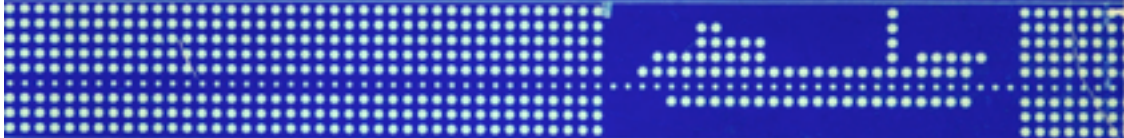


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A MODULAR Integrated Bridge System (IBS)

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The incorporation of computers in modern shipboard automation systems is now an accepted practice. The minicomputer, in particular, has become a useful tool for the rapid solution of complex ship problems. Its compact size, relatively low cost and flexible computational power accommodating high speed and large memory has permitted the design of a whole new generation of sophisticated systems intended to assist the bridge officer in the safe and economical operation of his vessel.

Computerized collision avoidance systems have been available for use on ocean going vessels for several years with over 500 now installed and in use at sea. Today additional applications of computers for bridge use include automatic position keeping and anti-stranding, improved automatic steering control, loading and discharge calculations, hull stress and trim analysis, and other functions normally associated with deck officer responsibility.

Inevitably, the demands of the industry and the technical approach of various suppliers have led to "integrated bridge systems" essentially combining all or most of the above functions. Various concepts affecting the basic design of such systems have created significant products differentiation.

This paper will discuss AUTO-MATE, a practical integrated bridge system which makes maximum use of computer technology and state-of-the-art electronics, yet offers an "owners oriented," modular building block approach in which only those functions desired by the buyer are included while retaining the ability to add other functions later without costly obsolescence. The system is also discussed from the viewpoint of technical considerations and usage and the practical results of the design in meeting the needs of the ship-owner.

INTRODUCTION

The staggering impact of worldwide inflation on ship repair costs and the alarming increase of ship losses, which are attributable to human error are putting a new emphasis on the use of computers to improve the performance of bridge functions. According to reports from the International Union of Marine Insurance Underwriters in Tokyo last

September, 65 to 75% of ship casualties are due to human error. Prevention committees are considering precedent making measures to reverse the trend.

The five to six times increase in fuel costs in recent years has made precision navigation and improved ship's steering control mandatory. Loading, stress and trim calculations are now recognized as suitable functions for computers to handle on-board merchant ships, and their proper execution will provide increased ship safety and an ability to carry more cargo. The important point now being recognized by ship-owners is the fact that these new integrated bridge systems can be paid for by the savings achieved from their use.

The **AUTO-MATE** modular integrated bridge system, developed and manufactured by the lotron Corporation is composed of:

- **DIGIPILOT**, automatic collision avoidance equipment;
- **DIGIDATA**, a continuous situation recorder for legal and training purposes;
- **DIGINAV**, an automatic radio navigation system;
- **DIGIPILOT**, a fully adaptive autopilot.

The **AUTO-MATE** system shows both charted guidelines referenced by the coastal radio navigation systems and collision avoidance radar data in a single easily interpreted picture. This is accomplished by indicating shoal areas, traffic lanes and planned track lines as well as land outlines and own ship's projected track together with the plotted tracks of up to 40 other ships shown simultaneously on the **DIGIPILOT** PPI display.

AUTO-MATE is unique in that it uses two separate, small but powerful computers, one with 32,000 word memory capacity for collision-avoidance and the other with 64,000 word capacity for navigation. The use of dual computers permits the total computational time of each to be dedicated to its specific function without resorting to time-sharing. This is particularly advantageous in restricted waters, where accidents occur and collision avoidance and anti-stranding navigation must have equal priority. Compromising the design by time sharing is both unnecessary and untenable from a legal point of view since an engineering compromise is no better than the premise, i.e., a compromise! Because the use of the separate computers allows the **AUTO-MATE** system to assume more of the collision-avoidance and navigation workload for the bridge officers, they can make better use of their skills and training by spending their time monitoring and evaluating complex situations—the functions a watch officer does best'.

When not operating in crowded waters, of course, either of the **AUTO-MATE** computers can be used for many other shipboard functions, such as DIGILOAD for cargo loading, stress and trim calculations and DIGIPAY administrative programs.

