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THE MICROCOMPUTER ABOARD SHIP:

Automatic Data Logging and

Most Profitable Speed Determination

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ABSTRACT

Aimed at marine managers without detailed knowledge of microcomputers, this paper discusses two applications of an 'on-line' microcomputer system for use aboard ship. The first section explains the way in which a microcomputer can be connected directly to a vessel's monitoring equipment and put on-line to automatically maintain an engineering log. The second section incorporates automatic data logging in an advanced microcomputer function used to determine the most profitable speed for a particular voyage on the basis of a performance characteristics empirically determined at voyage start, and financial data and general policy provided by management.

INTRODUCTION

Current trends in marine technology demonstrate that an increasing number of vessel related tasks are being accomplished more efficiently with the help of an on-board computer system. Perhaps even more enlightening are functions being discovered for on-board computers that have become feasible only by virtue of the computer. Applications well suited to the aboard ship computer include, but are certainly not limited to: spares stock inventory control, fuel consumption monitoring, automatic data logging, technical data assesment, trim analysis, hull and propulsion plant analysis, and optimum voyage speed versus a number of critical variables and the effects of fixed costs. These and other functions might be categorized as shown in Figure 1.

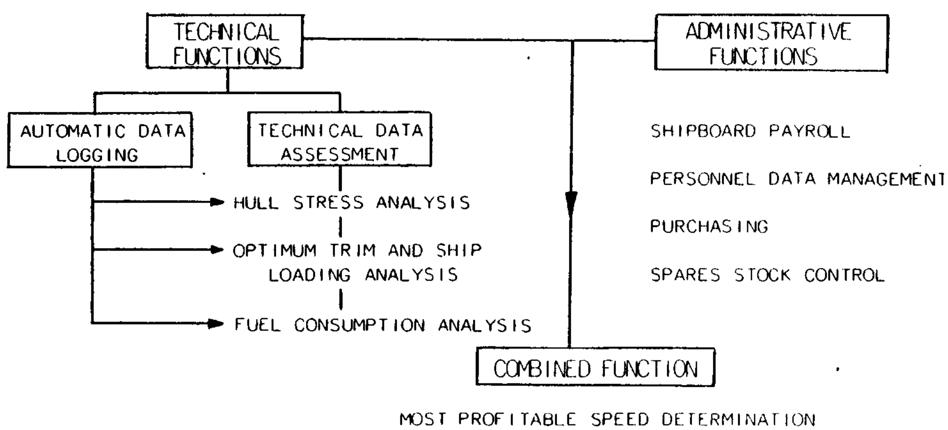

Figure 1

Many head offices have utilized computerized data processing systems for some time. Until recently, however, the cost and complexity of computerized systems may have appeared to outdistance the expected benefits of the limited applications available. With the introduction of the microcomputer, such attitudes are slowly being reevaluted. A complete general purpose microcomputer system including the necessary software may be had today for a relatively low cost. In addition, the microcomputer is designed for operation by a non-specialist after very little training, and for automatic data sampling a specially adapted microcomputer may be dedicated to one family of tasks, connected on-line, and treated as part of the machinery in what might be called a 'smart meter' function. Features of the microcomputer especially suited to on-board marine service are small size and dependability. The ability of the microcomputer to perform literally thousands of mathematical operations per second, automatically and without error, provides the capability to deal with a great many operational decisions.

Figure 1 breaks onboard microcomputer applications into two distinct functional areas:

1. Technical Functions
2. Administrative Functions

Technical Functions are divided between two general headings: Automatic Data Logging, and Technical Data Assessment. The last is further subdivided into several specific applications. Notice the link between Automatic Data Logging and the various forms of Technical Data Assessment. This discussion will comment on that interrelationship and the critical and oftentimes overlooked distinction between general purpose keyboard entry type computer systems and systems designed to automatically perform real world functions.

Administrative Functions are not the concern of this paper, except as administrative policies and management practices affect what has been termed 'Combined Functions'. The second half of this paper will deal at length with an advanced combined function labeled 'Most Profitable Speed Determination', a function that incorporates engineering performance data and management considerations in calculating optimum voyage speed. Before delving into that, however, we will familarize the reader with an explanation of a less involved on-board application for a microcomputer, that of an automatic data logging system.

Effort has been taken to approach the subject of microcomputers in a simplifed manner. A recent article in the 'Wall Street Journal' commenting on computers in management said:

> "According to consultants and managers themselves, middle-management reluctance to embrace computers often springs from one source: fear. Computers scare the daylights out of people unfamilar with them. The technology is foreign. The language is often incomprehensible."[1]

This discussion is designed to be understood by the person without knowledge of on-line computers. Topics that tend to confuse rather than enlighten are intentionally treated lightly. Pertinent details are introduced at an intuitive instead of technical level. The basis for justifying such a fundemental approach is that present microcomputer technology does not require a person to fathom enigmatic computer programming or the intricate internal workings within a system in order to effectively use one.

1 Bralove, Mary, "Computer Anxiety Hits Middle Management", Wall Street Journal, New York, (7 March 1983).

The first on-board application discussed in this paper is that of the microcomputer as an automatic data logger. If there is one item in the marine lexicon familar to all, it is the logbook. A log is a continuously updated record of various quantities deemed useful to some aspect of running a ship. The variables are recorded once per hour, watch, or some established time interval, and then a permanent record exists for future use as required.

Logkeeping lends itself very nicely to the microcomputer. Any assignment that can be broken down into a number of logical and sequential steps is the computer's bread and butter. To one even minimally knowledgeable with a marine log, it can be perceived that keeping a data log is a series of steps repeated over and over again. Logging any one quantity for an engine logbook entails transposing a value displayed on the associated monitoring equipment to the corresponding page, column, and row of the logbook, at the specified time. The specified time is generally a set interval since the previous log entry. The process appears to be straightforward and repetitive:

1. READ value indicated on equipment monitoring varaiable to be logged.
2. WRITE value indicated in the appropriate logbook record location.
3. WAIT the specified time interval.
4. THEN GO TO step 1.

