance and fuel comparisons were documented aboard the *Isabel Maier*. As previously noted, the 1.4 m^2 doors were roughly 50% smaller than the standard 9′ x 40″ (2.79 m^2) wooden ones. The engine speed necessary to maintain the 3 knot (kt.) speed-over-ground towing rate (used with rectangular, flat doors) was reduced by about 125 RPM with the cambered doors. Towing at 3 kt. with 125 fewer RPM saved 5.5 gallons of fuel per hour. This resulted in fuel consumption being reduced by 28% (see table below).

	Wooden	Cambered	Difference
Door Size	2.79 m^2	1.4 m^2	Area reduced by 50%
RPM @ 3 kt.	1,525 – 1,550 RPM	1,400 – 1,425 RPM	RPM reduced by ≈ 125 (8%)
Fuel Use	19.5 – 20.0 GPH	14.0 – 14.5 GPH	Use reduced by 5.5 GPH (28%)

Utilizing the same brand of fuel-flow meter, but the model specified for the engine type and horsepower on his vessel, the *Master Brandon*, Captain Louis Stevenson–the very first adopter of the untested cambered gear–experimented with various engine speeds (RPM) while monitoring fuel consumption. Captain Stephenson found that for every 50 RPM reduction in engine speed, fuel consumption decreased by approximately 1.5 to 2.0 gallons per hour. Although the *Master Brandon* was equipped with a 500 horsepower Cummins® KTA 19, the general reduction of fuel usage at lower RPM was consistent with the *Isabel Maier* which was equipped with a 500 horsepower Caterpillar® 3412.

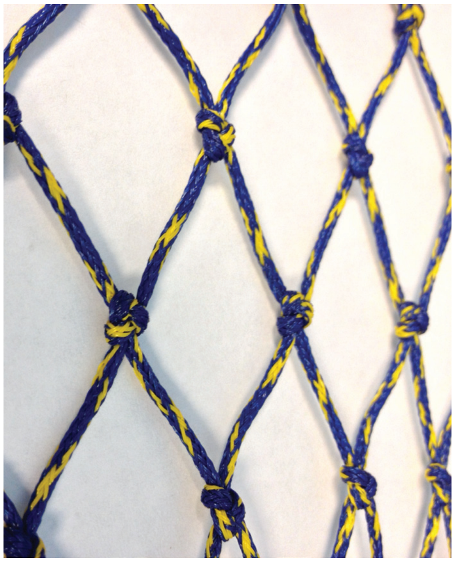
The Final, Exploratory Step – Proving Production Equivalency Between Traditional Doors and Vented, Cambered Doors

Modifications borne out of the proof of concept cruise and the subsequent comparison of fuel use and engine performance both pointed to the cambered doors as a new-found way to reduce fuel use. However, proving production equivalency between traditional and cambered gear was the third, essential requirement necessary to call the earlier, exploratory work a success. A three-week production cruise aboard the *Isabel Maier* simultaneously evaluated production differences between both types of doors. To measure differences in shrimp production, both door types were fished at the same time. After 15 good tows, gear was swapped to opposite sides of the vessel, and catches from 15 more good tows were recorded. The cambered doors actually produced about 2.6% more shrimp during this cruise, but this production increase was not statistically significant.

A Note about Braided Sapphire® Twine, Webbing, and Nets

The cambered trawl doors presented the greatest challenge to investigators and the largest potential benefit to industry. But, the evaluation of Sapphire® twine was also an important part of early, exploratory work. Today, fishermen have several choices among small-diameter, high-tensile-strength webbing. Some of these have a smaller diameter and greater tensile strength than Sapphire®. Braided, not twisted, Sapphire®—a high-density, polyethylene (HDPE) fiber—was chosen because of its high-strength, durability, and comparatively low cost among the other high-strength fibers.

The braided, 2.1 mm material (left photo) has a very high tensile strength. Braided fibers yielded positive fuel-saving and longevity results. This webbing never needs to be dipped (middle photo). In fact, dipping will destroy HDPE. Eliminating the expense of twice-yearly dipping can save the enterprise thousands of dollars. Also, braided Sapphire® nets last much longer than nylon. The first braided Sapphire® webbing used in Texas was put in service in 2005, and those nets were fished for 7 years through 2011 (right photo). As a number 2 plastic, HDPE webbing is also recyclable through customary, municipal channels.



The modification process to doors and sleds was complete. A preliminary comparison of fuel savings and engine performance with wooden doors and cambered steel gear documented that a slower engine speed could tow the cambered gear at the same speed-over-ground necessary to spread nets with flat doors. A three-week production cruise verified that the cambered gear produced quantities of shrimp equal to catches generated by the rectangular, flat doors.

With these milestones recorded, the new doors and nets were ready for assessment by cooperating fishermen across the Gulf and South Atlantic region. Importantly, this cooperative research effort focused on a diverse mix of operating conditions. Specifically, this testing occurred not just on the beach but in deep water, not just on hard bottom but on muddy substrate, and not just when fishing for brown shrimp using quad rigs but also when targeting white shrimp with dual bib nets.

Experimental Procedure

Preparatory work with each cooperating fishermen specified the size of cambered doors required to open their nets, enough braided Sapphire® webbing to duplicate the design and size of nylon nets currently used, two sleds, and an indicating fuel-flow meter designed for the brand (manufacturer), model, and horsepower of the main engine. To standardize the manner in which performance data were collected by cooperators, a research protocol was developed. This protocol had to meet two objectives. First, data collection had to be simple and quick so fishermen could collect the information at the frequency required without disrupting their other work. Second, the approach had to be rigorous enough so performance data from a handful of cooperators could provide realistic estimates of fuel savings. This protocol specified four steps.

Step 1 – Measure fuel consumption and engine performance with traditional gear. The first step established a baseline from which to make comparisons. This involved documenting how much fuel the vessel burned at the operator’s pre-selected knot speed while towing traditional gear. For example, if 3 kt. per hour was established as the standard speed-over-ground towing rate, the captain would record speed-over-ground, fuel burn rate, and engine RPM while fishing with his traditional gear.

Step 2 – Measure the contribution to fuel consumption and engine performance by Sapphire® nets. In Step 2, original nylon nets were replaced with nets of identical size and design constructed of braided Sapphire®. Again, the captain would tow the trawl at the same established speed-over-ground rate and record engine RPM, speed-over-ground, and fuel consumption. This step allowed us to document proportional fuel savings generated from the Sapphire® nets connected to the original trawl doors.

Step 3 – Prove production equivalency between both traditional doors and vented, cambered doors. This was the most difficult and perplexing of the four steps for cooperators, but one that was absolutely essential in migrating from flat trawl doors to the new vented, cambered ones. This step focused strictly on shrimp production, so more preparatory tows and adjustments to the gear were required.[2] Once the captain was convinced that both sides were fishing to maximum efficiency, 15 good tows were made and catch rates were recorded from nets connected to the traditional doors and the vented, cambered doors.[3] After 15 good tows were completed, the doors were swapped to the trawls on the opposite side of the boat. Data were then recorded from 15 more good tows. Swapping the gear eliminated any potential bias from trawls on one side of the boat. This completed step 3. Importantly, this step demonstrated to cooperating fishermen that no shrimp loss was occurring when cambered doors were used.

Step 4 – Measure fuel consumption and engine performance with cambered gear. The final step involved towing braided Sapphire® nets spread with cambered doors on both sides of the boat with the new webbing at the same speed-over-ground used in steps 1 and 2, and logging RPM and fuel use. This allowed us to compare the effect of the new cambered gear on engine RPM and fuel consumption.

---

[2] A short review of preparatory work follows. The captain first towed his standard doors with the Sapphire® netting. Comparative tows were made utilizing the old doors to be certain that both sides were fishing equally and that no additional tuning or adjustment of the original gear was necessary. This preparatory step was exactly the approach used in the three-week production cruise aboard the *Isabel Maier*. Once the original doors were determined to be fishing efficiently, one side was replaced with the cambered doors. At this point the vessel was now simultaneously fishing with both traditional and cambered gear. By making catch comparisons from the two sets of gear, the captain and crew were expected to adjust the cambered doors with the goal of producing quantities of shrimp that equaled harvests with the traditional gear.

[3] A good tow was designated as one that encountered no problem from fouled tickler chains, clogged turtle excluder devices (TEDs), damaged trawls, etc.

Ensuring Experimental Control

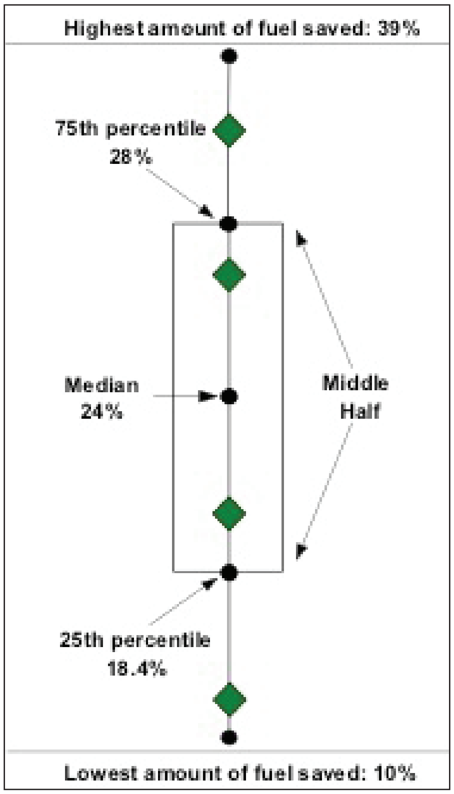
For steps 1, 2, and 4, operators were asked to record speed-over-ground, engine RPM, time of day, sea conditions and fuel consumption every half hour. In steps 1, 2, and 4, eight tows were required, each of which each lasted at least 3½ hours. After completing the required number of tows for step 1, the captain could proceed to step 2. Information was recorded across another 8 tows, each lasting at least 3½ hours.

Perhaps the most important consideration in this cooperative research project was to stress that the captain select a speed-over-ground towing rate and hold it constant when fuel consumption was being monitored (steps 1, 2, and 4). In addition, we worked to help cooperators minimize avoidable variation during the four-step procedure. One source of variation could be seasonal differences in sea conditions. We stressed that cooperators should complete their four-step evaluation procedure within a few weeks, and virtually all did. On the other hand, conducting steps 1 and 2 in July, but waiting until January to complete step 4 (when sea conditions are bad) would have made the performance comparison less meaningful.

Performance Summary – Fuel Savings with Braided Sapphire® Webbing and Vented, Cambered Doors

In addition to working in different backyards, each cooperator had a different combination of horsepower and trawl type/size. Horsepower ranged from 375 to 600. All cooperators pulled four nets of different design. Headropes ranged from 32 to 50 feet. Owing to the expense of outfitting each elite fisherman with a complement of trawl gear and an indicating fuel-flow meter, we were unable to replicate the mix of operational conditions (location, horsepower and trawl type/size) by recruiting additional cooperators.

Results from nine cooperators indicated that the new trawl gear generated immediate, and in most cases, significant fuel savings [3,4]. Overall, braided Sapphire® nets accounted for 20% of total fuel savings. In gallons-per-hour terms, this webbing choice reduced fuel use by between one-half to one-and-a-half gallons per hour. Of course this means that the cambered doors accounted for 80% of total fuel savings. As shown in the figure, the lowest amount of fuel saved was 10% while the maximum saved was 39%. Because we had so few data points, the cooperative research results are illustrated using the range in fuel savings plus different percentile values. The median amount of fuel saved with Sapphire® nets opened with cambered doors was 24%. At the 25th percentile (where 75% of fuel savings were greater), an 18.4% fuel savings was logged. At the 75th percentile (where only 25% of the savings were greater), fuel savings amounted to 28%. Green diamonds reflect cooperators' fuel-saving values that are not represented by the lowest values, the highest values, or any of the listed percentile values. Therefore, beginning at the bottom of the diagram, fuel-saving values represented by green diamonds were 12.2%, then 20%, followed by 27%, and finally 33%.