Paramount in the design of all lotron bridge system equipment are the following factors:

- Ease of use - ideally nearly "hands off" self explanatory operation to minimize human error.
- The equipment should fit into normal bridge practice to minimize training and familiarization and to facilitate acceptance in a conservative and reluctant to change industry.
- Operation should be "uncomputer like" including Read-Only-Memory for failsafe programming due to the erratic AC power available on ships.
- Stable system configuration - all options can be added to system during manufacture or once installed on the ship throughout its useful life.
- High reliability - whenever possible Mil Spec or "Mil type" components and techniques are used. All parts are 100% thermally shocked and performance tested. High temperature tests are performed on each system operating with simulated inputs for 350 hours. Each unit is subjected to simulated ship vibration.
- Ease of checkout and repair - built in fault test. Repair by replacement of modules and printed circuit boards permits repair underway. Computer diagnostic testing is used by serviceman to perform complete functional tests quickly in port.
- lotron warranty is not only on parts and *labor but free travel anywhere in the world for a year after installation. This policy affects the design and manufacturing strongly at all stages motivating the company to produce better equipment.*

COLLISION AVOIDANCE AND ANTI-STRANDING RADAR INTERPRETATION

Captain Oudet (1), perhaps clearer than any other writer, expressed the seaman's problem with radar, "What emerges with most force from several years' study of the problem is how much it is still misunderstood by many navigators. So far as they are concerned, there is no problem—an accident is something that happens to the other man. A most dangerous attitude: for the navigator today has to meet two contradictory demands, speed and safety. He must not lose a single minute unnecessarily, but he must resign himself to losing an hour if safety insists."

In clear weather, vessels take early positive action so that the other vessels will clearly see what is being done, and yet in fog, when radar is being used, skippers fail to carry out positive maneuvers which will help the other skipper to understand what is being done using an instrument far more difficult to interpret than the bridge view which is obvious at a glance. The problem with small maneuvers in an end on situation is that on radar they are often incorrectly interpreted by the other ship, and there is an even

chance of such maneuvering canceling the actions of the other vessel. When the distance separating the ships becomes small, the vessels tend to make bolder alterations of course to make up for lack of sea room, and these quite often are the results of panic just prior to a collision. Ironically, in many collisions, had both vessels maintained their original courses they would have crossed at close range or even if they had collided end on, they would have caused each other much less damage. When the vessels turn towards one another at the end of the maneuvering as they usually do, each vessel presents the other with a larger target, which increases the probability of collision and the resulting damage there from.

Oudet compares the visual versus radar encounter in terms of time consumed stating "...in clear weather five minutes are needed to recognize that there is a risk of collision and for the necessary evasive action to be carried out, whereas using radar at least twenty minutes are required to do this and to determine that the maneuver has been effective." Captain Oudet also uses radar plots in his book to illustrate the weakness of unstabilized radar in these end on encounters due to inherent bearing errors.

Unfortunately, most radar interpretation today is still performed on a head up, relative display! Of course, computer processing filters the data and actually improves on resolving this end on ambiguity at a much greater range (earlier) than is possible by plotting by the most conscientious, skilled radar observer.

Before describing **DIGILOT**'s fully automatic radar plotting in detail, it seems useful to summarize the aims of radar plotting as defined by Captain F. J. Wylie. (2)

"The general object of radar plotting is to present usefully the measured range and bearing data and time:

- to follow the movements of closing and other potentially threatening targets;
- to permit an assessment of the risk presented by each, and
- to facilitate consideration of the action most likely to reduce any significant risk of collision without increasing or creating other threats."

A potential target means a target, which poses little or no mediate danger, e.g., a ship on the bow or quarter with nearly the same course and speed, which would become a threat if she altered course or if own ship had to alter course.

The criteria, which are usually thought to be effective, are closest point of approach (CPA) and distance and time to CPA, for degree of risk, and target true course and speed, for aspect and choice of action. Assuming a multi-ship situation (though not necessarily a highly congested one) and not assuming any particular plotting system, the following sequence of actions might be followed:

- Examine and select radar echoes for tracking
- Rank selected echoes in degree of threat;
- Plot tracks of selected echoes:

(1) if relative track is plotted, note CPA distance and time to CPA, draw vector triangle to obtain true course and speed if required;

(2) if true track is plotted, note true course and speed of target and draw vector triangle to obtain CPA distance and time to CPA.