Figure 2

As we are already to some degree familar with the process of how a log is maintained manually, let's procede directly into how a computer might automatically maintain a log. In the explanation just provided, we considered the process of logging only one variable. An engine logbook is a record of all the factors contributing to the vessel's performance, including many, varied entries. Figure 3 is a block diagram showing the relationship between the functional units of an automatic microcomputer data logging system. In the interest of simplicity, this system is shown as monitoring only three variables by means of sensors A, B, and C. An actual system has the capacity to monitor up to several hundred inputs.

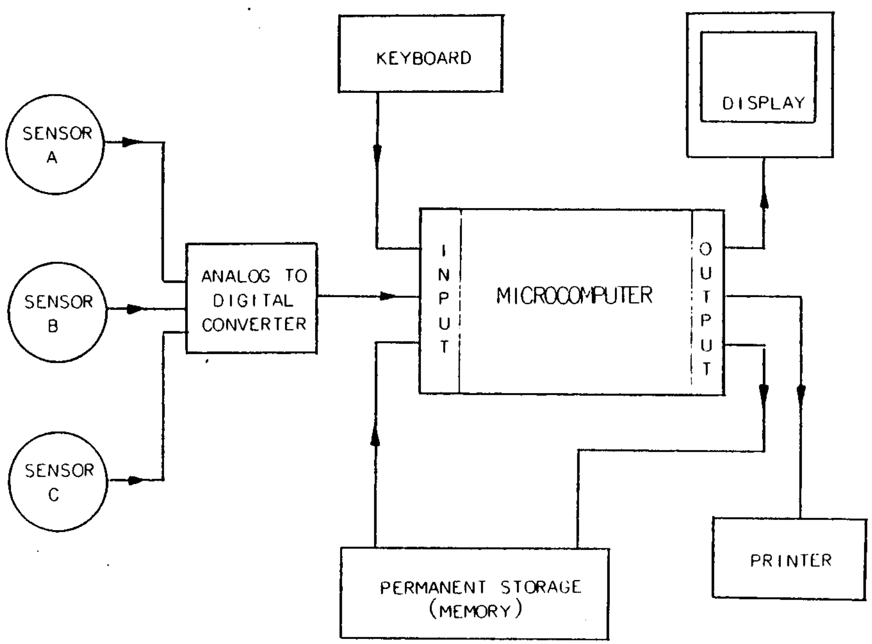

Figure 3

The inputs for sensors A, B, and C could be taken from the outputs of almost any type of indicating device. Log entries quite often are acquired from meters or other sort of electrically driven indicator. Sensors transform the magnitude of a physical quanitity into a precise electrical signal, which typically causes a meter to deflect in proportion to the magnitude of the quantity. This type of response is called analog. With a further conversion, the same signal that drives the meter or a digital readout could be utilized by a data logging computer.

Before speaking any further on Figure 3, let's pause to differentiate between the terms analog and digital for it is this distinction that separates general purpose keyboard entry computer systems from the automatic type we are discussing. Microcomputers operate on what is known as the digital principal. A digit is a number, more specifically an integer, and even more precisely, at least to man, an integer between zero and nine. All other numbers are combinations of these ten basic digits. The computer can understand only two digits, however, zero and one. The computer's two digit way of evaluating numbers is called binary, and like the ten digit decimal system, larger numbers are constructed with combinations of the basic digits. It is this restricted number system is what allows computers to be the speedy and precise machines they are, the reason for which is beyond the scope of this paper.

General purpose keyboard entry computer systems, such as those serving the functions illustrated under 'Administrative Functions' in Figure 1 rely wholly on the computer's intrinsic ability to perform from digital information. A 'smart meter' computer system must be connected with sensors and therefore an additional requirement is introduced. As already mentioned, sensing and monitoring devices typically provide an electrical signal proportional to the measured quantity, but the computer can only utilize digitally expressed values. As a result, a method of converting the analog monitoring signal to a representative digital value is necessary.

It is the responsibility of the 'smart meter' manufacturer to see that the computer is able to translate real world quantities into expressions acceptable for its operation. The general purpose computer system does not mandate this requirement for it does not perform in a fully automatic mode, but on information entered by the operator. A 'smart meter' system is designed to automatically record information, thus, that information must be in suitable form.

This form change is the function of the Analog to Digital Converter in Figure 3. It can be thought of as functioning similarly to the meter. The meter converts an electronic signal, incomprehensible to a human, to a numerical value indicative of the measured quanitity. The same is true for the Analog to Digital converter; it converts the same signal to a number the computer can utilize in its operations. In general, the term 'interface' is used to describe the requirements of interconnecting the computer with various input and output operating devices.

At this point, the computer has access to the data it needs to keep a log in the same way that meters give the watchstander access to the data for a log. Keeping a log requires that the indicator readings are recorded in an organized fashion at the specified times. The watchstander checks the reading and then enters in his log book the quantities to be recorded at that time. The computer has its own method of organizing data and keeping time.

Below the Microcomputer in Figure 3 is a box labeled 'Permanent Storage'. The arrowheads in the figure indicate that the permanent storage, or memory as it is commonly called, can feed the computer with information or that the computer can feed information to the memory. Appropriately, this is called Read/Write, Read meaning that the computer 'reads' the information stored in the memory, Write indicating that the computer 'writes' information down in the memory. Data logging concerns both of these functions, so lets take a moment to distinguish between Read and Write.

Before the computer can automatically begin to log data, it must be told how to do it. A computer can only perform as instructed. The most advanced computers in the world have absolutely no intelligence, no insight, no motivation. The same is true for the microcomputer: it cannot think. A pocket calculator will not divide 9 by 5 for you unless you first turn it on, hit the '9' key, the '/' key, the '5' key, and then the '=' key, precisely in that order. This cause and effect relationship holds for all computers. A computer will do only what it is told to do in the order in which it is told.

Today, there are several avenues open to one wishing to put a computer to work. Not too long ago, to make a computer perform a task, there was only one approach. One had to acquire a working knowledge of computer programming, which can be thought of as learning a second, precisely defined language. To instruct a computer on how to perform, the computer has to be addressed in its own language, it does not have the slightest capacity for yours.