The cooperative research with elite producers demonstrated that these new trawl arrays work. Fuel consumption was reduced, but shrimp production was equal to harvests from the traditional rig used for decades in the Southeastern U.S. shrimp-trawl fishery. This enables a producer to take advantage of record catch rates, but spend less money to do so. As will be shown in the economic analysis segment, the new trawl gear can significantly reduce production expenses. With all of the testing across the Southeast, we can state that the gear can handle mud and hard bottom, deep water and the nearshore area, and sharp turns. Several fishermen use the doors effectively in the nearshore, white shrimp fishery. However, more extensive use of the cambered doors is taking place in the offshore brown shrimp fishery.

We have not performed investigations when the cambered gear is towed at extremely slow speeds. However, some operators reported difficulty with the doors when their speed-over-ground was 2.2 kt. or less, which is an unusually slow towing speed. To return to the airplane wing example, there has to be enough forward motion to create a fast enough airflow over the top of the wing to lower atmospheric pressure. This difference in atmospheric pressure between the top and bottom of the wing generates lift. An identical forward-motion requirement is necessary to create a pressure differential underwater that enables the doors to pull outward. Ultimately, these unique concerns will be solved by producers committed to reducing their fuel consumption. For example, at a slower speed-over-ground towing rate, perhaps an attachment point farther aft on the horizontal rib could be selected so a greater angle of attack is created which may fully open the nets.

In summary, off-the-shelf cambered doors offered the promise of working in the Southeastern U.S. shrimp-trawl fishery, but hard work and dedication to modify the original design created the genuine production and fuel-saving benefits reported here. Several operators have mentioned other door styles that promise fuel savings as equipment they want to try, but these are unproven in the Gulf and South Atlantic shrimp fishery. While other designs may ultimately generate the same range of fuel savings with equivalent, reliable shrimp production as the doors we have discussed, remember that testing, evaluation, and subsequent modification were the real secrets to success.

Replacement, Adjustment and Maintenance Considerations

Replacement Considerations

An important consideration is matching the proper dimensions of the door with expected net sizes. As a general rule, we have found that cambered doors should roughly be about half the area as the flat doors currently in use. However, the type of webbing used in net construction also influences the size of door required. For example, two 45-foot nets made of nylon netting would require a larger door than two similar-sized nets constructed of SapphireFrutiger or Dyneema® because larger-diameter nylon creates more drag.

When towing four 40- to 45-foot nets, use 1.1 m² doors. When towing four 45- to 50-foot nets, use 1.4 m² doors. Sea trials of doors required to spread four 50- to 55-foot nets are preliminary and suggest that the 1.4 m² doors are marginal at the second towing point from the most forward position on the horizontal rib. Sea trials of doors required to spread two 55- to 60-foot nets have not taken place. Several cooperators utilized quad rigs when fishing for brown shrimp, but switched to double-rigged, bibbed-style trawls when fishing for white shrimp. It was found that a properly matched set of doors could be used with both gear arrays.

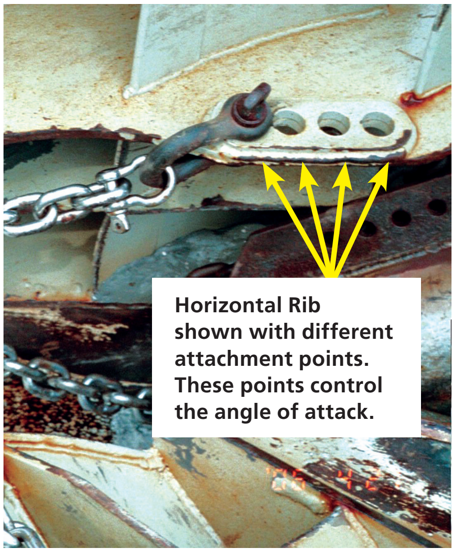
A smaller angle of attack reduces resistance and, in turn, improves fuel savings. Therefore, choose the door size that allows nets to spread fully when the doors are pulled from the most forward attachment point on the horizontal rib. This will ensure the smallest angle of attack. One trade-off may be choosing the next-larger sized door. With the greater spreading force of a larger door, a smaller angle of attack could be selected on the horizontal rib. This smaller angle of attack on a larger door would save more fuel than a smaller door that had to be attached at a greater angle of attack (that is in a towing point further aft on the horizontal rib). Differences in acquisition costs between the 1.1 m² and 1.4 m² doors are about $50 per door, or $200 per set. Likewise, the cost difference between the 1.4 m² and 1.6 m² doors are about $50 per door. When in doubt, choose the next larger door size so the required angle of attack can be minimized while still fully opening the nets.

Adjustment Considerations

The doors are not difficult to use, but the adjustment logic is different from traditional trawl doors.

Setting the angle of attack. One of the unique features of the cambered doors was the attachment of the towing cable to the door. As shown in the photo, a cambered door is equipped with a horizontal rib, a feature located along the inside of the door that follows the outward-most part of the door's curvature fore to aft. A horizontal set of holes found in the rib are used to connect the door to the towing cable. This is a very unusual connection compared to the 4-chain bridle system that has been traditionally used with flat doors in the Southeastern U.S. shrimp-trawl fishery. The hole in the forward-most position on the horizontal rib creates the smallest angle of attack. As the towing cable is attached in each towing point aft of the leading hole, the angle of attack successively increases by 5 degrees.

Headrope/footrope adjustment. Just like the multiple towing points in the horizontal rib, there are several holes for connecting the trawl at the back of the doors (right photo). Note that moving the headrope and footrope to an adjacent hole alters the angle of attack of the door by about 2½ degrees. However, this adjustment is just the opposite of the towing points on the horizontal rib. In other words, connecting the net in the forward-most attachment point increases the angle of attack, while attaching the net further aft on the door decreases the angle of attack.

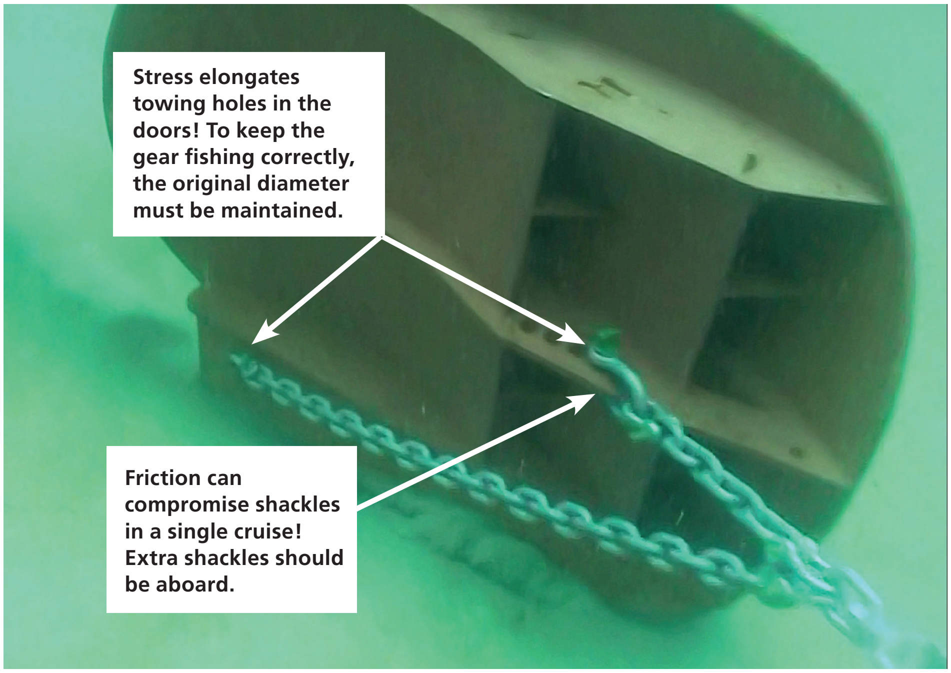


Setting the angle of attack

Headrope/footrope adjustment

Periodic Maintenance Is Essential

To ensure stability while trawling as well as production effectiveness, the towing holes on the horizontal rib require periodic maintenance, and pad-eyes on the bottom-aft position of each shoe require periodic replacement. If steps are not taken to inspect and correct for indicated wear, shrimp loss can occur. The photo (right) highlights areas that need periodic inspection and corrective action when wear is detected. In particular, the factory-specified diameters of towing points in the horizontal rib need to be restored (built up) at least once a year. In addition, friction and stress can compromise shackles used to attach the chain bridle to the horizontal rib, the pad-eyes, and the swivel that hooks to the towing cable. This hardware needs frequent inspection for wear, and it goes without saying that extra fittings should be carried on board.



Stress elongates towing holes in the doors! To keep the gear fishing correctly, the original diameter must be maintained.

Friction can compromise shackles in a single cruise! Extra shackles should be aboard.

A Note about Dockside Fabrication of Cambered Doors

A number of fishermen interested in the cambered doors have fabricated them to reduce cost. The design of these doors is quite complex, with many curves and angles incorporated in them. One fisherman who participated in the cooperative research project was so impressed with the fuel savings generated with the cambered doors that he decided to build a set for another vessel in his fleet. Upon completion, he noted that even with access to all the stationary rolling equipment and other metal-working gear, building four identical doors took him more than 40 hours (photo right). Opting to build cambered doors instead of buying them can be a risky, costly decision, since small mistakes in layout and/or fabrication can lead to disastrous performance consequences. Therefore, potential builders should realize that production losses encountered from improper layout and/or fabrication will erase any cost savings from building.

Experiences in the Brownsville shrimp fleet have provided notable examples of both good and bad layout and fabrication methods. Utilizing the pioneering spirit embodied in the shrimp industry, a number of shrimp-fleet owners decided to copy patented doors and build them for their own use. A couple of these businesses were successful with their built doors. In other cases, doors not identically copied failed miserably. This not only cost the company time and resources, but also negatively affected door behavior and, consequently, shrimp production. In some cases, improperly copied doors actually served to falsely indict the concept of utilizing cambered doors since fishermen did not realize that improperly functioning doors were a result of layout and/or fabrication errors. Some of the fabrication mistakes were so dramatic that one familiar with the gear could recognize differences simply by looking at them. On the other hand, the owner of a large fleet that has sharply reduced fuel consumption while catches have remained identical felt his good fortune was the result of buying the doors from the supplier. This fleet manager was quick to cite the failures that some of his colleagues had experienced by attempting to save money by constructing these curved, vented doors.

Do Vented, Steel, Cambered Doors and Nets Made from Braided, Sapphire® Fiber Represent a Better Economic Choice for the Shrimp-trawling Enterprise?

Background

Between 1994 and 2001 annual diesel prices averaged $0.74 per gallon. Over the next 11 years (2002 to 2012) the average price tripled to $2.22 per gallon. This rapid escalation in diesel prices hit shrimp fishermen extremely hard. By 2006, the cost of 66,101 gallons–the average quantity used each year by SPA cooperators–amounted to $140,399 and was, by far, the largest input expense.[4] Therefore, it should come as no surprise that roughly 40% of the 2,666 federally permitted offshore trawlers remained idle that year because of record-high fuel prices coupled with historically-low shrimp prices.

Texas Sea Grant-sponsored research with Gulf and South Atlantic shrimp fishermen documented reduced fuel consumption that ranged from 10% to 39% when using fuel-saving gear (comprised of vented, cambered, steel doors and nets fabricated from braided, Sapphire® fiber). Reduced fuel use is one thing, but cooperators also verified that catches remained identical to those produced with traditional trawl gear (comprised of wooden trawl doors and nylon nets) when both gear types were simultaneously fished. Early adopters of the fuel-saving gear also noted that doors and nets had a much longer useful life than traditional equipment. The old adage "you get what you pay for" is certainly appropriate here because the attributes of reduced fuel consumption, coupled with identical catch rates, and a much longer useful life came with a price. Specifically, the complement of fuel-saving trawl gear necessary to replicate an operator's existing trawl system in 2010 sold for $13,570 versus $8,965 for a traditional trawl system. The $4,605 difference represents a 51% increase. After years of operating in survival mode, the initial thought of spending more for necessary fishing gear may not seem like a wise decision to those fishermen who have weathered the economic storm that began in 2001. Of course, paying more for a consumable input like fuel when the same quality is available at a lower price elsewhere will always result in less income from a cruise, other things being equal. However, when faced with two choices for a durable input like trawl gear, a higher price may not have the same effect on income over time if the higher-priced option is more efficient and/or has a longer useful life. Thus, the question in choosing between traditional trawl gear and fuel-saving equipment is whether the additional cost for more efficient equipment is more than offset by savings from reduced fuel expense and greater longevity.