- Plan and plot maneuvering action to avoid top priority threats;
- Examine the effect of this action on lesser or potential threats;
- Watch movements of all threats while own ship's maneuver is in progress;
- Resume plot immediately after own ship completes maneuver;
- Plan return to original course or further evasive action.

It is doubtful in the general case; any of these actions could be regarded as unnecessary. They represent a considerable workload on a man plotting even in a two-threat situation and an impossible task in a multi-threat encounter where five or so echoes must be plotted. Bearing in mind that the information derived from a manual plot at each stage of the above series of actions is a few minutes out-of-date when reaching the master, the more targets plotted, the more out-of-date each item will be. For the plot to be fully effective, a continuous process of up-dating and checking, accepting new targets and dismissing past threats has to be undertaken. The conclusion must be that, with a manual plot, the more complex and critical

the situation, the less up-to-date and the less comprehensive will be the information on which the master has to base his bid for safety.

Although one might expect the object of modern radar plotting equipments to be a continuous supply of up-to-date intelligence, very few of the latest types of equipment, other than those which are fully automatic, achieve this object or even give, readily, all the information thought to be necessary.' In fact, several systems suffer significant shortcomings, while another aiming or claiming to simplify the situation by only indicating predicted danger areas to be avoided, offers only a YES/NO (risk) presentation without the necessary WHEN or WHERE.

Figure 1. DIGIPILOT and DIGINAV Consoles



DIGIPILOT, shown in Figure 1., is a self-contained fully automatic radar plotter in a waist high console which displays its information graphically on a bright PPI-type display and quantitatively on a digital data readout. **DIGIPILOT** has auto-acquisition, that is to say, it selects the echoes, which are to be plotted. The video output and antenna bearing data from the parent radar is fed into the video processor, which discriminates between ship, sized echoes and those larger than the largest ship, which are obviously land area returns. All of the shipsized echo range and bearing data is continuously fed into the computer for further processing. The computer program maintains continuous surveillance over 200 of the nearest within 17 mile maximum range, ranks them in range and selects the closest 40 for full course and speed calculations and simultaneous display.

Two manually adjustable chordal limit lines may be placed anywhere on the screen to reject any echoes whose plotting is not considered necessary by the observer, for example, one line may be placed in front of a sandy beach whose radar appearance fools an auto-acquisition system thus wasting its capacity. The other line may also be placed 2 miles astern, at right angles to own ship's track causing DIGIPILOT to plot the closest 40 targets forward of that line. This area rejection capability is extremely useful to a ship operating in crowded waters

allowing operator judgment to be introduced without the tedious echo by echo selection required in manual acquisition systems.

The course and speed data is up-dated every scan of the radar, approximately every 2-3 seconds. Thus, although a target entering the plot requires about 90 seconds to achieve its full speed vector, changes of course by an approaching target already being plotted will be shown much more quickly, in as little as 15 seconds. The currentness of the aspect shown on the display approaches real time, and gives the operator an impression of maneuver response, which is nearer to the visual case than radar. This rapid response permits DIGILOT's use in clear weather to make more quantitative, safer maneuvers earlier!

The information is presented on a 16—inch bright tube, with own ship always remaining at the center of the relative motion display. Range scales of 3, 6, 12 or 24 miles may be selected independent of the parent radar. Orientation may be "north up" or "ship's head up" and the projected position plot may be true or relative. Own ship's course is fed to the plotter from the gyro and the speed input is either taken from the ship's log, or RPM indicator or it may be entered manually. Own ship is shown as a circle in the center and the positions of the targets are also shown as small circles superimposed on their radar echoes. Land masses are shown similar to a conventional radar picture except that it is two color and brighter than normal. The green intrinsic radar picture with red vectors is easily viewed by more than one observer on a daylight bridge requiring only a sunshade to remove direct glare. If desired, the intrinsic radar picture may be turned off and the closest coastline shown as a line of bright red dots spaced 2 apart. This display can be viewed in direct sunlight.