These days, not having an inclination to learn how to instruct or program a computer does not leave one without options. Perhaps more than anything else, the mircocomputer owes its increasing popularity to the introduction of prepackaged and custom developed programs. Software is the common designation for the instructions or program a computer needs to operate in a desired way, whereas hardware is the tangible parts of the system, like the various blocks in Figure 3.

With prepackaged software or software developed by an outside source to to meet specific requirements, a computer user need only load the program into the computer and the computer will be ready to go. Currently, most commercial microcomputer software is available on what are known as 'floppy disks' These look like undersized phonograph records, permanently enclosed in the dust cover. Instead of grooved vinyl, the disk is composed of magnetic material similar to recording tape. They are inserted into a slot in the Permanent Storage of Figure 3, and when the computer is turned on, right away it Reads the program from the disk. The computer is then ready perform as instructed.

Since it is not necessary that we know how to program, let's continue with the data logging software loaded into the system and the system ready to perform. Figure 2 outlined the basic steps by which a log is kept manually. Since then we have added another step necessitated by the computer: that of converting the sensor signal to a digital expression. Therefore, we will change the procedure accordingly:

1. CONVERT sensor output to an equivilent digital expression.
2. READ digitally converted value.
3. WRITE value indicated into the appropriate logbook record location.
4. WAIT the specified time interval.
5. THEN GO TO step 1.

Figure 4

The capitalized words are the key functions. Exactly how the computer will handle this task is not our concern, but a simplified explanation is in order. We have three sensors that we want the computer to log for us. Let's say policy dicates that Sensor A be logged each hour on the hour, Sensor B logged every two hours on the hour, and that Sensor C be logged once every four hours on the hour.

The microcomputer will need to be told of this course of action, so the next order of business is to format the log. This is done at the home office. Formatting at the home office accomplishes the following:

1. Establishes the plan for keeping the log acccording to home office policy, i.e, when to record what.
2. Sets up the form of the completed log.
3. Assures the home office that the log will be maintained in an accurate and timely manner. After the log has been formatted, forwarded to the ship and put on line, all entries will be made automatically. The watchstander may be given access to the log, but the log is kept by the computer, indelibly and permanently.

Formatting is not difficult. The home office operator is led through the procedure step by step. Going back to Figure 3, there is a box labeled Keyboard and a box labeled Display. A typical microcomputer keyboard is almost identical to an electric typewriter keyboard and is the means through which the operator communicates with the computer. The Display is similar to a small portable television. According to the program previously loaded, the display screen will allow the computer to communicate with the operator. Note that the communication we are speaking of is actually only the appearance of a conversation. Each piece of information that shows up on the screen is there because the programmer who wrote the software said for it to be there. When the operator creating the format answers a prompt from the Display, he must do so in the way prescribed on the screen or in the operator's manual, otherwise the results will be something other than desired.

Here is a sample of the intial dialogue between the format creator and the computer:

Computer:	Welcome to Data Log - Press RETURN key to begin. Note: All entries are made by pressing RETURN after answering prompt.
Operator:	Presses carriage RETURN on keyboard.
Computer:	Enter number of quantities to be logged.
Operator:	Presses '3' key, then RETURN.
Computer:	Enter in decimal hours the time interval between log entries for Sensor A.
Operator:	Presses '1' key, then carriage RETURN
Computer:	Enter time in military style for initial entry.
Operator:	08:00, carriage RETURN
Computer:	Sensor A will be logged every 1 hour, beginning at 08:00. If this is correct, press RETURN. If something is incorrect, press X and RETURN.

Figure 5

The last statement gives the operator a chance to correct a possible mistake made in any of the entries. If the operator entered 'X', he would be

automatically taken back through the procedure again. The computer will ask the same questions for sensors B and C and the correct answers must be provided. After it is ascertained that all entries made are correct, the log is formatted. A final command will issue a code that disallows reformatting the instructions without proper authorization.

The point to be made here is that no one from the home office need have a Ph.D in computer science in order to format the log. Once formatted, the disk containing the log is forwared to the ship and the 'smart meter' is put on line. Assuming that the senors have been correctly interfaced, the on-board computer will begin automatically maintaining the log when it is turned on and instructed to start. A cursory examination of what is going on inside the computer aboard ship will provide us with ample insight to the process without getting bogged down with a myriad of acronyms and technical nomenclature.

First, let's say the shipside computer was put on-line at 7:46. Since the initial entry isn't to be made until 08:00, we are starting out at step 4, from Figure 4. Scrutinizing Figure 4, we might notice that the entire data logging process goes from step 1 through step 5, and then loops back to step 1 again. The computer idles until 08:00 when the program instructs the computer to convert the analog sensor signals of A, B, and C to equivilent digital expressions, Read the digital values, and then Write these values into the 'logbook'. The logbook at this point is contained within the computer's memory and is not a physical enity in itself. The 08:00 log entries may be displyed on the screen if so desired. Before examining the logbook within the computer's memory, let's follow the computer through a four hour cycle.

Until 09:00 the computer will sit counting the minutes until the next entry is to be made. At 09:00 the computer is instructed to Read Sensor A and Write the value into the log. Our initial dialogue told the computer to record only Sensor A, every hour. The computer now passes the time until 10:00 at which time it records the value at both Sensors A and B. At 11:00, the computer records only Sensor A again. After counting away another hour, at 12:00, we are at the beginning of the cycle and the computer converts and Reads all three sensors and Writes the values into the log. The cycle will repeat itself continuously or until told to stop.

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Time of Entry	Sensor A	Sensor B	Sensor C
08:00	10	25	150
09:00	12	--	---
10:00	10	25	---
11:00	10	--	---
12:00	11	20	175

Figure 6

Figure 6 is an example of what might appear on the display at 12:00. This is also similar to how the data is actually contained within the computer's memory and how it will be recorded on a data diskette for permanent storage. For reasons that will become apparent in the second part of this discussion, a matrix of data like that in Figure 6 is a convenient method of organizing data. It even coincides with the typical marine log format. The software that got the system started instructed the computer to collect and display the data in this fashion. Each time the microcomputer Reads the sensors, in addition to updating the log on the display, it records the reading on the data disk.