Three steps are necessary to make this decision. Step one estimates future annual cash costs attributable to both traditional rigs and fuel-saving gear for every year the trawl system is expected to last. This step is the most time consuming because many different considerations must be folded into each annual cost estimate for every year in the planning horizon. For example, what will happen to prices for fuel and other production inputs moving forward? What information exists to suggest whether input prices will remain the same, increase or decrease, as well as forecast those annual up or down price changes? To summarize, step one creates two sets of anticipated cash costs across every year in the planning horizon that are relevant to each gear choice. These annual cash costs occur over several years so an additional set of computations is required. These additional calculations are necessary because cash costs (cash outflows) or cash inflows that occur in different years cannot be directly compared until their values are standardized at the same point in time[5]. Therefore, the second step requires that all future, estimated cash costs be appropriately converted to their values today; in other words, to their present values. Converting an estimated, future value back to its present value requires additional information which will be discussed later in this section. Step three compares the present values of cash costs generated by each gear type across the expected useful life of the two investment alternatives. This three-step process will determine which trawl-gear choice will result in reducing cash production costs in a hypothetical shrimp-trawling enterprise. These three steps define net present value (NPV), a decision-support tool rooted in economic concepts that is widely used to evaluate capital expenditures, like trawl gear, which last longer than a single, 12-month operating cycle.

The following section introduces the idea of NPV and addresses how results from the analysis should be interpreted. The purpose of this section is simple. Owners and managers need a decision-support framework that objectively evaluates investment choices for durable inputs that will economically affect the shrimp-trawling enterprise over several years. Making the correct decision is critical today because of the crushing cost-price squeeze that gripped shrimp fishermen between 2001 and 2010. The reason: for many operations that survived, the sum of retained earnings plus current income may be insufficient to cushion the operation from the effects of an improperly determined investment choice that cannot be immediately undone. It is our hope that readers will use this case study example of trawl gear choice for two purposes. The primary purpose addresses whether higher-priced gear with a longer useful life and greater efficiency can reduce production costs and thus increase income going forward. The secondary purpose is to examine how this NPV analysis was conducted to generate theoretically correct results. After all, there will always be capital expenditures that are promoted as helping you do things better, faster, or cheaper. Every one of those expenditures requires a monetary commitment. The best, most objective way to determine whether you should commit your money to such capital expenditures is with an NPV analysis. Just like a set of blueprints, the NPV process allows you to estimate what you think will happen down the road before committing to that specific course of action.

Ultimately, NPV results will either refute or defend the idea that investing in fuel-saving trawl gear today can reduce total production expenses going forward. Of course, other circumstances in your operation may play a larger role in dictating the choice of trawl gear than NPV results.

---

[4] In contrast, among Texas shrimp trawler owners who participated in the SPA research project, the average, annual cost for diesel over the 1986 to 1997 study period was the third-largest input cost behind crew shares and repairs and maintenance.

Understanding Net Present Value and Interpreting the Results

What is net present value? NPV analysis uses projected cash outflows and inflows to estimate the economic performance (not the accounting profit) of a given capital expenditure over its expected useful life.[5] Economic performance is measured by subtracting the present value of all future cash outflows from the present value of all future cash inflows. NPV is measured in dollars, and the value can be positive, zero, or negative.

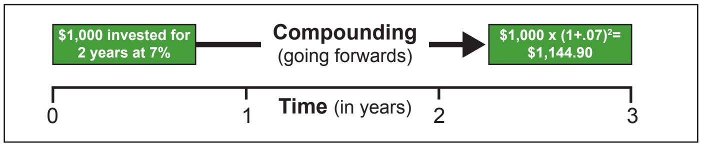
Comparing performance of various capital expenditures is the heart of NPV analysis. For example, NPV is frequently used to rank a variety of potential investments under consideration. NPV is also used to help managers decide between mutually exclusive projects (that is, when only one alternative can be selected). Choice of trawl gear is an example of two mutually exclusive projects where the expected performance of each gear type is being estimated and compared because only one gear type can be selected.

Three primary features of NPV make it a superior, comprehensive screening tool. First, NPV considers the entire useful life of a capital expenditure, not just a small segment.[6] The second key feature of NPV is its adherence to a principle called the time value of money. The time value of money states that a dollar in hand today is worth more than a dollar promised in the future. The higher value placed on money we have today results from our being able to use it immediately or invest it and earn a return. On the other hand, money promised in the future is worth less today because we have no current use of it, either for consumption or investing and it is, in fact, just a promise. Screening tools that do not consider the time value of money cannot correctly value future cash flows, and have generally been rejected by those responsible for assessing and comparing the economic performance of capital expenditures. The third attribute that pushes NPV over the top as a screening tool is using a market-determined cost of capital to convert future cash flows to their present values. These three features support the primary purpose of NPV analysis which is to identify those capital expenditures that add value to the enterprise by highlighting alternatives that exceed the firm's market-determined cost of capital.

Considerations like the time value of money and a market-determined cost of capital may sound like new ideas. Actually, both concepts are rooted in how most of us already think about the money we invest and which benchmarks we should use to evaluate expected investment results. These two issues directly affect how the NPV of a capital expenditure is calculated, but both are equally important because of what they tell us about the performance of a proposed capital expenditure.

How is the time value of money calculated? Because a capital expenditure extends beyond a single 12-month operating cycle, all cash flow projections over the useful life of a proposed investment must be converted to their present values so "apples to apples" comparisons of cash flows can be made. Only when future net cash flows are standardized to the same point in time can the economic performance be correctly estimated and compared against other proposed capital expenditures.

Time value of money calculations are made in two directions. Moving forward through time, the expectation is to earn interest on capital as time passes. When we move forward, we begin with a present value (PV) and calculate a future value (FV). The formula for figuring FV is: FV = PV x ((1 + i)^{n}) where "i" represents the interest rate offered, and the exponent "n" represents the number of periods (generally years) the PV will be allowed to grow.[7] As the diagram illustrates, investing $1,000 in an account that pays 7% interest for 2 years compounds to a future value of $1,144.90 by the end of the second year. Added value results from the combination of the interest paid on the beginning amount and the number of periods interest is paid.



On the other hand, what is a future value worth today? If offered $1,000 in 2 years, what is the most you would pay for that offer today? In other words, what would be the PV of that $1,000 promised in 2 years? Here, we begin with a FV and move backward to compute PV. All of the elements used to compute a PV are the same as when we go forward in time (that is, the interest rate "i" and number of periods "n"), but now we multiply the FV by the expression (1 ÷ (1 + i)^{n}). The formula becomes PV = FV x (1 ÷ (1 + i)^{n}).[8] As the diagram shows, the most you should pay for the promise of $1,000 in 2 years–assuming your capital could earn 7% somewhere else–would be $873.44. Moving backward through time to reach a PV is called discounting, and the percentage value used to convert an FV to its PV (7% in this example) is called the discount rate.

---

[5] Accounting profits are sensitive to changes in accounting methods. Thus, net income can be changed by valuing inventory differently, or by changes in depreciation methods. Rao [5] notes that "bad investments should not become good through management-induced changes in accounting policy." To ensure an accurate assessment of proposed investments, NPV estimates and compares cash flows which are not affected by accounting techniques.

[6] The pay-back method is an example of a screening tool that considers only a portion of expected useful life. Pay-back calculates the number of units (time periods, gallons of fuel consumed, etc.) necessary to pay back the investment. This method is simple and quick, but is limited to evaluating just a portion of the cost-saving benefits of gear that lasts several years. Unfortunately, the analysis stops once the pay-back is calculated. Pay-back analysis is primarily concerned with quick repayment, and cannot estimate the economic performance that results from an investment in new technology. This approach makes it impossible to determine whether the investment will be economically beneficial.

[7] When computing a future value, multiplying the PV by the expression (1 + i)^{n} creates a larger value, and is called the Future Value Factor for a lump sum that grows at interest rate *i* for *n* years or $FVF_{i,n}$.

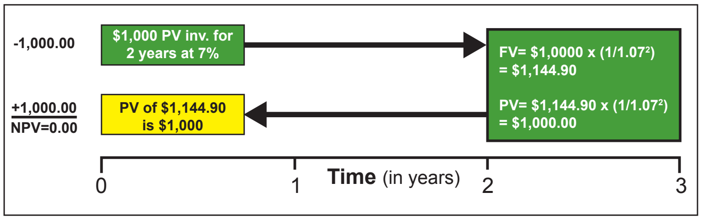
[8] When computing a present value, multiplying the FV by the expression (1 ÷ (1 + i)^{n}) creates a smaller value, and is called the Present Value Factor for a lump sum discounted at interest rate *i* for *n* years or $PVF_{i,n}$. In NPV analysis, the value of *n* in the first year of the planning horizon is zero, not one. Raising any value to the exponent value of zero equals one. This is why the PV of cash flows in year 0 always equal the value of current cash flows in year 0 since (1 ÷ (1 +.03)^{0}) simplifies to (1 ÷ 1) which equals 1. Thus in year 0, multiplying a FV by a PVF of 1 equals both the FV and the PV.

What is the market-determined cost of an enterprise's capital and why is it important? Choosing between alternatives always involves sacrifice. A lost benefit–like giving up the ability to earn a return from your firm's capital–is a sacrifice that occurs when you choose to use those funds for a capital expenditure such as more-expensive, fuel-saving trawl gear. This sacrifice is called an opportunity cost, and is the true economic cost of choice.

The choice of a discount rate should reflect what an enterprise's capital could earn. Therefore, your discount rate is a market-determined opportunity cost of capital (that is, what the enterprise would give up by making any proposed investment) [5]. If your firm's capital is currently earning 7%, the best rate available, then your firm's market-determined opportunity cost of capital is 7% because that rate is the most valuable alternative you would give up to pursue a capital expenditure in new trawl gear. This is why the discount rate is often called the required rate of return that the proposed investment needs to beat if the economic well-being of the firm is to be improved with the proposed investment.

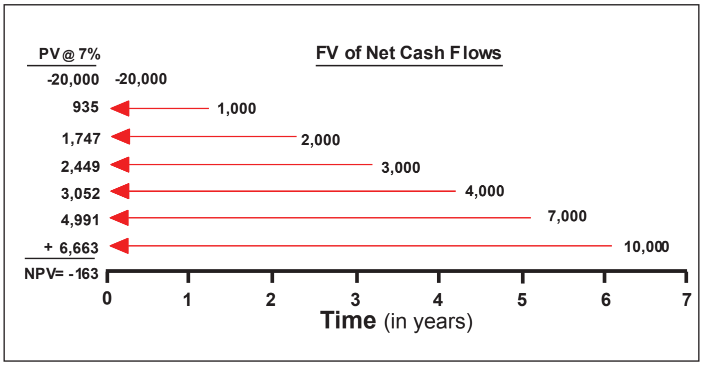
Earlier it was mentioned that ranking and comparing the performance of prospective capital expenditures is the essence of the NPV process. Comparisons require at least two alternatives. The mutually exclusive choice between types of trawl gear we have been discussing is a classic example. When your market-determined opportunity cost of capital is used as the discount rate to convert future cash flows to their present values, the computed NPV of the proposed project is automatically compared against what your firm's capital could earn.