Each target in motion will have a line (vector) extending from the circle at its present relative position in the direction of its motion. In true motion, the direction will be the true course of the target; in relative motion it will be the relative track. The length of the line will represent the distance which the vessel will run in the interval of time set on the variable future position control. This vector length is, of course, an indication of speed. In true motion own ship will have a vector along the course line, which is proportional to ship's speed. In relative motion it will not have a vector. In either case, some targets may display no vector, i.e., in true motion when they are anchored ships or fixed objects, and in relative motion when their motion is identical with that of own ship.

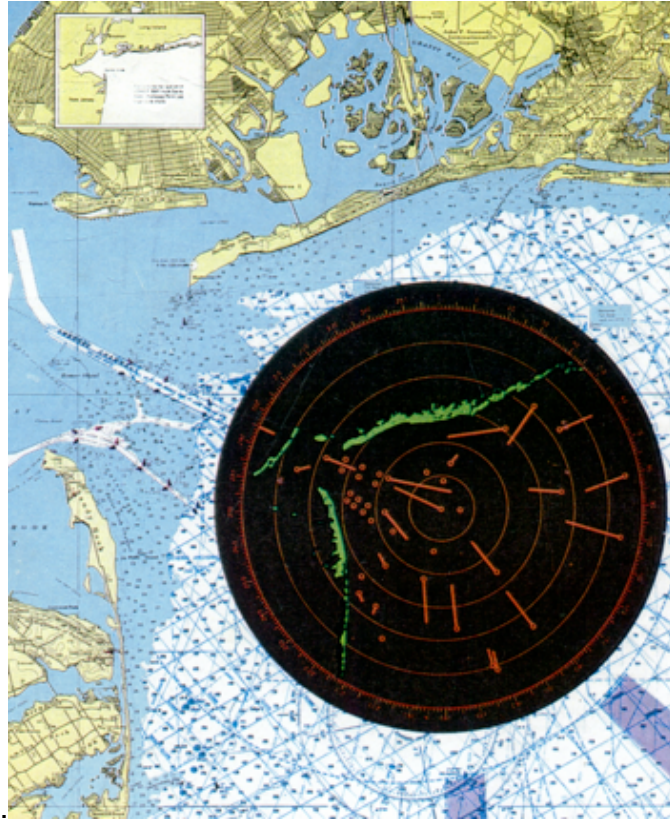


Figure 2.

Figure 2 shows the DIGIPLOT intrinsic chartlike display with own ship at the center on a north up orientation on 12-mile range (2 mile range rings). Own ship is approaching New York at 12 knots on a course of 298. True vectors are projected ahead 12 minutes. Note the buoy abeam two miles to the north and the two vessels ahead on the 4-mile range ring. One is going south with CPA of 3 miles and the other, now passing a buoy at 3.8 miles, will pass to starboard clearing own ship by 1 mile CPA in about 10 minutes.

The future position control selects time from 0 to 69 in one minute increments for projecting target motion. The vector length of all targets on the display represents the distance traveled during this interval. Obviously, adjustment of the control can be used to bring the end of the vector of a particular target to the CPA position, and the appropriate distance and time of CPA will be seen. Alternatively, readjustment of the minute control can be used to show if and when a situation may develop between two target ships, which might affect own ship's maneuvering. It also allows very rapid assessment of the degrees of threat of several other vessels, ranking them instantly when viewed on relative plot. This data is calculated every scan of the radar, so the information is really up-to-date. When own ship is maneuvering, the true or relative vectors of other ships can easily be watched to see if they are maintaining their courses and speeds during the maneuver.

On both true or relative plot, the vector display permits the observer to check up on the view from the bridge. This is particularly easy to do on a Head-up/True plot, where stationary objects are shown plotted as circles without vectors and the moving aspect of ships is easily compared with the true vectors.

Numerical Data

A "digital data read-out" is also provided, which uses a joy-stick for controlling the position on the display of a bright flashing marker used to identify the ship of interest. There is also a selector switch marked TAG or MARK, and four push button switches for selecting the desired readout data. When TAG is selected and the flashing marker is placed adjacent to a target, it will lock-on and follow. Pushing each of the four buttons calls for simultaneous display of two items of information on the "tagged" target:

- bearing and range;
- true course and speed;
- target CPA distance and time to CPA;
- own ship's true course and speed.