The data disk then becomes a permanent record of the log. A marine log contained on a disk has inherent advantages.

A typical floppy disk is small, 5-1/4" x 5-1/4" x approximately 1/16" thick, yet it may store between 100,000 to 200,000 characters of information, a character being one letter or number. This equates to about 40 full size typed pages. The great capacity of a disk with respect to its size allow for convenient storage of the log while faciliting transportation of logs forwarded to the home office. Specific areas of interest, say a several hour time period or just one entry within the log may be located quickly, as required. A disk may be copied in seconds for mutiple distribution, if necessary, but a disk cannot be used by parties not having access to the appropriate software.

The last item to speak of in Figure 3 is the box labeled 'Printer'. It is all well and good to be able to assess information on a display screen, however, quite often it is desirable to have a printed copy of the log. By adding a printer to the system it is possible to reproduce the information contained in the log on paper. The end result is a neatly printed log, equivilent to or superior than a log that has been maintained manually. The Printer may be located on board ship or at the home office, as necessity dictates.

In general, the principles of automatic data logging may be applied to logkeeping situations where the log entries are made from electrical indicating equipment. A specific application currently finding acceptance is the collection of data pertaining to optimum trim analysis.[2] The automatic logging of other quantities such as speed through water, shaft horsepower, shaft

2 Bertram, K. M., et al., page 12.

revolutions per minute, fuel flow, manifold temperatures, lubrication line pressures, and others are also intrinsically suited to 'smart meter' systems.[3]

In the preceding description of automatic microcomputer data logging we did not interest ourselves with a specific real life example of this function. Instead, we attempted to acquire a conceptual overview of the requirements of such a system and to develop a fundemental understanding of the relationship between the different aspects, both hardware and software, home office and watchstander. Computer jargon was avoided wherever possible. We purposely did not examine at length the complex processes going on inside any of the components because it is not essential that a microcomputer user understand digital electronics and computer programming in order to benefit from the same. The microcomputer industy's ultimate design goal has been to make these machines 'user friendly', meaning able to be effectively operated by virtually anyone.

The same is true for the prepackaged and custom developed software we spoke of. Reputable software developers generally spend much effort coming up with programming that incorporates messages and prompts on the display screen that explain what is required to successfully operate the program. In the next section we will incorporate automatic data logging into a complex microcomputer function for determing vessel effiency on the basis of engineering data, mangagement strategy, and other dynamic parameters. Computerized data logging provides the opportunity to improve upon an established marine practice; the following topic, continuously updated, on-board vessel efficiency analysis has been made feasible only by the microcomputer and could likely become a standard in the near future.

3 Perry, M., page 20.

MOST PROFITABLE SPEED DETERMINATION - A Target Speed

Computerized data logging demonstrated what might be termed a limited application of an on-board microcomputer system. The remainder of this paper will comptemplate a microcomputer system tackling a dynamic and complex calculation on the basis of technical paramters, engine room data, and management's role in determining what voyage speed will maximize the profit for a voyage. Again, the function is complex, the discussion is not. We will begin by explaining how a microcomputer may be made to understand and abide by management policy, then proceed with a discussion of the factors contributing to the calculation of optimum speed. The biggest problem in determining optimum speed is the conflicting nature of the influencing factors. By optimum speed we mean the speed that will allow realization of the greatest profit for the vessel, the vessel being the profit/loss center.

The factors affecting optimum speed are many, some of which are the responsibility of engineering, while others are under the jurisdiction of management. It so happens that the goals of management are generally circumscribed by engineering parameters.

> A general rule in this business is that billing is maximized by providing the greatest serviceability while profit is enhanced by developing the least cost.

In the maritime industry, serviceability increases as more voyages are completed. Fuel constraints tend to financially limit greater serviceability by increasing costs. Therefore, we must develop a method of determining the point of balance where increased costs outweigh the benefits of increased serviceability.

The microcomputer provides the potential to do just this. Keep in mind that we are not speaking of a computer operator sitting down at a terminal, entering a few numbers, and producing an approximation of optimum speed based on sea trial data, nomographs, and the like. We would like to determine optimum speed based on actual, up to the minute performance data and the way in which the same affects and is affected by management voyage data and policy. As a means towards this end, in order to compile accurate and timely performance data we will have to utilize the 'smart meter' type automatic microcomputer system.

It can be difficult to see how a computer might be able to incorporate a policy or objective of management in the course of making a decision. An operational policy is typically based on quanitative limits which can be expressed numerically. As a simple example, suppose a policy exists requiring that one of a fleet shall not motor at greater than 25,000 shaft horsepower for greater than 4 hours over any 2 week period without the home office receiving notification of the event. The data logging system previous discussed could be very easily instructed to monitor the SHP totalizer readings and whenever it is discovered that the ship has operated at excessive SHP, automatically issue a summary report to be forwarded to the home office for action. This is a simple cause and effect procedure where the computer incorporates a policy and responds accordingly.

The determination of optimum speed is not as simple because it is based on not a single policy, but on a number of conflicting policies. It has in common with the previous example, however, that the policies can be expressed numerically and thus be assessed by the computer. The policies in conflict are those designed to maintain maximum serviceability and those structured to

incur the least opertaing cost. Let's explore the elements of these two policies so that we might fully understand why they are in opposition.

It is universally accepted that 'slow steaming' requires less propulsion power, which in turn reduces fuel consumption and therefore the expenditure for fuel. Ideally at least, making a voyage a the slowest practical speed will incur the lowest cost for fuel for that voyage. For the ideal model, the relationship between propulsion power (which equates to fuel consumption) and speed is: the power required to steam at a certain speed is roughly proportional to that speed cubed ($P \sim s^3$). Bear in mind that we are making a case for the the effect of speed on fuel cost only. To illustrate how voyaging at increasing lesser speeds can affect fuel consumtion, consider the following simplified example.