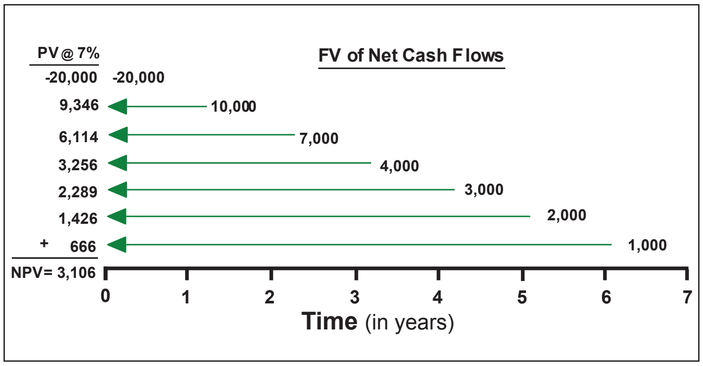
Here is how this comparison works. First, let's compute the NPV of what your capital could earn. When all future cash flows of your invested capital are discounted to their present values using your opportunity cost of capital, a dollar value results. As illustrated by the diagram, considering the NPV from such an investment begins with a $1,000 cash outflow in year 0. That $1,000 grows to a FV of $1,144.90 by the end of year 2, but NPV requires that we discount that FV to its PV. The PV of the $1,144.90 is $1,000. Subtracting the PV of cash outflows from the PV of cash inflows returns the computed NPV of what your firm's capital could earn (that is, your next-best alternative). The NPV of your next-best alternative is always zero. This does not mean that nothing was earned from your 2-year investment at 7%. In fact, your wealth (that is, your accounting profit) increased by $144.90 when compounded at 7%. However, when considered as an investment project, you did give up the use of $1,000 in year 0 to let the bank use your money, so the year zero amount becomes an outflow.



How are NPV results interpreted? When using your market-determined opportunity cost of capital as the discount rate, if the NPV of the proposed capital expenditure is greater than zero, then the PV of net cash returns from the proposed project will exceed what your capital could earn. If the computed net present value of the proposed investment is zero, then the proposed investment will just equal what your next-best alternative could earn. Finally, if the computed net present value is less than zero, then the present value of cash returns from the proposed investment will be lower than what your next-best alternative could have earned.

Summarizing the NPV process with examples. When considering two possible investments, both the size of net cash flows and when they occur have a large impact on the computed NPV of each alternative. The left diagram (below) shows a $20,000 commitment in year 0 to purchase a machine and a series of positive net cash flows over the next 7 years. In this choice, future net cash flows get larger through time. When all future values are converted to their present values using a market-determined opportunity cost of capital of 7%, and then added together, the NPV from this investment is negative, so choosing this alternative will reduce the future economic well-being of the enterprise. Expressed differently, not investing in this project will make the firm better off. Consider another investment choice (right diagram, below). Machine cost is the same and the sum of future values of the net cash flows are identical, but these amounts occur at different time periods than in the previous example. When these future net cash flows are discounted to their present values at the same 7% rate and added together, the NPV is greater than zero. In this instance, the timing of net cash flows creates a better outcome since, at the end of seven years, the enterprise would be rewarded beyond its 7% market-determined opportunity cost. Choosing this investment would improve this firm's economic well-being. The reason: in accounting for the true cost of the investment over the 7-year planning horizon, the computed net present value (that is, the present value of expected cash inflows minus the present value of required cash outflows) will equal $3,106.





The two 7-year hypothetical investments shown above illustrate why the time value of money and the market-determined opportunity cost of capital are essential contributors to the power behind NPV analysis. If only future values were considered, the difference between the $20,000 initial outlay and the sum of all future net cash flows (which were identical at $27,000) would be $7,000 for both investment choices. However, when cash flows in each year are discounted to their present values, the second option emerges as the clear winner. What these two hypothetical investments illustrate is that the farther out in time a net cash flow is expected, the lower its present value. What the NPV approach offers is an "apples to apples" comparison between projects since all future cash flows are converted to their present values through the discounting process. Likewise, when the market-determined cost of capital is used to discount future cash flows to their present values, the NPV of each proposed investment is being compared against the firm's next-best alternative. In the first instance (the left diagram, above) the NPV is below what the firm could generate without undertaking the project. (Recall that the NPV of what your capital could earn is always zero.) The second instance returns an NPV that exceeds the return available from investing your capital at 7%, so accepting that investment alternative would add additional value to the firm.

Both diagrams (above) that illustrated the NPV of two investments when the cash flows were the same but occurred in different years presented a traditional investment where, after the initial outlay in year zero, future net cash flows were positive. However, in the case before us, the choice of trawl gear is considered a *revenue-neutral, cost-reducing* investment. Remember that cooperating fishermen demonstrated equal shrimp catches when both the traditional and fuel-saving trawl gear types were simultaneously fished. Since production and thus revenues remain equal regardless of equipment chosen, only cash production costs attributable to the two types of trawl gear are considered in this NPV analysis. A unique aspect of a revenue-neutral, cost-reducing investment is that all the estimated values will be negative since they strictly reflect cash production costs. Under such circumstances, the NPV acceptance criterion changes so that the smallest, negative NPV (in other words, the value closer to zero) reflects the better investment.

Assumptions, Information Needs, and Sources of Information Used to Compare the Net Present Values of Each Trawl Gear Choice

Before any estimate of expected cash production costs can be made, several assumptions about future conditions and expected performance of both gear types are required. Four elements frame the operating climate we believe shrimp fishermen will face in the future. These include (a) establishing the number of years considered for the NPV analysis, (b) estimating future annual prices for diesel, (c) estimating future prices for other inputs required by fishermen, and (d) selecting both a baseline quantity of fuel used each year plus a fuel-reduction value expected from the fuel-saving gear. The first element is a calculation specified by the NPV process that requires an opinion. The other three elements are assumptions about the future operating climate.

NPV is a straightforward process that produces an answer. Most importantly, the assumptions made about the operating climate, expected useful lives of equipment, plus acquisition and annual maintenance costs determine the accuracy of the analysis. In other words, an NPV result is only as good as the opinions, assumptions, and forecasts made about future operating circumstances. Therefore, it is reasonable to examine these opinions, assumptions and forecasts because everyone's belief about what the future holds differs. The remainder of this paragraph highlights the information we used in the NPV analysis. To estimate the expected useful lives of traditional and fuel-saving trawl gear and year 2010 prices for doors and nets as well as services such as overhauls and net dipping, we relied on the expert opinions of elite fishermen, fleet managers, and owners of marine supply firms. Out of necessity, the expected useful-life estimates for the cambered, steel doors and braided Sapphire® nets came from early adopters of this gear. These opinions were perhaps beyond the expected useful life other operators may realize. Therefore, in the interest of conservatism, we shaved some time off their estimates of expected useful life.[9] To estimate future prices for diesel fuel, we relied on the 2010 forecast published by the U.S. Department of Energy (DOE) [6]. To estimate annual, expected fuel use for the offshore shrimp trawler, we used information collected under the SPA program between 1986 and 1997 [1]. Fuel-savings data were generated through the four-step protocol used by fishermen who participated in the cooperative research project [pp. 8-9 above and references 3,4].

---

[9] Western Seafood and other early adopters have used the vented, steel, cambered doors since 2006, suggesting a useful life of 8 years. One elite operator noted that with proper annual maintenance and replacement of the shoes (as needed) the steel doors could last much longer. We established an expected useful life of 7 years for the steel doors with replacement occurring at the beginning of every eighth year.

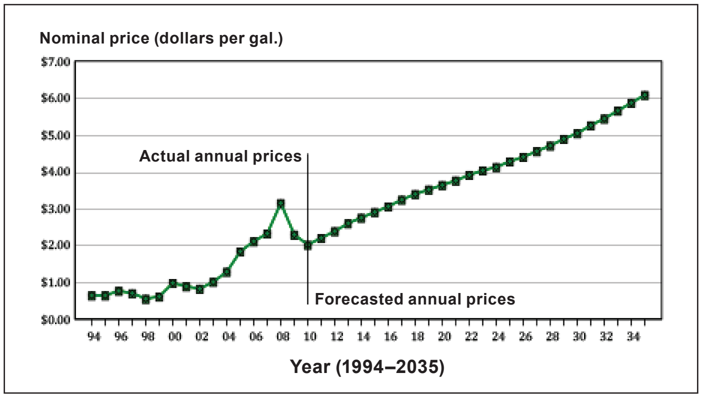
Using expected useful lives of wooden and steel doors to establish a time frame for NPV analysis. The primary step in any NPV analysis is to determine the number of years to be considered. In this instance, we are undertaking an evaluation that compares the net present values of two trawl gear choices. This comparison will indicate which gear choice most improves the economic wellbeing of the enterprise. Therefore, this is a competition between expected results generated by traditional equipment and fuel-saving gear since only one gear type can be chosen. When only one investment choice can be selected from a field of contenders, and if periodic re-investment in the equipment is necessary to continue the activity (shrimp trawling in this case), these conditions mandate that expected performance of each alternative be evaluated across the same number of years to generate theoretically-correct results [7]. Therefore, rather than picking an arbitrary number of years for the analysis, the NPV process includes a procedure that standardizes the useful economic lives that exist among competing, recurring investment alternatives. This procedure is called the replacement chain method, and computes the number of years necessary in the analysis so that each gear type ends its useful life in the same time period. Accounting for such differences in useful economic lives may require a longer time frame than the expected useful life of the longest-lived alternative. Therefore, the replacement chain method not only mandates the initial investment but may require repetitive re-investment(s) too.

In the offshore fishery, wooden doors are replaced about every 2 years while steel doors last 7 years. To find the **fewest** number of years so that each door type ends its useful life in the same period, multiply the two expected, useful lives together. Therefore, a 14-year interval will be used that begins January 1, 2010, and ends December 31, 2023. We assume that both sets of doors are initially purchased in January 2010 and replaced in the January that follows after their useful life ends. The table shows those years when each door type must be replaced after its initial purchase. Across the 14-year span, wooden doors will be replaced six times beyond the initial investment, while the cambered doors will be replaced only once. Both door types end their useful lives in December 2023.

Standardizing Useful Lives with the Replacement Chain

Year	Wooden	Steel
2010	Each set of doors initially purchased in January 2010	
2011		
2012	Jan. replacement	
2013		
2014	Jan. replacement	
2015		
2016	Jan. replacement	
2017		Jan. replacement
2018	Jan. replacement	
2019		
2020	Jan. replacement	
2021		
2022	Jan. replacement	
2023		
2024	Each set of doors is replaced in January	

Estimating future diesel prices. The chart shows actual yearly industrial diesel prices between 1994 and 2009, and forecasted annual prices from 2010 through 2035. From 2010 to 2035, the DOE forecast suggests diesel prices will increase by about $0.15 per gallon each year [6]. That means that every 7 years, the forecasted annual price increases by $1.05 per gallon. Importantly though, this forecast only reflects trend. Supply interruptions, additional regulations further limiting sulfur, and other factors can dramatically influence actual prices. For example, the forecasted value for 2012 suggested $2.405 per gallon while the actual diesel price that year was $3.49; a $1.09 per gallon increase or 45% above the DOE estimate.

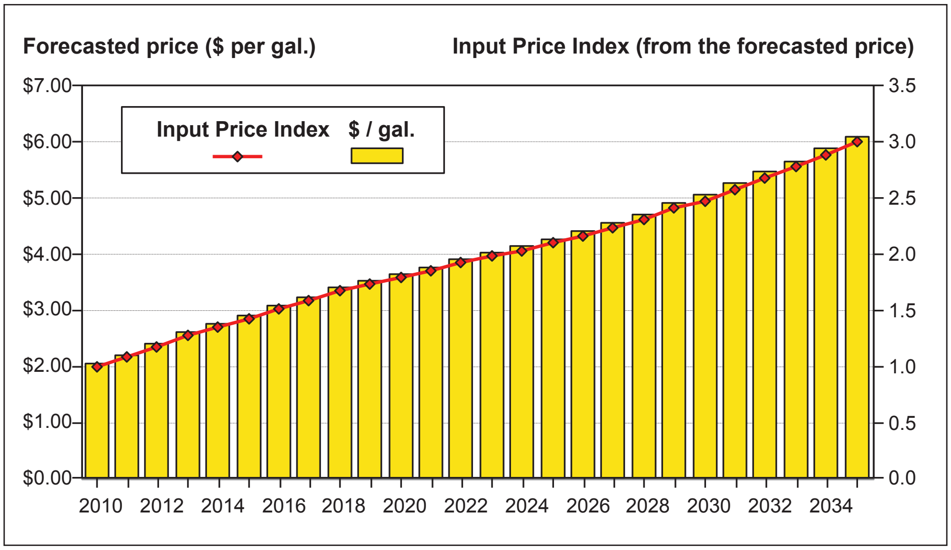


The published DOE forecast is certainly defensible, and reflects a conservative approach with respect to increases in fuel prices. Between 2010 and 2023, the average, forecasted price was $3.11 per gallon. Of course, increasing prices for diesel would favor any asset with fuel-saving capability, but remember that searching for gear that could mute the impact of record diesel prices was the main reason the evaluation and modification of cambered doors took place.

