Some Uses of a Fuel Monitor

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ABSTRACT

Vessel performance-measuring equipment is coming on the market that includes various combinations of fuel flow meters, vessel speed sensors, and clock and microprocessor. The use of such equipment to control river towing operations is explored, mainly through financial performance estimates based on samples of the information from such fuel monitors. The factors on which commercial performance depends are enumerated first. Some are measured by a fuel monitor but financial and environmental factors are equally important. Commercial objectives for a towing operation are formulated next for two different conditions. Least added cost per mile is shown to be the appropriate operating objective when the company is underemployed (i.e., has idle equipment). When all assets are working, on the other hand, operating speeds should not exceed those that maximize the time rate of earning net income. Examples are given of pursuing these different objectives in the operations of a tanker and of sample river tows. Results are incidentally shown to be sensitive to current speed, acutely so when freight is being moved upstream.

The equipment to be discussed has various other names. "Vessel management system" is popular, and one sees advertisements for a "fuel log," an "integrated marine system," and others.

The system typically includes fuel meters for the main engines, a means of measuring vessel progress, a display, and supporting microprocessor with clock. Besides processing and displaying its sensors' outputs, it is usually programmed to compute and display a variety of functions that it measures, such as gallons of fuel burned per mile of progress, vessel speed, and time rate of fuel consumption.

Some of these systems measure ground speed, whereas others measure water speed. It will be shown that they would be better for the purpose suggested here if they measured both. None of them measures water depth, but reasons will be given why they all should.

THE OPPORTUNITY: CONTROLLING LINE-HAUL OPERATIONS

The question naturally arises, What does one do with this system? It looks like a reasonable way of turning the computer revolution against the energy shortage, but how can it be used for this purpose? It may be nice to know how many gallons of fuel one's tow burns per mile, but how can this knowledge be turned to advantage?

One use of a fuel monitor system is to put line-haul towing operations under better control, with the objective of improving the commercial performance of the towing company. During the underway portions of a towing operation, towboat speed and power can be chosen freely most of the time. Why not choose them so as to improve company profitability?

During a given trip, a towboat cannot, of course, deliver more than its maximum horsepower (and usually not even that much). But even this constraint can sometimes be lifted by assigning another towboat for the next trip. Why not assign towboats so as to improve company profitability?

Let us now consider how a fuel monitor system can be used to achieve these objectives.

FACTORS ON WHICH COMMERCIAL RESULTS DEPEND

As far as speed and power choice are concerned, the factors that affect commercial performance can be reduced to only a few. The first, and purely financial, factor is the costs that run at a constant time rate, in dollars per hour for instance, regardless of what the boat and barges may be doing. Crew costs are one major item that must be paid in cash, and other such cash expenses are maintenance and repair, insurance, and overhead. The other major item of this type, which may or may not include a cash component, is the cost of the capital tied up in the boat and barges, which are depreciated.

Figure 1 (1) shows how these "fixed" costs behave as towing speed changes. The cost per mile of paying $100/hr is plotted as a function of ground speed. The higher the speed, the lower becomes the cost per mile. This is why, in the halcyon days before 1973, the best way to run a towing operation was as fast as possible.

The trouble now is that going faster runs fuel consumption up to the point where its cost becomes troublesome. Figure 2, based on a trial by Dravo Corporation of a 15-barge Ohio River type tow, shows how shaft horsepower varies with speed and water depth. Horsepower is roughly proportional to the time rate at which the towboat burns money, in the form of fuel.

Both speed and water depth have strong effects on propulsion power. High speed is a well-known fuel burner, but shallow water is much more of a drag than most people believe. A tow three barges wide at 9 ft draft begins to "feel" the bottom in water about 67 ft deep; so it is in effectively shallow water most of the time. Fuel cost can be doubled by shallow water alone. A full report on this effect has been given by Schlichting (2).

This is important, because one use of fuel monitor systems is to accumulate tow performance information for future cost-estimating purposes. If water depth is not measured, recorded, and corrected for, the performance records may show so much random-looking scatter as not to be useful.

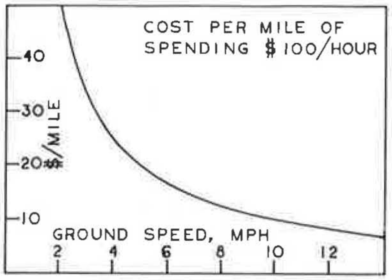

FIGURE 1 Cost per mile of spending $100/hr.