First, we will express the approximate relationship between power and speed as the equality function:

$$P = ks^3,$$

where 's' is equal to the speed of the vessel, 'P' is equal to the power (and as a result, fuel consumption) required to maintain speed 's', and 'k' is the constant of proportionality, used to scale the formula to individual situations. In the interest of simplicity, we will let k = 1, because differing values of 'k' do not affect the point to be made here.

The following table was developed from the above equation and shows the relative amount of fuel, in units fuel required to power our hypothetical ideal ship at various speeds ranging from 5 to 25 knots, if motoring at one knot consumes one unit of fuel. The third column indicates the percent decrease in fuel consumption with respect to the speed from the row above, while the fourth column represents the overall percent decrease in fuel consumption for that speed when compared to fuel consumption at 25 knots. The last column will be explained momentarily.

SPEED (kts)	FUEL CONSUMPTION (units fuel)	%/STEP DECREASE	OVERALL % DECREASE	PROFIT ($)
25	15,625	---	---	-56,300
20	8,000	48.8	48.8	+20,000
18	5,832	27.1	62.7	+41,700
16	4,096	29.8	73.8	+59,000
14	2,744	33.0	82.4	+72,600
12	1,728	37.0	88.9	+82,700
10	1,000	42.1	93.6	+90,000
5	125	87.5	99.2	+98,800

Figure 7

This table exemplifies the non-linearity of fuel consumption versus speed characteristics. A reduction of speed from 25 to 20 knots is only a differece in speed of 20%, yet only half as much fuel is required to propel the ship at the lower speed. A speed of 12 knots is approximately half of 25 knots, however, a fuel savings of close to 90% is realized. The %/STEP DECREASE column shows that even a small reduction in speed, say from 18 knots to 16 knots, effects a substantial decrease in fuel consumption, 29.8%. Notice that each 2 knot decrease in speed causes a greater decrease than the row above.

The hypothetical 'units fuel' could be gallons, barrels, pounds, or whatever unit is convenient. In any case, this is the amount of fuel required to propel the ship from port A to port B at the speed listed in the first column. The column labeled PROFIT is based on the total billings for this voyage being 100,000 dollars and a cost for fuel of ten dollars per unit fuel. Remembering that the only consideration here is fuel consumption and not other factors that will be introduced in a short time, it can be concluded that, in this case at least, billings minus fuel expenditure will equal the profit for the voyage at that speed.

For our ideal ship, viewed on the basis of fuel cost, we can perceive that the most economical speed is the lowest practical speed that can be maintained throughout the voyage guarantying on time arrival. Stated another way, if it is required that a vessel make a certain voyage in a specified amount of time, the optimum speed for that voyage is the speed that will get the vessel from port to port in that amount of time.

It should be remembered that when fuel expenditure is reduced, we sacrifice serviceability because by maintaining slower voyaging speeds, each voyage takes longer to complete. As a result, over an equal period of time, a year for example, if we had voyaged at higher speeds we would have been able to complete more voyages, each being a source of income. This becomes especially notable for high income voyages. There is a point where increased income over a period of time makes it more profitable to increase speed. The fuel bill will be greater, however, not so great as to negate the increase in income from transporting a higher dollar value of cargo overall.

With this in mind, let's take a look at profits with respect to voyage time. Scheduling is a management function and we will see that the amount of time it takes to complete a voyage influences the most economical voyage speed in several ways. That the following example is hypothetical is quite apparent. The figures chosen were simplified to make a point and do not represent typical costs for any type of vessel. For this part of the discussion we will disregard propulsion plant fuel costs all together.

There are certain expenditures required to operate a vessel which are independent of propulsion fuel costs. Among them are overhead expenses such as loan payments, insurance, taxes, registration fees, the cost of home office support, yearly maintenance costs, salaries, etc. These are designated fixed costs because they are relatively constant. Another fixed expense is that of hotel services aboard ship. It is defined as a constant expenditure required to support the vessel whether its speed is zero or full ahead. Auxiliary machinery, electrical needs, heat, etc., all require power of some sort. This energy is likely supplied by the conversion of fuel, but has nothing to do with the fuel used to propel the ship.

The sum of these two costs can be thought of as heing fixed for a voyage that will be made over a set period. For instance, the expenditure for fixed costs during a one month voyage would be equal to the yearly fixed cost sum divided by twelve. In that we are attempting to determine the effect of fixed costs on a per voyage basis and eventually wish to include the influence of speed variation, it might be more convenient to consider fixed costs on a per day basis, or the yearly expenditure divided by 365.

Let's say we are planning a voyage from port A to port B which is 4,800 nautical miles distant. To make our point, we will assume that fuel costs are not a consideration. Billings will contribute for a gross income of 100,000

dollars for this voyage. It has been calculated that the fixed costs for our vessel amount to 3,500 dollars per day. Immediately, we can see that each day spent on this voyage will offset the revenue by 3,500 dollars. To maximize profit, we would want to make the voyage in as fews days as possible. We might use the following formula to determine the effect of different speeds on profit:

$$\text{Profit} = \text{Total Revenue} - \text{Voyage Time} \times \text{Fixed Costs/day}$$

Using this equation we could conceive the table of Figure 8.

SPEED (kts)	VOYAGE TIME (Days)	PROFIT ($)
5	40	-40,000
10	20	+30,000
15	13.3	+53,330
20	10	+65,000
25	8	+72,000

Figure 8

This table confirms our thought that profit increases with an increase in speed because the higher the speed, the less days spent on the voyage. At 5 knots, fixed costs are greater than the total billings, causing us to operate at a loss of 40,000 dollars. If the ship can sail at 25 knots, the voyage will take only eight days, which when multiplied by the fixed cost expenditure of 3,500 dollars per day and subtracted from the revenue total, produces a profit of 72,000 dollars for the voyage. Under these conditions it makes good sense to complete the voyage as swiftly as possible. Not only do we maximize our profit for this particular voyage, but over the course of a year, if we followed this rule on all voyages, we could make more voyages.