Estimating future prices for other inputs. Inflation is a concern, particularly with petroleum-based materials used to manufacture webbing, net dip, etc. The U.S. Bureau of Labor Statistics tracks prices received by producers for their outputs via a suite of various indices collectively called the Producer Price Index. However, there are few annual forecasts of expected, future prices for inputs shrimp fishermen require that span 14 years. As previously noted, unit prices for overhaul services and acquisition and annual maintenance of trawl gear were obtained in 2010 from industry interviews. Since these inputs are required over a 14-year time frame, some method was required to inflate these 2010 prices.

To estimate future unit prices for inputs besides fuel, an input price index was created from the 26-year DOE diesel forecast. As the chart (above right) shows, the yellow bars represent annual, forecasted diesel prices. The red line, the input price index, was derived by dividing each year's forecasted diesel price by the 2010 price. The right-hand, vertical axis titled "Input Price Index" shows increments from zero to 3.5.

As the figure (above) and table (right) show, because forecasted diesel prices range from $2.038 (in 2010) to $6.11 (in 2035), the computed input price index begins at 1.0 and increases to 2.998. This index allows a 2010 price for an input such as door maintenance, an overhaul, net dip, re-investment in doors and nets, etc., to be inflated over time. The estimated future unit price is found by multiplying the 2010 price by the index number for the year that cost was incurred. Reading from the table, to inflate a 2010 price to the expected amount in 2017, find where the year and index intersect and use that index value. For example, if the 2010 price for net dipping is $2,000 then the estimated price in 2017 would be $2,000 x 1.591 or $3,182.



Year	$ / gal.	Index	Year	$ / gal.	Index
2010	2.038	1.000	2023	4.035	1.980
2011	2.203	1.081	2024	4.139	2.031
2012	2.405	1.180	2025	4.280	2.100
2013	2.602	1.277	2026	4.415	2.166
2014	2.755	1.352	2027	4.559	2.237
2015	2.907	1.426	2028	4.724	2.318
2016	3.084	1.513	2029	4.910	2.409
2017	**3.242**	**1.591**	2030	5.056	2.481
2018	3.406	1.671	2031	5.262	2.582
2019	3.536	1.735	2032	5.468	2.683
2020	3.662	1.797	2033	5.663	2.779
2021	3.775	1.852	2034	5.878	2.884
2022	3.916	1.921	2035	6.110	2.998

Comparing annual, expected fuel use with a traditional rig and fuel-saving gear. For this analysis, the baseline quantity of fuel used each year with traditional gear was assumed to be 66,101 gallons, the median 12-year value computed from SPA data [1]. Another key variable in this comparative analysis was fuel savings, but what level of fuel-saving should be used? Cooperative research demonstrated fuel savings that ranged 10% to 39%. However, with a cadre of just nine fishermen participating in the cooperative research project (due to funding constraints), we are hard-pressed to use an average value because of differences in (a) door size, (b) net size and type, (c) horsepower, and (d) fishing location. Instead, we opted for conservatism, and used a 10% reduction in fuel use for this NPV analysis. This was the least amount of fuel saved in the cooperative research work [3,4]. Using 10% less than the 66,101 gallon baseline quantity each year reduces expected annual consumption to 59,491 gallons.

Step One – Estimating Expected Cash Costs Attributable to Traditional Equipment and Cambered Doors/Sapphire® Nets

The next three sub-sections demonstrate the procedure used to determine whether investing in fuel-saving trawl gear today makes economic sense across the 2010 to 2023 timespan. While the main objective is to show how such a decision is made, we also want to demonstrate how the NPV approach can be used when contemplating a commitment of money for something that lasts several years. This first step is essentially organizing your experience and common sense with Microsoft Excel. Once the worksheet is created and verified, it is simple to change a value and have the new result automatically computed.

Estimating annual fuel use with each gear type. The left table (below) shows the amount of fuel used each year when a traditional rig is used along with a running total showing cumulative fuel use over time. The final column, which shows the estimated, annual cost of those 66,101 gallons, is figured by multiplying the forecasted unit fuel prices for each year (shown in the table on the preceding page) by annual use. The right table (below) shows annual quantities used with the fuel-saving gear plus cumulative gallons burned over the 14-year interval. Annual costs for those 59,491 gallons are shown in the far right column. Over the planning horizon, traditional trawl gear uses 925,414 gallons of diesel, which is 92,450 gallons more than the fuel-saving gear, to produce the same quantity of shrimp.

Baseline Fuel Use With Traditional Gear			
Year	**Annual Use**	**Cum. Use**	**Annual Cost**
2010	66,101	66,101	-$134,714
2011	66,101	132,202	-$145,620
2012	66,101	198,303	-$158,973
2013	66,101	264,404	-$171,995
2014	66,101	330,505	-$182,108
2015	66,101	396,606	-$192,156
2016	66,101	462,707	-$203,855
2017	66,101	528,808	-$214,299
2018	66,101	594,909	-$225,140
2019	66,101	661,010	-$233,733
2020	66,101	727,111	-$242,062
2021	66,101	793,212	-$249,531
2022	66,101	859,313	-$258,852
2023	66,101	925,414	-$266,718
		Total	**-$2,879,756**

10% Reduction in Fuel Use With Fuel-saving Gear			
Year	**Annual Use**	**Cum. Use**	**Annual Cost**
2010	59,491	59,491	-$121,243
2011	59,491	118,982	-$131,059
2012	59,491	178,473	-$143,076
2013	59,491	237,964	-$154,796
2014	59,491	297,455	-$163,898
2015	59,491	356,946	-$172,940
2016	59,491	416,437	-$183,470
2017	59,491	475,928	-$192,870
2018	59,491	535,419	-$202,626
2019	59,491	594,910	-$210,360
2020	59,491	654,401	-$217,856
2021	59,491	713,892	-$224,579
2022	59,491	773,383	-$232,967
2023	59,491	832,874	-$240,046
		Total	**-$2,591,785**

Estimating the timing, type, and cost of main-engine overhauls. Overhauls are specified by the engine manufacturer, and are based on the cumulative amount of fuel used. Caterpillar® requires a top-end overhaul after every 256,000 gallons are burned while the major overhaul is specified once 512,000 gallons are used. For the fictitious shrimp trawler used in this comparison, we assumed that major overhauls were completed at the end of 2009–just prior to the first year in the NPV analysis. Thus, only fuel used between 2010 and 2023 determined when overhauls would be required. For this analysis, those years when cumulative fuel-use values trigger the services are the same years when those overhauls are completed. In 2010, the price of a top-end service performed by Caterpillar® was $8,500 (parts and labor) while the major overhaul cost $20,000. Over the 14-year interval, cumulative fuel used by both gear types triggered two top-end overhauls and one major overhaul. As shown in the left table (below) which presents the overhaul schedule when using traditional trawl gear, top-end overhauls occur in 2013 and 2021, with one major overhaul in 2017. The right table (below) shows the overhaul schedule when fuel-saving trawl gear was used. Top-end services occur in 2014 and 2022, and the major overhaul is in 2018.

Traditional Gear: Using Accumulated Fuel to Estimate When Different Overhauls Are Required and the Cost

Year	Cum. Use	Top-end	Major	Top-end Cost	Major Cost
2010	66,101			$0	$0
2011	132,202			$0	$0
2012	198,303			$0	$0
2013	264,404	🟦		-$10,855	$0
2014	330,505			$0	$0
2015	396,606			$0	$0
2016	462,707			$0	$0
2017	528,808		🟦	$0	-$31,820
2018	594,909			$0	$0
2019	661,010			$0	$0
2020	727,111			$0	$0
2021	793,212	🟦		-$15,742	$0
2022	859,313			$0	$0
2023	925,414			$0	$0
Total		**2**	**1**	**-$26,597**	**-$31,820**

Fuel-saving Gear: Using Accumulated Fuel to Estimate When Different Overhauls Are Required and the Cost

Year	Cum. Use	Top-end	Major	Top-end Cost	Major Cost
2010	59,491			$0	$0
2011	118,982			$0	$0
2012	178,473			$0	$0
2013	237,964			$0	$0
2014	297,455	🟦		-$11,492	$0
2015	356,946			$0	$0
2016	416,437			$0	$0
2017	475,928			$0	$0
2018	535,419		🟦	$0	-$33,420
2019	594,910			$0	$0
2020	654,401			$0	$0
2021	713,892			$0	$0
2022	773,383	🟦		-$16,329	$0
2023	832,874			$0	$0
Total		2	1	-$27,821	-$33,420

Estimated costs of acquiring, maintaining, and replacing trawl doors and nets.
We believe that the high unit price for fuel-saving trawl gear—*"sticker shock"*—was one reason that has slowed its adoption. However, as prices for acquisition, annual maintenance, and replacement are fitted into the tables based on expected useful lives, a clearer estimate of the future costs generated by each gear type is created.

The 2010 price for a set of wooden doors was estimated at $3,500. With a two-year useful life, wooden trawl doors are replaced in January of every third year (top table). With such a short useful life, no annual maintenance is performed on wooden doors. The 2010 price for nylon nets was estimated at $5,465. The replacement schedule for nylon nets is identical to that of the wooden doors. Nylon nets are dipped every 6 months, or 4 times over their 2-year useful life. Based on interviews with industry members, the annual price for dipping nylon nets was $2,000 in 2010. The price for a set of 1.4 m^2 steel, cambered doors was $7,000 in 2010. With a 7-year useful life, the cambered, steel doors are replaced in January of every eighth year (bottom table). Annual maintenance is required on the cambered, steel doors. Early adopters note that the original diameters of towing holes in the horizontal rib must be restored (built up) each year. Likewise, pad-eyes attached to the aft end of shoes must be replaced each year. Sacrificial zincs are also required annually to prevent deterioration of the steel. The 2010 price for annual steel door maintenance was estimated to be $58.50 per door ($234 per set). The price for braided Sapphire® nets in 2010 was estimated at $6,570 based on interviews with elite fishermen, fleet managers, and owners of marine supply firms. Early adopters in Texas noted they had used the braided Sapphire® material for 7 years. We opted for a more conservative useful life of 4 years, with those nets being replaced at the beginning of every fifth year. Sapphire® material never needs to be dipped, so there are no annual preventive maintenance charges for HDPE nets.

Estimating Costs for Traditional Gear
Over a 14 Year Replacement Chain

Year	Trawl Doors		Nets	
	Acq. Cost	Maint.	Acq. Cost	6 Mo.Dip.
2010	-$3,500	$0	-$5,465	-$2,000
2011	$0	$0	$0	-$2,162
2012	-$4,130	$0	-$6,449	-$2,360
2013	$0	$0	$0	-$2,554
2014	-$4,732	$0	-$7,389	-$2,704
2015	$0	$0	$0	-$2,852
2016	-$5,296	$0	-$8,269	-$3,026
2017	$0	$0	$0	-$3,182
2018	-$5,849	$0	-$9,132	-$3,342
2019	$0	$0	$0	-$3,470
2020	-$6,290	$0	-$9,821	-$3,594
2021	$0	$0	$0	-$3,704
2022	-$6,724	$0	-$10,498	-$3,842
2023	$0	$0	$0	-$3,960
Total	**-$36,519**	**$0**	**-$57,022**	**-$42,752**

Estimating Costs for Fuel-saving Gear
Over a 14 Year Replacement Chain

Year	Trawl Doors		Nets	
	Acq. Cost	Maint.	Acq. Cost	6 Mo.Dip.
2010	-$7,000	-$234	-$6,570	$0
2011	$0	-$253	$0	$0
2012	$0	-$276	$0	$0
2013	$0	-$299	$0	$0
2014	$0	-$316	-$8,883	$0
2015	$0	-$334	$0	$0
2016	$0	-$354	$0	$0
2017	-$11,137	-$372	$0	$0
2018	$0	-$391	-$10,978	$0
2019	$0	-$406	$0	$0
2020	$0	-$420	$0	$0
2021	$0	-$433	$0	$0
2022	$0	-$450	-$12,621	$0
2023	$0	-$463	$0	$0
Total	**-$18,137**	**-$5,002**	**-$39,052**	**$0**

Summarizing relevant cash costs by gear type over the 14-year interval. The next two tables incorporate the three previous sets of relevant costs *(i.e., fuel, engine overhauls, and initial acquisition, annual maintenance and replacement of doors and nets)* and show future cash costs across the 14-year planning horizon. All costs incurred in each year are summed into a total, future, cash cost for that year (the far right column in each table). The first table presents annual costs for the traditional gear while the second table shows costs when the cambered doors and Sapphire® nets are used. Each series of total, annual, future cash costs–highlighted in blue–becomes the starting point for step two in the NPV analysis which converts these future cash costs to their present values.