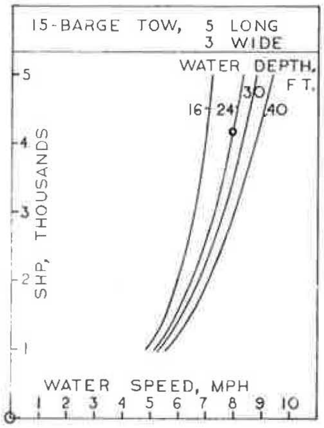

FIGURE 2 Shaft horsepower versus water speed for a 15-barge tow.

Curves like those in Figure 2 also depend on the size and makeup of the tow, a large subject to which there is not room to do justice here. It should, however, be noted in passing that the effects of tow size and arrangement are reflected in the measurements of fuel monitor systems, and learning more about them is a motive for using the systems.

Another major influence on commercial performance is the current. Curves like those of Figure 2 can be converted to cost per hour versus speed. Then, by correcting for the effect of current, they can be converted to cost per mile versus speed. In this form, a curve of fuel cost versus speed can be added directly to one of fixed cost versus speed, as in Figure 1, to produce a U-shaped curve of total cost per mile versus speed, like those in Figure 3 (1),

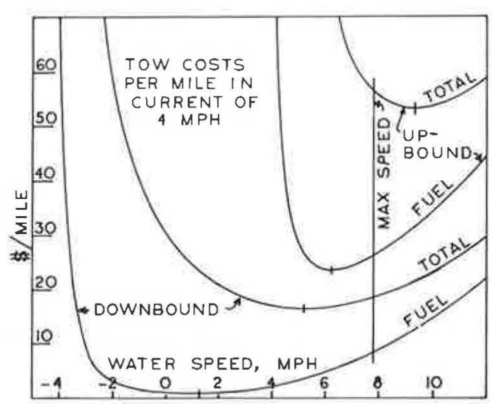

FIGURE 3 Tow cost per mile in 4-mph current.

which shows both total cost per mile and fuel cost per mile. The fuel-only curves include fuel burned while the boat is standing still as well as propulsion fuel.

The cost per ground mile is of interest, because the tow is paid for moving over ground. A lot of variation is evident in Figure 3. The effect of speed is shown directly. The effect of current can be inferred from the fact that the cost of moving the tow upstream is more than three times the cost of moving it downstream, with current at 4 mph in both cases. The effect of water depth is not shown.

Last, but certainly not least, revenues affect commercial performance of a towing operation. Now a list can be made of the factors that affect a choice of towing speed and power, with the object of improving commercial performance, as follows:

- Revenues ($ for a round trip),
- Operating or fixed costs ($/hr),
- Tow size and arrangement,
- Current (mph),
- Water depth (ft),
- Curve of fuel rate (gal/hr) versus water speed (mph) (result of tow size and arrangement, water depth, and, to a minor extent, choice of towboat),
- Price of fuel ($/gal), taxes included.

Our list contains seven items, of which three are available at company headquarters and four on the boat. In order to obtain and record the latter four for both control and planning purposes, a fuel monitor and related equipment are necessary. Older means of acquiring such data are too tedious to be practical.

THOUGHTS ON OBJECTIVES

Given the prospect of improved control of towing operations, exactly how should it be exercised? It was suggested earlier that it be with the object of improving commercial performance. This is socially acceptable but still too vague for practical use.

Two more concrete examples were also given; the least-fuel-per-mile speed of a tow was shown to be somewhat lower than the least-total-cost-per-mile speed. These objectives are clear enough for daily use, but is either of them, as a rule, desirable? The bad feature of the least-fuel alternative is shown in Figure 3; it runs total costs up substantially and unnecessarily.

Reflections on the problem have produced the following two criteria for an objective:

1. It should be computable for an individual boat, because it is at the towboat that towing operations are controlled, and
2. At the same time, it must promote the prosperity, not of the controlled boat, but of the company that owns it.

No single objective that meets these requirements has been discovered, but the combined use of two criteria appears to do so. At this writing, it appears that operations should be conducted at speeds determined by the principle of least added cost, but speeds should not exceed those that maximize profitability. [Derivations and discussions are presented elsewhere (3).]

Maximizing profitability sounds like a good thing. Why not do it all the time? The answer is that it can be done only when there is plenty of work waiting to be done, more than the company's fleet can possibly do. That is not true all the time; it has not been true recently.

As long as a company has idle capacity, tied-up towboats for instance, the principle of least added cost will give better results. To make it easy to explain, let us consider a towing company that is all ready to operate but has no work to do. It has no income, but it still has expenses: overhead, mortgage payments on boats and barges perhaps, expenses of keeping them laid up.

Now suppose that work appears and a towboat is put into service to do it. Doing the work entails additional expenses, mainly for crews and for fuel, all cash expenses. The principle of least added cost states that the company will be as well off as possible if these added costs of doing the work are minimized. Also, the work is worth doing as long as the revenues it brings exceed the added costs of doing it. One way of minimizing the added costs is to select towing speeds so that the sum of crew, fuel, and minor cash costs is as low as possible. A suitable monitor system will facilitate this process.