Unfortunately, fuel costs are a most pressing concern for any voyage and we are therefore confronted with a dilemma. On the one hand, we have discovered that in making the voyage in the shortest possible time, we minimize profit offset due to fixed costs. However, to make the voyage quickly demands that we increase speed and we know that fuel costs escalate according to our voyage speed cubed. It would be helpful to us if we could somehow combine these two trends and determine the one speed that will produce the greatest profit for a voyage, while proportionally weighing the variables involved.

So far we have said that the formula relating profit and voyage time was valid only if fuel costs had no bearing in the matter. We also said that fuel costs are proportional to the voyage speed cubed, if nothing else is to be taken into account. Let's now consolidate the characteristics of profit versus speed due to fuel expenditure and the effects on profit versus speed on account of fixed costs:

$$\frac{\text{Profit}}{\text{voyage}} = \frac{\text{Revenue}}{\text{voyage}} - \frac{\text{Fixed Costs}}{\text{voyage}} - \frac{\text{Fuel Expenditure}}{\text{voyage}}$$

In words this says: the amount of profit for a voyage is equal to the total income produced by the voyage, minus the fixed cost for the voyage, minus the cost for fuel consumed to complete the voyage.

Let's examine the three variables in this formula. Although the billings for a particular voyage won't change according to speed, the faster the voyage is completed, the sooner a new one can be begun. At present, however, we will consider the revenue per voyage equal to the total billings of the voyage. As already pointed out, both the fixed cost and fuel expenditure variables are functions of speed, though opposing in their effect on profit. A greater speed is in the interest of negating the influence of fixed costs, while a slower speed will minimize fuel expenditure.

As we did previously for the fuel consumption formula and profit versus fixed costs formula, we will now do for this equation, that is, determine the effect of voyage speed on on profit, taking into account the contrasting significance of each. In demonstrating the effect of of speed on fuel consumption, our table contained a column labeled 'FUEL CONSUMPTION' in units fuel. Let us now consider that the quantity listed in each row for a given speed is the number of units fuel necessary to complete the 4,800 mile voyage of the previous example, and that the fuel must be purchased at ten dollars per unit fuel. The other quantities remain as in the example for the 4,800 mile voyage, that is: Total billings = 100,000 dollars; and fixed cost = 3,500 dollars a day. Testing speeds between 5 and 25 knots would provide us with the profit versus speed comparison shown in Figure 7.

SPEED (kts)	PROFIT ($)
5	-41,300
6	-18,800
7	- 3,500
8	+ 7,400
9	+15,000
10	+20,000
11	+23,100
12	+24,400
13	+24,200
14	+19,600
15	+15,300
16	+ 9,800
17	+ 2,800
18	- 5,700
19	-15,000
20	26,000
21	38,300
22	52,100
23	-67,400
24	-67,400
25	-84,300

Figure 9

This table allows one to quickly grasp the effect voyage speeds between 5 and 25 knots will have on the profit for this hypothetical voyage. Since negative profit is a loss, it is apparent that only speeds between 8 and 18 knots will be profit generating. The most profitable speed will be 12 knots, with the profit margin decreasing around this point towards both extremes. For speeds less than 12 knots, savings derived from reduced fuel consumption are nullified by the increased influence of fixed costs. At speeds greater than 12 knots, fuel expenditure rises, outweighing the decreased effect of fixed costs.

We have spent time reviewing what is involved in determing optimum speed versus profit in order that we might better understand why, in the absence of an on-board 'smart meter' type microcomputer system, such an advanced determination is difficult. If it doesn't seem that a computer is required for this, remember that the example has been developed only in the most simple terms. Revenue was considered as a fixed quantity, even though we said earlier that revenue is actually a function of speed. Fixed costs were treated as having no relationship to fuel costs when in actuality the hotel services cost would most likely show on the fuel bill. And, if we want to apply the system in determining what the optimum speed for a voyage will be, there will have to be a means for calculating prior to the voyage, fuel consumption characteristics at various speeds based actual performance characteristics of the vessel - not theoretical or sea trial data. Only after acquiring accurate preliminary information can we go ahead and have the computer weigh the vacillating effects of each quantity and provide us with a veritable optimum speed forecast.

As we now have a basic understanding of what must be accomplished if we are to determine the speed which will optimize profit for a voyage, let's complete our discussion with a brief rundown of how an actual 'smart meter' type microcomputer system might go about performing the task. Instead of belaboring the point with a detailed dissection, we will discuss the Most Profitable Speed Determination system from the standpoint of expedience and results.

Since this is an advanced huristic analysis based on both vessel performance data and the objectives and policy of management, it requires a source of the pertinent information from each. The concept of automatic data logging can provide us with the technical data needed, while financial and statistical data for the voyage shall come from the home office:

Technical Data	Management Data
Ship's characteristics for fuel consuption vs. speed	Fixed operating costs a) Capital expenditures b) Hotel services cost
	Voyage Billings
	Unit Fuel Cost
	Voyage Distance
	Currents

The first order of business is supplying the software instructions with the necessary information from the home office. As was shown for the automatic data logger, we would load the software disk into the system's memory and a well programmed system would lead the home office operator through a series a questions, the answers to which will provide the system with the financial data requirements. At this point, the system is ready to begin automatic operation once the 'smart meter' microcomputer is put on line.

To determine the vessel's characteristics for fuel consumption with respect to speed, the microcomputer will be interfaced through the analog-to-dgital section of the system to the ship's sensors which will provide the necessary information, i.e., a shaft horsepower meter to supply data on power, a fuel flow indicator to indicate fuel consumption, and a speed through water indicator for vessel speed. The exact operational means or particular device indicating these quantities is not critical to our discussion as long as it is remembered that the results of the final optimum speed determination can be no more faithful than the precision of the sensors. The motto of those well schooled in computers is:

'Garbage in - Garbage out',

meaning that if the data used by a computer is incorrect, the final result will be erroneous also. Since we are attempting to eliminate the faults of typical sea trial/nomograph vessel performance calculations by arriving at the actual vessel performance for the ship in question, it behooves us to provide the microcomputer with exact data.