Estimated Annual Costs Over a 14-Year Replacement Chain With Traditional Trawl Gear

Year	Fuel			Overhauls	Doors		Nets		Total, Ann. Future Cash Costs
	Annual Use	Cumulative Use	Annual Cost	Total Cost	Acq. Cost	Annual Maint. Cost	Acq. Cost	6 Month Dip. Cost	
2010	66,101	66,101	-$134,714	$0	-$3,500	$0	-$5,465	-$2,000	-$145,679
2011	66,101	132,202	-$145,621	$0	$0	$0	$0	-$2,162	-$147,783
2012	66,101	198,303	-$158,973	$0	-$4,130	$0	-$6,449	-$2,360	-$171,912
2013	66,101	264,404	-$171,995	-$10,855	$0	$0	$0	-$2,554	-$185,403
2014	66,101	330,505	-$182,108	$0	-$4,732	$0	-$7,389	-$2,704	-$196,933
2015	66,101	396,606	-$192,156	$0	$0	$0	$0	-$2,852	-$195,008
2016	66,101	462,707	-$203,855	$0	-$5,296	$0	-$8,269	-$3,026	-$220,446
2017	66,101	528,808	-$214,299	$0	$0	$0	$0	-$3,182	-$249,301
2018	66,101	594,909	-$225,140	$0	-$5,849	$0	-$9,132	-$3,342	-$243,463
2019	66,101	661,010	-$233,733	$0	$0	$0	$0	-$3,470	-$237,203
2020	66,101	727,111	-$242,062	$0	-$6,290	$0	-$9,821	-$3,594	-$261,766
2021	66,101	793,212	-$249,531	-$15,742	$0	$0	$0	-$3,704	-$268,977
2022	66,101	859,313	-$258,852	$0	-$6,724	$0	-$10,498	-$3,842	-$279,915
2023	66,101	925,414	-$266,718	$0	$0	$0	$0	-$3,960	-$270,678
Total			**-$2,879,756**	**-$26,597**	**-$36,519**	**$0**	**-$57,022**	**-$42,752**	**-$3,074,465**

Estimated Annual Costs Over a 14-Year Replacement Chain With Fuel-saving Gear with a 10% Fuel Reduction

Year	Fuel			Overhauls	Doors		Nets		Total, Ann. Future Cash Costs
	Annual Use	Cumulative Use	Annual Cost	Total Cost	Acq. Cost	Annual Maint. Cost	Acq. Cost	6 Month Dip. Cost	
2010	59,491	59,491	-$121,243	$0	-$7,000	-$234	-$6,570	$0	-$135,047
2011	59,491	118,982	-$131,059	$0	$0	-$253	$0	$0	-$131,312
2012	59,491	178,473	-$143,076	$0	$0	-$276	$0	$0	-$143,352
2013	59,491	237,964	-$154,796	$0	$0	-$299	$0	$0	-$155,094
2014	59,491	297,455	-$163,898	-$11,492	$0	-$316	-$8,883	$0	-$184,589
2015	59,491	356,946	-$172,940	$0	$0	-$334	$0	$0	-$173,274
2016	59,491	416,437	-$183,470	$0	$0	-$354	$0	$0	-$183,824
2017	59,491	475,928	-$192,870	$0	-$11,137	-$372	$0	$0	-$204,379
2018	59,491	535,419	-$202,626	$0	$0	-$391	-$10,978	$0	-$247,416
2019	59,491	594,910	-$210,360	$0	$0	-$406	$0	$0	-$210,766
2020	59,491	654,401	-$217,856	$0	$0	-$420	$0	$0	-$218,277
2021	59,491	713,892	-$224,579	$0	$0	-$433	$0	$0	-$225,012
2022	59,491	773,383	-$232,967	-$16,329	$0	-$450	-$12,621	$0	-$262,366
2023	59,491	832,874	-$240,046	$0	$0	-$463	$0	$0	-$240,510
Total			**-$2,591,785**	**-$27,821**	**-$18,137**	**-$5,002**	**-$39,052**	**$0**	**-$2,715,216**

Step Two – Converting Estimated, Future Cash Costs to Their Present Values

Choice of a single discount rate–certainly the approach an individual firm should use in evaluating the NPV of different trawl gear types–would not be relevant to all readers. Likewise, when a range of possible discount rates are used, the effect on NPV becomes important performance information we did not want to omit.[10] Therefore, seven discount rates ranging from 3% to 15% are used to convert annual future cash costs to their present values.[11] Converting each annual future cash cost to its present value is an intermediate step, and must be done individually because each annual future cash cost is a unique value. As can be seen in both tables (below), the "apples to apples" comparison that is the hallmark of the NPV approach is the summation of those present values across the 14-year time frame. The bottom total row in each table is highlighted in green. Comparing the present values of costs by gear type for each discount rate indicates that the present values of relevant cash costs generated with the fuel-saving trawl system over the 14-year time frame were consistently closer to zero across all the discount rates used. Therefore choosing the more-expensive, longer-lived fuel-saving gear and realizing at least a 10% reduction in fuel use would improve the economic well-being of the shrimp-fishing enterprise.[12]

Present Values of Future Cash Costs with Traditional Gear

Year	Total, Ann. Future Cash Costs	Discount Rates Used to Convert Annual Estimated Cash Costs to their Present Values						
		3%	5%	7%	9%	11%	13%	15%
2010	-$145,679	-$145,679	-$145,679	-$145,679	-$145,679	-$145,679	-$145,679	-$145,679
2011	-$147,783	-$143,478	-$140,745	-$138,114	-$135,580	-$133,137	-$130,781	-$128,507
2012	-$171,912	-$162,043	-$155,929	-$150,154	-$144,695	-$139,527	-$134,632	-$129,990
2013	-$185,403	-$169,670	-$160,158	-$151,344	-$143,165	-$135,565	-$128,494	-$121,906
2014	-$196,933	-$174,972	-$162,017	-$150,239	-$139,512	-$129,726	-$120,783	-$112,597
2015	-$195,008	-$168,215	-$152,794	-$139,038	-$126,742	-$115,728	-$105,842	-$96,953
2016	-$220,446	-$184,620	-$164,500	-$146,892	-$131,444	-$117,859	-$105,884	-$95,305
2017	-$249,301	-$202,705	-$177,174	-$155,252	-$136,376	-$120,078	-$105,968	-$93,722
2018	-$243,463	-$192,192	-$164,785	-$141,697	-$122,186	-$105,645	-$91,581	-$79,588
2019	-$237,203	-$181,796	-$152,903	-$129,023	-$109,215	-$92,729	-$78,961	-$67,428
2020	-$261,766	-$194,778	-$160,702	-$133,069	-$110,573	-$92,190	-$77,113	-$64,705
2021	-$268,977	-$194,315	-$157,265	-$127,789	-$104,238	-$85,342	-$70,122	-$57,815
2022	-$279,915	-$196,327	-$155,867	-$124,286	-$99,520	-$80,011	-$64,578	-$52,318
2023	-$270,678	-$184,318	-$143,546	-$112,322	-$88,289	-$69,703	-$55,263	-$43,993
Total	**-$3,074,465**	**-$2,495,109**	**-$2,194,065**	**-$1,944,899**	**-$1,737,213**	**-$1,562,919**	**-$1,415,681**	**-$1,290,504**

Present Values of Estimated, Future Cash Costs with Fuel-saving Gear Assuming a 10% Fuel Reduction

Year	Total, Ann. Future Cash Costs	Discount Rates Used to Convert Annual Estimated Cash Costs to their Present Values						
		3%	5%	7%	9%	11%	13%	15%
2010	-$135,047	-$135,047	-$135,047	-$135,047	-$135,047	-$135,047	-$135,047	-$135,047
2011	-$131,312	-$127,487	-$125,059	-$122,721	-$120,469	-$118,299	-$116,205	-$114,184
2012	-$143,352	-$135,123	-$130,024	-$125,209	-$120,656	-$116,348	-$112,266	-$108,395
2013	-$155,094	-$141,933	-$133,976	-$126,603	-$119,761	-$113,404	-$107,488	-$101,977
2014	-$184,589	-$164,005	-$151,862	-$140,822	-$130,767	-$121,594	-$113,212	-$105,539
2015	-$173,274	-$149,468	-$135,765	-$123,542	-$112,616	-$102,830	-$94,046	-$86,148
2016	-$183,824	-$153,950	-$137,173	-$122,490	-$109,608	-$98,280	-$88,294	-$79,472
2017	-$204,379	-$166,179	-$145,248	-$127,277	-$111,802	-$98,441	-$86,874	-$76,834
2018	-$247,416	-$195,312	-$167,461	-$143,998	-$124,170	-$107,360	-$93,068	-$80,881
2019	-$210,766	-$161,535	-$135,862	-$114,643	-$97,043	-$82,394	-$70,161	-$59,913
2020	-$218,277	-$162,418	-$134,003	-$110,961	-$92,202	-$76,874	-$64,302	-$53,955
2021	-$225,012	-$162,553	-$131,560	-$106,902	-$87,200	-$71,393	-$58,660	-$48,365
2022	-$262,366	-$184,018	-$146,095	-$116,494	-$93,280	-$74,995	-$60,529	-$49,038
2023	-$240,510	-$163,775	-$127,547	-$99,803	-$78,449	-$61,935	-$49,104	-$39,090
Total	**-$2,715,216**	**-$2,202,803**	**-$1,936,682**	**-$1,716,512**	**-$1,533,070**	**-$1,379,194**	**-$1,249,256**	**-$1,138,838**

[10] Earlier it was demonstrated that the same net cash flow generated later in time had a lower present value than the same net cash flow generated sooner when using the same discount rate. Likewise, two equal net cash flows generated at the same future period but discounted using different required rates of return will result in different present values. Given equally valued cash flows that occur at the same time, a higher discount rate lowers the present value.

[11] The conversion from future to present value uses the following formula: [Total, Annual, Future Cost in period n x (1 ÷ ((1 + discount rate)^n))]. To convert the 2012 future cash cost of -$171,911.61 using a discount rate of 3% to its present value, the equation would be [-$171,912 x (1 ÷ ((1 + 0.03)^2))]. Simplifying equals [-$171,912 x 0.942596], which yields a present value of -$162,043. As shown in both tables that follow, this conversion from future value to present value was made for each year in the 14-year planning horizon. Once each year's costs are converted to their present values, these present values are summed, which becomes the computed NPV for the investment at a particular discount rate.

[12] Recall that only cost data were considered here, since the cooperative research project verified that both trawl systems caught equally when simultaneously fished. In a revenue-neutral, cost-saving investment, the smaller the negative net present value, the better.

“Drilling down” to uncover the comparative advantage fuel-saving trawl gear offers fishermen. The two tables on the previous page presented computed net present values for traditional gear and fuel saving gear across seven discount rates. This section examines the conditions that created a lower computed net present value of relevant costs when the fuel-saving trawl gear was chosen.