The best boat to start operating with is the one whose added costs are least, presumably the newest and most efficient one suitable for the trade. As business increases to take up the first boat's time, its speed can be increased until its added costs reach the minimum possible to the next-best boat, which is the next to be reactivated, and so forth.

This process can continue until all towboats are occupied full time at their most profitable speeds, above which it does not pay to run them. To raise capacity further, more towboats must be found at reasonable rates, or higher freight rates must be obtained, to justify speed increases for all the boats.

Finding the most profitable speed is essentially a matter of mathematical programming with a pro forma calculation that responds to towing speed changes. Curves of fuel rate versus speed are necessary, such as those that can be obtained from a fuel monitor system. The calculation deducts from the revenues of a round trip the costs of capital, crew, fuel, and so on, and then divides net income by the length of time occupied by the trip to obtain net profit per hour averaged over the trip. To maximize the profit per hour, diligent search is made to find the best set of speeds, one for each leg of the trip (3).

RESULTS OF PURSUING DIFFERENT OBJECTIVES

In Table 1, the results of using these two objectives, least added cost and maximum earning rate, are compared with full-power operation. The comparison applies to a 50,000 deadweight ton tanker on a 2,000-mile round trip, but the resulting speed-power pattern is quite similar to that of a river tow, except for the omission of the effects of the current (3).

Speeds for loaded and ballast legs have been chosen so as to optimize the quantities in the boxes. Minimum cash cost per voyage is not much different from least added cost per voyage. Charging interest on cargo value to the ship is a custom of oil companies, which increases the speed on the loaded leg by nearly 2 knots in one instance.

Even the maximum-earning-rate (most profitable) speeds are below full power. The least-cash-cost speeds and powers are lower still. The lowest power called for is only 36 percent of full power, and that is in the absence of current. The effect of a current would have been to increase the optimum power for going against it and to decrease the optimum power for going with it, thus widening the already wide range of propulsion power called for by normal operations.

TABLE 1 Financial Results of Pursuing Different Objectives

Objective	Interest on Cargo Value Charged?	Speed, Knots (Fuel Rate, bbl/hr) Loaded	Ballast	Net Earnings $/hour	Cash Cost, $/voyage
Full Power (no optimizing) or Least Time	no	16 (15.20)	17.6 (15.20)	64.02	102,048
	yes	16 (15.20)	17.6 (15.20)	.74	112,636
Maximum Earning Rate (Upper Speed Limits)	no	14.8 (11.91)	16.2 (11.91)	69.12	97,633
	yes	15.5 (13.87)	15.7 (10.74)	5.82	109,212
Minimum Cash Cost per Voyage (Lower Speed Limits)	no	11.3 (5.40)	12.5 (5.40)	31.91	91,959
	yes	13.2 (8.53)	12.5 (5.40)	-16.40	105,745

Fuel rate, bbl/hr	5.40	8.53	10.74	11.91	13.87	15.20
Fuel Rate, % of full power	36	56	71	78	91	100

There being about 8,400 hr in an operating year, the speed reduction from full power to most profitable speeds would be worth not quite $443,000/year for this example.

A noteworthy feature of these results is that in the absence of current and when no charge is made for interest on the cargo's value, the best fuel rate turns out to be the same for both legs of the voyage. The ship should go faster in ballast, but should burn fuel at the same rate as when loaded.

To see the effects of currents, let us look at some river tow results. Figure 4 (4) is a plot of net profitability before taxes versus current for four different speed-power policies, three of which are practical in some sense and one of which is ideal. The left side of the figure pertains to moving loaded barges upstream and empties down, whereas the right, more profitable half is for moving loads downstream and empties up.

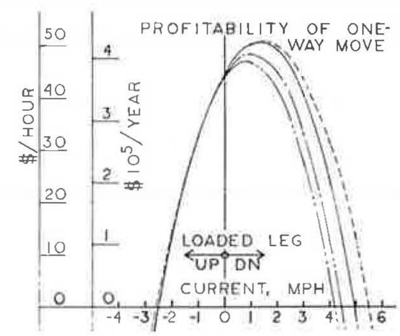

FIGURE 4 Profitability of a one-way move versus current for several speed-power policies.

Whatever the speed-control policy, profitability is seen to be quite sensitive to current. A current increase of only a few miles per hour can plunge profits from hundreds of thousands of dollars per year to below zero. The best current is not zero, but a weak current that favors the loaded leg. In the calculations that produced this figure, no credit was taken for smart piloting. Instead, current was assumed to be just as strong when the ship was upbound as when it was going down.