The system will 'learn' the vessel's performance characteristics during the initial hours of the voyage. At set intervals, the automatic data logger will record shaft horsepower, fuel consumption rates, speed through water, etc. In doing so, the microcomputer determines and records the propulsion power required to motor across the range of possible speeds (Figure 10). Because this data is collected during actual performance, it includes the effects of variables such as plant efficiency, hull condition, propeller, trim and loading. As a result, the characteristics reflect the amount of power required to propel the vessel at varying speeds according to the conditions of the present voyage. This is not an estimation, but a measured performance analysis.

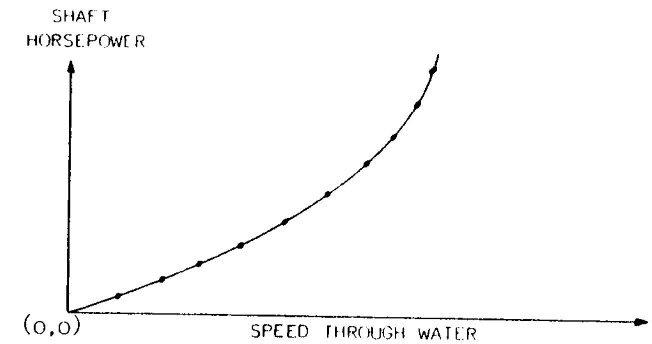


Figure 10

Having learned these characteristics, the microcomputer is able to derive a mathematical function or formula similar to the $P = ks^3$ equation of which we spoke. Basically, the computer is solving for the value of k, which is unique to each vessel and the vessel's present condition. The graphical presentation included here illustrates the major operations performed by the microcomputer, while it is determining the optimum voyage speed.

From the fuel flow data recorded by the automatic data logger, the microcomputer relates fuel consumption to speed. It now has information on the actual fuel consumption rate for various speeds.

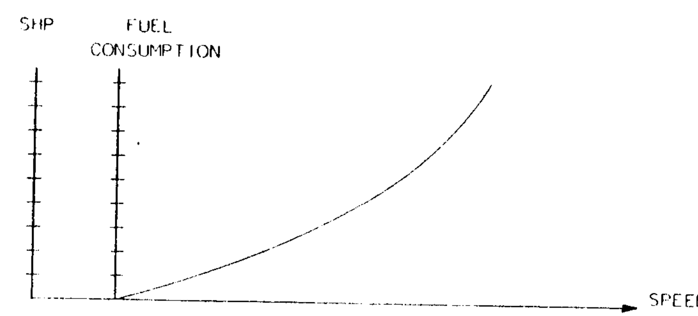


Figure 11

On the basis of cost per unit fuel and other information such as the voyage distance and anticipated currents, the microcomputer calculates how much fuel will cost to complete the voyage at various speeds.

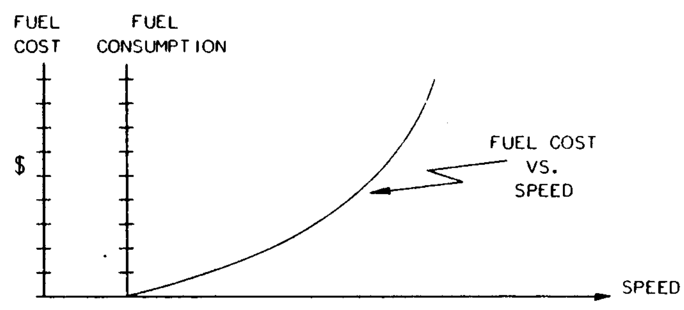


Figure 12

There is no fuel cost when speed equals zero, however, fixed costs must be met regardless of speed. The microcomputer adds the fixed costs to the variable fuel costs across the range of possible speeds.

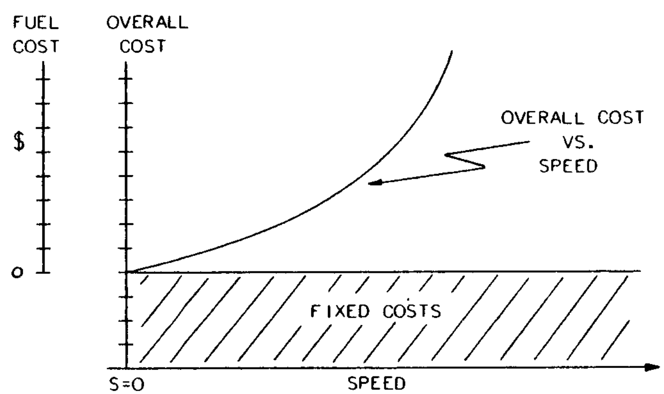


Figure 13

Billings are introduced as a function of speed. This is due to the aforementioned consideration that even though billings are fixed per voyage, as speed increases so does serviceablity and the potential to increase income over a greater time period.

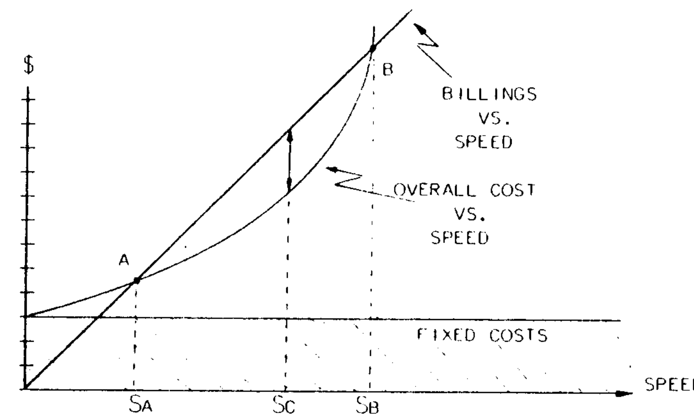


Figure 14

The curves intersect at the break-even speeds, points A and B. Speeds below S_A or above S_B are non-profitable and increasingly loss incurring. The greatest profit will occur at the speed between S_A and S_B, where the distance between the curves is greatest (profit is equal to the difference between billings and overall costs). Speed C is the most profitable speed. Profit decreases from S_C towards both S_A and S_B.