Why consider the present values of relevant costs since a discount rate has to be selected, and may be different for operators across the fishery? Recall earlier that future values generated in different years first have to be standardized to their present values before values can be compared. This section compares the present value of each relevant cost estimated over the 14-year planning horizon by gear type using a discount rate of 3%. Any rate, from 3% to 15%, could have been used. As discount rates increase, the present values of identical future values decrease, but the percentage contribution made by each relevant cost to overall cost reduction does not change.

The table (below) shows a side-by-side comparison of the present values of costs for fuel, overhauls, door and net acquisition, and annual maintenance of doors and nets over the 14-year time frame. Present value totals of these costs by gear type, which are shown in the last row of the table, equal the totals shown in each table on page 23 under the 3% discount rate column.

A Comparison of the Present Values of Relevant Cash Costs Discounted at 3% Over the 14-year Time Frame

Relevant Cash Costs	Type of Trawl Gear		Difference	Pct. Diff.
	Cambered/ Sapphire®	Wooden/ Nylon		
Fuel	-$2,102,664	-$2,336,289	$233,625	79.9%
Overhauls	-$48,045	-$47,178	-$867	-0.3%
Door Acquisition	-$16,055	-$30,045	$13,989	4.8%
Door Maintenance	-$4,058	$0	-$4,058	-1.4%
Net Acquisition	-$31,981	-$46,913	$14,932	5.1%
Net Maintenance	$0	-$34,684	$34,684	11.9%
Total	**-$2,202,803**	**-$2,495,109**	**$292,306**	**100.0%**

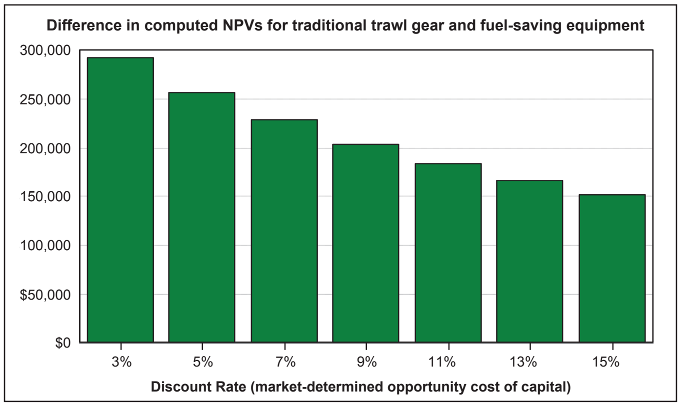
Three conditions created lower costs when cambered doors and braided Sapphire® nets were used. First, the 10% reduction in fuel use of 6,610 gallons annually resulted in an estimated present value of savings that equaled $233,625. This modest reduction in annual fuel use accounted for 80% of all costs saved when fuel-saving gear was chosen. Second, the longer useful lives of steel doors and braided Sapphire® nets resulted in fewer replacements and thus lower acquisition costs over time. In particular, even though the fuel-saving gear was more expensive on a unit basis, it collectively generated a present value of savings that amounted to $28,921 (that is, $13,989 for doors plus $14,932 for nets). The lower present value of acquisition costs accounted for roughly 10% of total costs saved. The third condition was sharply lower annual maintenance costs associated with nets made from braided Sapphire® fiber. Being able to eliminate twice-yearly dipping of nylon nets reduced the present value of annual net maintenance by an estimated $34,684, which was almost 12% of all costs saved. Annual maintenance on steel doors added roughly $4,058 (1.4%) to the present value of their cost. Considering acquisition and ownership costs together, when cambered doors and nets constructed of braided Sapphire® fiber nets are chosen, the present value for that gear type is $59,547 lower than traditional doors and nets (that is, a $28,921 savings in acquisition costs for cambered doors and nets plus a $34,684 savings in dipping charges since HDPE fiber should never be dipped, less $4,058 for annual cambered door maintenance).

Finally, note that the present values of overhaul costs were slightly higher at $867 when cambered doors were chosen. This increase amounted to a 0.3% increase. Recall that with a 10% annual reduction in fuel use, overhaul services occurred 1 year later with fuel-saving gear but the price for that service was also about 4% higher due to estimated inflation.

Step Three – Comparing the Present Values of Relevant Cash Costs for Each Trawl Gear Type

Thus far the relevant cash costs anticipated when using the two types of trawl gear have been estimated over a 14-year time frame. These future cash costs have been converted to their present values across seven different discount rates (also called the required rates of return because each is a market-determined opportunity cost of your capital). To figure today's value of costs saved, the present value of costs attributable to traditional gear is subtracted from the present value of costs that resulted from the fuel-saving equipment across each discount rate. As shown in the table (below) and chart (right), when the required rate of return was 3%, the present value of cost savings was $292,306. At 15%–a much higher market-determined opportunity cost of capital–the present value of cost savings was $151,666.

Remember that the computed net present value of your next-best alternative investment will always equal zero. Therefore, an investment with a positive, computed, net present value will improve the economic wellbeing of the enterprise. In other words, when choosing the fuel-saving trawl gear and achieving a 10% reduction in fuel consumption, the present value of cost savings over a 14-year planning horizon far exceed the computed net present value of what your capital could earn when the required rates of return range from 3% to 15%.



Present Value Differences Between Traditional Gear and Fuel-Saving Gear With a 10% Use Reduction							
	Discount Rates Used to Convert Future Cash Costs to Their Present Values						
	3%	**5%**	**7%**	**9%**	**11%**	**13%**	**15%**
PV of costs from fuel-saving gear	-$2,202,803	-$1,936,682	-$1,716,512	-$1,533,070	-$1,379,194	-$1,249,256	-$1,138,838
PV of costs from traditional gear	-$2,495,109	-$2,194,065	-$1,944,899	-$1,737,213	-$1,562,919	-$1,415,681	-$1,290,504
PV of cost savings with fuel-saving gear	$292,306	$257,383	$228,387	$204,143	$183,725	$166,425	$151,666

A Summary of the Net Present Value Analysis

The NPV process is a straightforward method for valuing the potential impacts of investments on the operation. Often the mechanics of the process are stressed while explanations of how specific values were determined are omitted. We believe that understanding the sources of information used in the NPV analysis are just as important as proper use of the process itself.

Future projections relied on a combination of four elements: (a) previously-collected performance data uncovered in our various research efforts with shrimp fishermen, (b) assumptions, (c) published forecasts, and (d) expert opinions. Annual fuel consumption and fuel-savings values used in the analysis are each the result of different, past applied research projects. Two assumptions guided our analysis. The first was that input prices would increase over time, and the second was selecting (that is, assuming) a conservative fuel-savings value attributable to the new gear. The third element used in making future projections was the DOE forecast of yearly prices for diesel fuel, which were presented in the department's annual energy outlook e-publication [6]. This fuel-price forecast also served as the basis for creating an input price index that allowed us to inflate unit prices for all inputs except fuel. Finally, we relied on the expert opinions of fishermen, fleet managers, and owners of marine supply firms to estimate prices for acquisition and annual maintenance of trawl gear as well as overhauls. Collective industry opinion also suggested expected useful lives for both types of doors and nets.

The NPV analysis demonstrated two important points. First, the unit price of required equipment with a useful life measured in years should not solely drive the purchase decision. As demonstrated in the analysis, even though the fuel-saving gear was 51% more expensive than traditional doors and nets, less frequent replacements (due to a longer useful life) and sharply reduced annual maintenance requirements made fuel-saving gear the least-cost option when considered over time. The second point is common sense. Replacing less-efficient equipment with trawl gear that maintains historic output but does so with fewer inputs generates significant cost-savings that fall right to the bottom line and positively impacts the economic well-being of the shrimp-trawling enterprise.

Discussion

Milestones Reached in the Search for More Efficient Trawl Gear

Initial sea trials, subsequent physical modification, and cooperative industry research. This applied industry research effort began in 2005 as fuel prices rose to $2.00 per gallon. Concerned that a fundamental change in trawl gear was required to offset rapidly escalating fuel prices, Western Seafood and Texas Sea Grant undertook pioneering efforts to evaluate and modify a trawl door never before used in the Southeastern U.S. shrimp-trawl fishery. Four modifications to off-the-shelf cambered doors used in the initial sea trials resulted in a more efficient door that could replace a traditional flat door when fishing quad rigs for brown shrimp or when pulling dual bib nets in the hunt for white shrimp.

The goal of this multi-year project was to reduce input costs while maintaining the production generated with cooperators' traditional trawl gear. Achieving this goal would result in higher levels of operating income. This goal was met through a rigorous four-step research project involving cooperating offshore operators from across the Gulf and South Atlantic shrimp fishery. Ultimately, this research documented two key findings. First, production performance with the new fuel-saving trawl gear was identical to that of traditional gear when both gear types were simultaneously fished (demonstrated by step 3 of the four-step research protocol). Meeting this objective was essential if the project was to move forward. The second key result from the four-step cooperative research project was a documented reduction in fuel consumption that ranged from 10% to 39% (steps 1 and 4).

Third-party responses after the cooperative industry research was completed. Although the cambered doors were roughly half the area of traditional flat otter boards, they were taller than the maximum height allowed in Louisiana and Mississippi. At the request of industry leaders in those states, presentations by Texas Sea Grant faculty about the pilot work with these new doors were made to both the Louisiana Department of Wildlife and Fisheries and the Mississippi Department of Marine Resources. As a result of these events, both states relaxed their regulations regarding maximum door height, which legalized vented, cambered, steel trawl doors in Louisiana and Mississippi.

A second, third-party response essentially picked up where the cooperative industry research project ended. The Ocean Conservancy and the Walton Foundation created a cost-sharing program designed to help Gulf and South Atlantic shrimp fishermen get the new gear aboard their vessels. This project covered half of the acquisition cost for the new gear and also offered financing for the remaining balance if needed. In addition to cost-sharing, this program also offered a consulting fisherman to assist participants with adjustment and tuning procedures as well as roughly $3,000 for sea trials (which reduced the economic risk in learning about the new doors).

Net present value investment analysis. To examine what this fuel-saving gear could mean to a hypothetical operator, a net present value analysis compared those cash production costs that would be impacted by gear type (fuel use and cost, overhaul frequency, plus door/net acquisition and maintenance). This analysis demonstrated that higher-priced, longer-lived trawl gear that could save at least 10% of historic fuel used was, by far, the better investment choice, since the NPV across all seven discount rates represented lower operational costs.

The difference between the present value of costs estimated with the fuel-saving gear and the present value of costs estimated with traditional trawl systems demonstrated a consistently positive NPV regardless of discount rate. According to NPV criteria for acceptance, a positive difference between competing choices suggests that the investment in fuel-saving equipment would improve the economic well-being of the shrimp-trawling operation. The expectation going forward with the new gear would be an increase in the operator's bottom line.

Future Significance of Project Results

Determinants of profitability then and now. Fishermen who survived the darkest days in the economic history of the Southeastern U.S. shrimp-trawl fishery now represent a fraction of the effort that existed prior to 2001. As a result of less gear in the water, catch rates for remaining operators have skyrocketed.[13] The catch rates currently experienced would have been enough to keep shrimp-fishing enterprises moving forward economically from the seventies through 2000. In those days, fishermen landed a high-dollar product with relatively low-cost inputs, but, catching enough shrimp was the limit to profitability. Now and in the future, the limit to profitability will likely be control of costs, because even with higher catch rates, fuel prices have significantly escalated since 2002 while dockside shrimp prices dramatically declined between 2001 and 2010.[14] With cambered, steel trawl doors and Sapphire® nets proven across the Gulf and South Atlantic, operators are now in a position to generate a greater net return by using fewer inputs to harvest identical quantities of shrimp than with traditional equipment. In other words, the fuel-saving gear will not catch any more shrimp than a traditional trawl, but it will cost less to produce that shrimp, and these cost savings fall right to the operator's bottom line.

Can operating margins be increased in other ways? No operator would willfully walk away from additional expected cash returns with net present values that range from $151,666 to $292,306 over a 14-year planning horizon. However, the current low levels of adoption suggest that the fuel-saving trawl doors evaluated, modified, and proven in the Southeastern U.S. shrimp-trawl fishery by their peers may not be the pathway many fishermen will choose. Outlining other technological solutions that improve income is beyond the scope of this report. However, comparing what would be necessary to generate expected cash returns equal to those from the fuel-saving gear through another approach is just another adaptation of the time value of money.