As to speed policies, the lowest curve (worst performance) (marked dash-dot-dot) is for using full power all the time. Full power is assumed to be 4,000 hp with loaded tow, but only 3,000 hp with empty tow, restrained by the engine governor. On a downstream move only, this can be improved by as much as $30,000/year by using least-cash-cost powers downstream and full power upstream. (Least-cash-cost powers upbound are greater than full power.)

A greater improvement could be made (from the dash-dot to the solid curve) if the towboat were modified so as to be able to develop its full 4,000 hp with an empty tow, which is what it has upbound. The final improvement (from the solid to the dashed curve) is what could be achieved by a towboat that had all the power required, paying for fuel but not for bigger engines, and was run always at the tow's most profitable speeds.

The freight rate, net of voyage costs other than fuel, for Figure 4 is about 6.7 mils/ton-mile. To get the rate that would be paid by the average customer, one would have to add the costs of fleeting, tug services, and so on.

The fuel rates and approximate horsepower that produced Figure 4 are shown in Figure 5 (4) for a tow loaded downstream, empty up only. Note that greater power is called for when the tow is empty than when it is loaded, because when empty, it is going upstream.

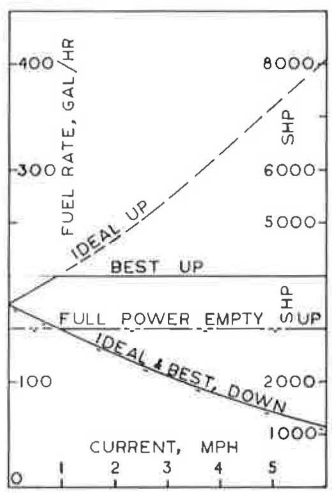

FIGURE 5 Fuel rates that produce the profitabilities shown in Figure 4 versus current when tow loaded downstream, empty upstream only.

Most towboats are set up to deliver just the opposite--full power with a heavy tow and less power with a light one. That makes them commercially suitable for moving cargo upstream and commercially unsuitable for moving it downstream, which many of them nevertheless do. Here is yet another area where there is room for improvement.

SUMMARY OF POSSIBILITIES

As the foregoing examples show,

1. It is possible to improve towing operations by better control alone, without any change in the basic equipment;
2. The fuel monitor both makes the necessary measurements and provides feedback for control of operations; and
3. Understanding and analysis of the operating company's situation indicate how to use the fuel monitor's output to the company's advantage.

As to company situations, a few examples, intended as illustrations, are all there is room for here. The number of possible operating and financial circumstances is large, and they change continuously. Full coverage is unfeasible. Everyone must therefore continually analyze his own situation. One who does so can make fuel monitors serve him very well.

The examples have treated mostly control of towing speed, the payoff for which can be estimated. There are also other applications for which the improvement is less easy to quantify, though it may be larger. It is possible to imagine a not-too-distant future in which collection and organization of towing performance data will have made great improvements in

1. Prediction of operating schedules (ETAs, etc.) and
2. Prediction of cost of operations.

The latter would appear to be especially important in these days of marginal freight rates. In one of the examples, for instance, the profitability of an upstream move fell from a rate of more than $300,000/year to less than zero as current increased from zero to only 3 mph. The current of the Ohio River does this every year. Why should the freight rates not change also? It might be safe to offer cheaper transportation if costs were under better control and operations were more thoroughly understood.

The possibility of better control is offered by fuel monitors. Better control leads in turn, and by many paths, to better performance. Fuel monitors can enable those who control towing operations to see what they are doing and thereby to improve.

ACKNOWLEDGMENT

The information in Figure 2 was supplied by the river boat building division of Dravo Corporation. Until it went out of business recently, this company was a rare source of dependable towing performance information.

REFERENCES

1. F. Marbury. Least-Energy Operation of River Shipping. Marine Technology, Vol. 16, No. 2, April 1979, pp. 136-155.
2. O. Schlichting. Ship Resistance in Water of Limited Depth--Resistance of Sea-Going Vessels in Shallow Water. Jahrbuch der Schiffbautechnische Gesellschaft, Vol. 35, 1934, pp. 127-148. (EMB Translation 56, Jan. 1940).
3. F. Marbury. The Finer Points of Slow Steaming. Proc., Ship Costs and Energy 1982 Symposium, Sept. 30-Oct. 1, 1982, N.Y. Metropolitan Section, Society of Naval Architects and Marine Engineers, pp. 101-124.
4. F. Marbury. Towboat Propulsion: How Economic Is It? The Work Boat Show Industry Seminars, New Orleans, La., Jan. 21, 1984.

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