When MARK is selected, the flashing marker may be placed on a fixed point such as a prominent point of land, and when this has been done, continuous readout of the bearing and range will be given from own ship to the dead reckoned point.

Due to variable errors in the radar and gyro data, the direction of target vectors will vary periodically by a degree or two. Changes of course and speed by target ships show up very quickly. The quickest change is shown on the digital read-out, provided that the target of interest has been tagged. This is the surest way to monitor the movement of a particularly threatening target when, -for example, own ship is executing an evasive maneuver; a counter maneuver by the other ship can be seen immediately.

Automatic Warning Alarms

The calculated CPA's of all plotted targets are monitored continuously. The CPA distance and the warning time to CPA, which the observer desires, are set on two controls. If any target comes within these limits, the alarm will flash a red light and sound a buzzer.

' The audio alarm may be silenced for a target but another one violating the settings will cause it to sound again. Vectors of echoes triggering the alarm are displayed brighter than normal.

Trial Maneuver

A trial maneuver can be performed by setting the trial course and speed controls and then pressing and holding down the trial interrogation switch. A control also permits the maneuver to be delayed any number of minutes up to nine. Own ship's maneuvering dynamics are combined with the trial course and speed to show the resulting maneuver in true motion speeded up thirty times, thus several alternative trials may be evaluated within a minute or two. In this mode the digital read-out shows numerical results during the trial and the automatic alarm facility operates normally, monitoring the actual situation.

BENEFITS OVER RADAR

The type of display and the information presented on it, as well as method of operation, are unique for each manufacturer of the new generation of computerized radar plotters, although there are many similarities. The first definitive user oriented study of this subject was performed in 1975 by the Liverpool Polytechnic Maritime Operations Research Unit, under the sponsorship of Shell International Marine, Ltd. This study compared the display features of commercially available computerized radar displays.

Specifically, the study was designed to:

1. determine how much more, if any, intelligence could be gained from these "systems" over what the observer normally would get from a basic radar equipped with a reflection plotter.
2. determine whether systems with manual or auto acquisition were best for evaluating the danger associated with the radar echoes of other ships or objects.
3. determine if the use of these systems reduces the workload, influences the decisions the mariner makes, and reduces the voyage deviation.

The test sample was composed of experienced seamen who were attending courses at Liverpool Polytechnic. The maneuvering situation presented for the study required the operator to evaluate the motion of eight targets.

These targets were assigned the following roles:

- One target caused a fast closing, near miss situation.
- One target represented a more remote collision risk.
- One target was stationary, (lightship).
- Five other targets were moving but posed no risk of collision.

Basic Radar

The study concluded that when operators used a Head-up unstabilized relative motion radar display, the type used on most ships, 37% could not identify the stationary target;

The simulated situations involved own ship doing 12 knots with the lightship echo among 7 other vessel's echoes moving 9 to 20 knots. Lack of identification of the navigation aid in this circumstance, points out a significant radar interpretation deficiency which has not been widely publicized to date as a cause of strandings.

When using the relative motion radar display, not one of the seamen could assess the over- all situation with accuracy greater than 82% , and the majority scored less than 70%.

None of the men could forecast the results of his own ship making an alternation for avoidance. Only 28% of the sample plotted in order to extract true motion from the relative display. Another 18% casually marked on the face of the reflection plotter.

When using basic radar the marines accept a closer approach of another ship rather than attempt what appears to be a risky maneuver since they do not: fully understand the situation.

These startling results should not be very heartening for the ship-owner, because the principals conducting the study reluctantly concluded that this performance probably reflects their capability when performing their navigational duties onboard ship. A captain, who is an instructor at a radar training school, expressed surprise upon hearing these results and doubted that seamen would be able to perform this well if measured the same way on a ship on a relative radar display. If there were several small boats in the vicinity of the lightship going 3-7 knots, identification would be extremely difficult, for example.