The microcomputer has generated the analysis in the above figure and retained it in its memory. The graph shows what has been accomplished in a functional sense. The computer has not actually produced the graph; the points represented along the curves have been stored in large matrices within the computer's memory. An estimated time of arrival (ETA) is calculated for each speed and added to the appropriate matrix location. Viewing the matrices would not be a convenient method of analyzing the information so the data is automatically sorted and rearranged. For the sake of clarity, only essential information is included in the final process.

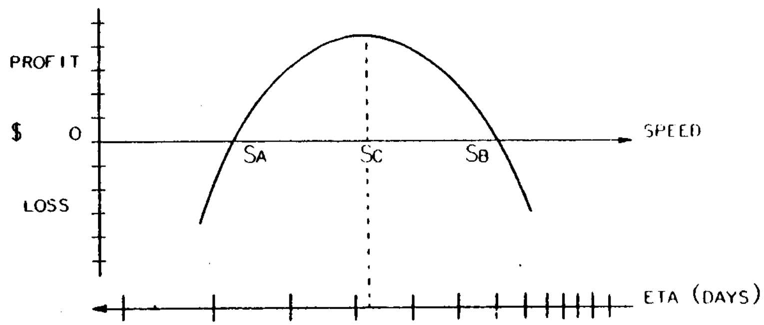
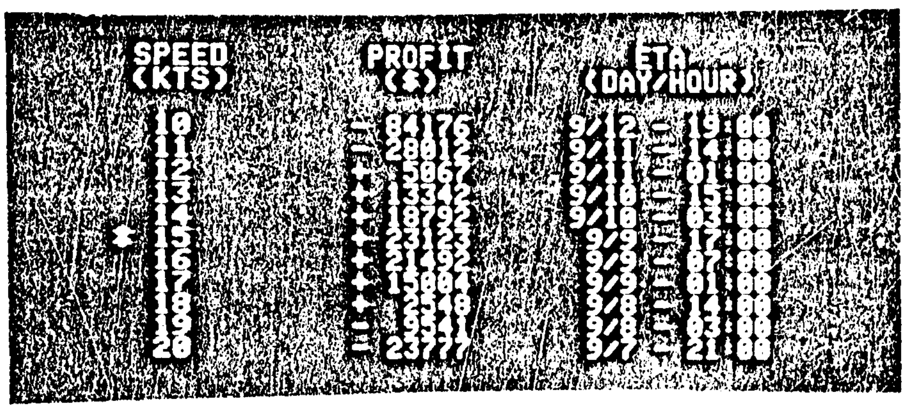


Figure 15

A table, similar to the following, is constructed by the microcomputer and shown on the Display screen.



	SPEED (KTS)	PROFIT ($)	ETA (DAY/HOUR)
	10	- 84176	9/12 19:00
	11	- 28012	9/11 14:00
	12	+ 5067	9/11 01:00
	13	+ 13342	9/10 15:00
	14	+ 18792	9/10 03:00
*	15	+ 23123	9/9 17:00
	16	+ 21492	9/9 07:00
	17	+ 15004	9/9 01:00
	18	+ 2548	9/8 14:00
	19	- 9541	9/8 03:00
	20	- 23777	9/7 21:00

Figure 16

The sample information appearing on the Display in Figure 16 depicts the calculated profit for the voyage at the motoring speeds of the first column. The column labled ETA is the day and hour the ship will arrive at the final destination if the voyage is completed at the speed in the first column. This information is compiled and computed in the early hours of the voyage so that decisions may be made as to whether or not the astericked 'Target Speed' coincides with scheduling demands, tides at the time of arrival, berth availability, in-port time costs, and other mercurial factors that might offset profit at the 'Target Speed'.

Supposing completing the voyage at the 'Target Speed' would cause the vessel to arrive at port at an unfavorable time, the voyage speed could be adjusted for a more desirable arrival time according to the PROFIT and ETA columns. For instance, if the 'Target Speed' would make for a late arrival and subsequent late fee, the size of the fee could be weighed against the diminishing profits at higher speeds. As another example, if tides at estimated arrival time for the 'Target Speed' would not allow berthing until the following day, it could be decided whether it would be more profitable to speed up to beat the tides or slow down at the expense of another day at sea.

CONCLUSION

The optimization of a vessel's speed with respect to profit for a voyage is a complex task requiring the precise mathematical manipulation of a large number of quantities and the skillful balancing of conflicting objectives. It is a feat naturally tailored to present microcomputer technology. 'Smart meter' type microcomputer systems, with their ability to transform real world measurements into the language of the microcomputer, can provide vessel operators with new insight and a well developed means of maximizing profits.

With fuel costs generally amounting to better than fifty percent of overall operating costs, vessel performance can not be ignored.[4] As vessel performance deteriorates with time, the optimum engineering speed determined during sea trials is an inadequate indicator of vessel efficiency some time after the trials are conducted. Optimum speed is based not only on vessel performance, but conditions that differ from voyage to voyage. Because of the great number of continuously changing parameters affecting the optimum voyaging speed, the microcomputer is practically a necessity to the operator who wishes to increase profits by means of speed variation.

Although a microcomputer system is a complex piece of machinery, those who design such equipment do so with a basic premise: to make them easy to operate by the non-expert. In this age of specialization, it is impossible to be knowledgeable in all aspects of the rapidly advancing technologies. Few people can explain the electro-mechanics of a telephone, the telemetrics of radio and television transmission, the various interactions within an internal combustion engine, or any of the ever increasing multitude of devices understood by an esoteric handful, but taken for granted by the many beneficiaries.

The 'smart meter' type microcomputer system functions automatically once it has been formatted at the home office and put on-line aboard ship. The format

4 Buxton, Dr. I. L., et al., page 9.1.

creator does not need to know a single thing about micro-electonics or programming in order to set up the system according to particular home office requirements. The same is true for the shipside operator. It is not necessary that he be a computer technician, or that he be aware of the decisions behind the computer generated profit/loss analysis being performed aboard the vessel.

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