An operator desiring the same present value of $292,306 that was generated through cost savings (assuming a 3% discount rate) could conceivably catch more shrimp. Specifically, that producer's gross stock would have to increase by $36,957 in each of the 14 years. Seventy percent of that additional revenue each year—the vessel's share—would amount to $25,877. Discounting that additional revenue stream at the required rate of return of 3% would equal $292,309 at the end of 14 years. Of course, this would require the enterprise to earn additional revenue without increasing any production cost but crew shares. While conceivable, consistently increasing annual revenue by almost $37,000 over all 14 years may be a difficult undertaking. By comparison, spending less on acquisition and maintenance of longer-lived, more fuel-efficient trawl gear that also generates an annual saving in fuel consumption of just 10% (6,610 gallons) seems like the simpler, more certain pathway to improved, sustainable economic performance.

Putting greater retained earnings to work. Becoming more efficient suggests greater annual earned operating income levels that add to retained earnings. Consistently reducing avoidable production costs with the same catch rates can also help an operator to weather short-term economic shocks like spiking fuel prices or lower dockside shrimp prices. Increased income also allows management to consider uses for additional funds. We believe that investing in more-efficient trawl gear will enable operators to consider four other uses of additional retained earnings generated with that equipment.

1. ***Preventive maintenance.*** The first is completing necessary maintenance that may have been deferred over the past several years. Maintaining the production platform through a sound, preventive maintenance program keeps the vessel operational longer and is generally less expensive than making repairs as wear and tear problems arise.

2. ***Explore investment in more modern propellers and nozzles.*** A second possible use of greater retained earnings generated with the fuel-saving trawl gear could be investment other fuel-saving projects that passed the enterprise's NPV screening process. In particular, operators should consider replacing an open propeller with a modern wheel and nozzle system. Olds Engineering, a marine engineering and service company headquartered in Queensland, Australia, states that open-wheel trawlers similar in length and horsepower to what those used in the offshore Gulf and South Atlantic shrimp fishery can reduce fuel consumption by 23% if the existing propeller is replaced with a Rice speed wheel and speed nozzle [9,10].

---

[13] Of course in any given year, annual harvests will always be influenced by springtime weather-related ecological changes in the coastal bay systems that ultimately affect abundance.

[14] Regarding increased prices for diesel, even though the forecasted diesel price for 2012 was $2.40 per gallon, the actual average price for the year was roughly $3.50 per gallon. Using less fuel is the only way to insulate the enterprise from the full brunt of such price increasess.

Regarding shrimp prices, in 2013 dockside shrimp prices returned to levels not seen in more than a decade because of disease problems that affected production of shrimp from farms in Southeast Asia. How long those prices will last remains to be seen because domestic shrimp fishermen supply just 10% of the U.S. market. Conversely, farm-raised product imported from Ecuador, China, India, Thailand, and Vietnam accounts for two of every three shrimp consumed in the American marketplace.This makes domestic fishermen very susceptible to continued lower prices that likely will return once current diesease problems that limit production in ponds across Southeast Asia are resolved. A November 25, 2013 report in *Seafood.com News* suggests that the Thai shrimp industry appears to be recovering from EMS-related production declines [8]. As the article stated, "According to analysts, shrimp output has improved after the company switched to a bio-plus bacteria that eats EMS-causing bacteria in the ponds. The analysts said Thailand's shrimp industry bottomed out in the first half of the year (2013) and now expects production to gradually improve in 2014 and beyond now that the industry has a better understanding of EMS."

The Queensland marine engineering firm also notes that shrimp trawlers with Kaplan-style propellers inside Kort nozzles can reduce fuel use by 7% with the Rice speed wheel and speed nozzle combination [9, 10]. This assertion is consistent with preliminary results we completed in the multi-year fuel-efficiency research work. In addition to the trawl gear research previously detailed, we also replaced an existing Kaplan-style propeller inside a traditional Kort nozzle with a skewed propeller that was installed inside the existing nozzle. This switchover generated an additional 6% reduction in fuel consumption over and above the fuel savings previously generated with the fuel-saving trawl gear.[15]

The fuel savings from a more efficient wheel and nozzle are entirely dependent upon engineering research and on-site installation because, unlike the fuel-saving trawl gear, there is no learning curve. Our limited experience with upgrading the propeller with a more efficient design also suggests that the one-time cash outflows for acquisition, haul-out and installation will be higher than the costs associated with trawl gear, but the expected fuel savings will begin immediately, and the useful lives of propeller and nozzle are extremely long.

This potential capital expenditure presents another classic use of NPV to assess projected benefits through time and to estimate whether such an investment will create economic benefits over and above what your capital could generate. For operators using Kaplan-style propellers inside traditional Kort nozzles who are contemplating such a switchover to the more efficient wheel and nozzle system, a similar NPV process to the one used in this publication would be important to carry out since the fuel-saving benefit noted by Olds Engineering was 7%.

3. ***Increasing on-deck, brine-freezing capacity.*** A third use of additional retained earnings is increasing on-deck brine-freezing capacity. With catch rates extremely high for remaining operators due to reduced effort in the fishery, fishermen can certainly benefit from freezing larger quantities of shrimp in each on-deck freezing cycle. This will enable faster solid freezing of the entire catch, and will contribute to fewer culls in the processing plant. With two-thirds of all shrimp consumed in the American marketplace originating from just five shrimp-farming countries, improving domestic shrimp quality so it consistently matches the appearance of farmed product from high-grade facilities is the best way to ensure full market prices and maximize producer revenues [11].

4. ***Retirement planning.*** The fourth use of new-found retained earnings each year, or perhaps the first, would be to withdraw a portion of retained earnings and contribute them to a personal retirement account. This is important regardless of age, and is one of the most important uses of funds we all need to make.

Summary and Conclusions

Patrick Riley, the General Manager of Western Seafood, sought a more efficient trawl door that would result in lower production costs. His search ended with an Icelandic design typically used in mid-water fisheries across the eastern Atlantic. With the financial commitment of Western Seafood, Riley undertook proof of concept testing aboard the *Isabel Maier* captained by Manuel Calderon. Early on, Riley asked Gary Graham–Professor and Marine Fisheries Specialist with the Texas A&M AgriLife Extension Service, the Department of Wildlife and Fisheries Sciences, and the Texas Sea Grant College Program at Texas A&M University–to join the evaluation team. Four necessary modifications were identified to off- the-shelf cambered doors during the proof of concept cruise that made the more fuel-efficient cambered doors a legitimate choice for Gulf and South Atlantic shrimp fishermen.

Funds to conduct broad-scale comparative testing of traditional and new fuel-saving trawl gear by interested fishermen were obtained by Texas Sea Grant/Texas A&M AgriLife Extension faculty in the departments of Agricultural Economics and Wildlife and Fisheries Sciences. This cooperative research work developed a four-step research protocol, and put a complement of newly modified cambered trawl doors, braided Sapphire® nets, sleds, and an indicating fuel-flow meter aboard nine offshore vessels from Texas to North Carolina. Comparative results generated by fishermen demonstrated that the fuel-saving gear immediately reduced fuel consumption while maintaining catches equal to those produced with the operator's traditional equipment.

An investment analysis was conducted using (a) performance information generated through the cooperative research process, (b) forecasts of future diesel prices, and (c) expert opinions about costs and useful lives of both types of trawl gear. Using a 10% fuel-savings rate–the minimum amount documented through the Gulf and South Atlantic cooperative research project–the net present value of cost savings with the more expensive but longer-lived, more fuel-efficient trawl gear was consistently positive across discount rates that ranged from 3% to 15%. This means that the investment in fuel-saving gear will exceed the returns expected when the firm's cost of capital ranges from 3% to 15%. When the cost of capital is 3%, net present value of cost savings equals $292,306. When the cost of capital is 15%, the net present value of cost savings is estimated at $151,666. In practical terms, this means the fuel-saving trawl gear will boost annual operating income by producing the same revenue stream, but with lower costs.

---

[15] This additional fuel savings value is likely on the conservative side because the before and after sea trials were performed at different times of the year. Specifically, the baseline data were collected during the summer months while fuel-consumption measurement once the skewed propeller was installed took place during the winter months in the Florida straits; a location known for rough seas and strong currents.

References

1. **Haby, M.G., L.L. Falconer, and J.L. Parker.** 2001. "Developing an Economic Profile of Texas Shrimp Trawling Operations in the Gulf of Mexico." Johnstone, R., and A.L. Shriver, compilers. *Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade,* July 2000. Corvallis, Oregon. 6 pp.

2. **Bankston, J. David.** 1984. "Otter Doors and Fuel Consumption." A Louisiana Cooperative Extension/Louisiana Sea Grant College Program Paper. Louisiana State University, Baton Rouge, Louisiana. 14 p.

3. **Haby, M.G., and G.L. Graham.** 2010. *Investigations and Demonstrations Leading to Enhanced Fuel Efficiency in the Southeast Shrimp Fishery: A Final Report Outlining Work Undertaken and Achievements to Date.* (Contract: CM725 / TAMU Sponsored Project: 0000421118). May 1, 2007 through February 28, 2010. Prepared for the State Energy Conservation Office. Austin, Texas. Texas AgriLife Extension Service / Sea Grant Extension Program. TAMU-SG-10-201. The Texas A&M University System, College Station, Texas. 70 pp.

4. **Haby, M.G., G.L. Graham, and R.J. Miget.** 2010. *Intensive Technical Assistance for the Gulf and South Atlantic Shrimp Industry: A Final Report Outlining the Work Undertaken and Achievements to Date.* (Award Number 2005-48605-03347). Prepared for the Southern Region Risk Management Education Center. Stephenville, Texas. Texas AgriLife Extension Service / Texas Sea Grant Extension Program. TAMU-SG-10-202. The Texas A&M University System, College Station, Texas. 83 pp.

5 **Rao, R.K.S.** 1987. *Financial Management – Concepts and Applications.* McMillian Publishing Company, New York, NY. 797 pp.

6. U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy. 2010. "Annual Energy Outlook 2010 with Projections to 2035". DOE/EIA-0383(2010). [www.eia.doe.gov/oiaf/aeo/]. Accessed October, 2010. 221 pp.

7. **Sherrick, B.J., P.N. Ellinger, and D.A. Lins.** 2000. "Time Value of Money and Investment Analysis: Explanations and Spreadsheet Applications for Agricultural and Agribusiness Firms, Part II." The Center for Farm and Rural Business Finance, Department of Agricultural and Consumer Economics, and Department of Finance, University of Illinois, Urbana-Champaign, Ilinois. 34 pp.

8. **Ramsingh, M.** *Seafood.com News.* 2013. Accessed via email November 25, 2013.

9. **Barringhaus, D., and R. Olds.** "Maximizing Propulsion Efficiency – Are There Gains to Be Made by New Technology?" [www.olds.com.au/marine/maximizing_propulsion_efficiency/index.html]. Accessed September 17, 2013. Olds Engineering, Marine Division, Maryborough, Queensland, Australia.

10. **Barringhaus, D., and R. Olds.** "Rice Speed Nozzles More Efficient than Kort 19a Nozzle." [www.propellerpages.com/?c=nozzles&f=Speed_Nozzle_Tests]. Accessed September 17, 2013. Olds Engineering – Marine Division – Maryborough, Queensland, Australia.

11. **Haby, M.G., R.J. Miget, and E.A. Reisinger.** 2013. "The Steps Required to Produce Visually Perfect, Premium Quality, Great Tasting, Wild Shrimp." A Texas A&M AgriLife Extension Service / Texas Sea Grant College Program Staff Paper. TAMU-SG-13-502. The Texas A&M University System, College Station, Texas. 18 p.

Issued in furtherance of Cooperative Extension Work in Agriculture and Home Economics, Acts of Congress of May 8, 1914, as amended, and June 30, 1914,
in cooperation with the United States Department of Agriculture. Douglas L. Steele, Director, Texas A&M AgriLife Extension Service, The Texas A&M University System.

02-14