Radar Plotting Displays

All of the computerized system displays gave the operators a much better understanding of the overall situation than they were able to get from the basic radar display. All of the systems let the operator make early and more economical maneuvers, because the overall situation was more clearly defined and this confidence was reflected in prompt, decisive action. Conventional vector presentations were singled out as being noticeably better in this regard than the others.

The use of auto acquisition is essential, although the operator should be able to select or reject any target. It was determined that 70% of the seamen using an auto acquisition system could assess the overall situation with 90% accuracy. In contrast, practically no one using a manual acquisition system could assess the overall situation with that accuracy, and the same is true for an automatic system without adequate display capability to present all of the processed information simultaneously on the PPI.

These manual acquisition systems and limited display systems did not result in any significant improvement over radar in accurately assessing the situation, and the watch officer's workload actually increased!

The study results showed that **DIGILOT's** type of display is superior because it:

- lets more seamen readily distinguish between moving and stationary targets. The ability to correctly identify navigation aids provides an anti—stranding capability significantly better than radar.
- lets more seamen identify risky passings with greater accuracy and full understanding with little likelihood of confusion after minimum training. This capability provides improved anti-collision safety with minimum voyage deviation.
- needs only 1/3 the effort required by the other types of displays whose workload was higher than using the raw radar. This lack of involvement with the equipment gives the mariner much more time for making a well considered maneuvering decision.

It is surprising that a limited 8 echo situation is sufficient: 10 show the clear advantage of all of the systems over radar and the real value of an auto acquisition system with adequate display capability. **DIGILOT's** superiority is more obvious in real life crowded situations, (where collisions occur),

since plotting the closest 40 echoes around own ship gives the watch officer much less anxiety, because he has a fuller understanding of the complete situation around him. In the English Channel, for example, the relative workload of **DIGIPILOT's** "hands off" operation compared with manual acquisition or limited display systems is much more pronounced.

"At a Glance" Radar - A Clear Weather Maneuvering Aid

From experience we know that most ships equipped with DIGIPILOT initially use it in clear weather to gain confidence for its use in fog. Gradually it is used to help interpret the operational situation in crowded areas in clear weather. Captain Oudet's original deficiencies of radar have, in fact, been reversed since automatically computed plotted radar data is many times better than visual interpretation of the situation since it is quantitative. Actually, its clear weather use is needed more as a safety aid since collision statistics show that there are many more casualties when the visibility is reduced in clear weather and at night than in fog. The automatic plot with visual confirmation will help reduce human error, which has been identified as the major cause of the ship casualties. A particular example is the collision between the LPG carrier "Yuyo-Maru" and the cargo ship "Pacific Ares" in November 1974. (8) "The direct cause of this accident seems to be that the Yuyo failed to sight the Ares early enough to take the necessary steps to avert collision, partly because of the poor visibility at the time (2 miles) and that the Ares failed to take cooperative steps most effective to prevent collision."

DIGIDATA Continuous Situation Recorder

The **DIGIDATA** disc recorder shown in Figure 3. provides a continuously updated record of the position, course and speed of up to 40 surface objects and the closest land outline.

Automate - modular integrated bridge system

DIGIPILOT and the **DIGINAV** computer are interconnected with a data line and the **DIGIPILOT** Adaptive Autopilot provides direct digital control of the rudder based on proportional, integral and derivative (PID) action to give proper initial rudder and timely counter rudder. The steady courses achieved minimize cross track velocity, which cause heavy drag losses, and the ship's speed is increased slightly because the rudder response is prompt and effective without overshoot or hunting. Better long-term course keeping is also accomplished due to the integral characteristic of **DIGIPILOT**, which removes steering error and windage effects. These effects are not always compensated in conventional autopilots.

DIGILOAD

DIGILOAD utilizes the computer in either **DIGILOAD** or **DIGINAV** together with a control console and input/output terminal for load planning and stress monitoring. The terminal provides easy data input and hard copy output. The system is extremely easy to use, because after starting, it automatically asks the operator for all required information.

The operator enters tank-by-tank ullage readings in conjunction with temperature and API. The computer has the ship's tank characteristics and computes the load for each tank. The fixed-point shear forces and bending moments are calculated as percent allowable stress at each of up to 24 stations.

Trim, mean draft, and dead weight are also determined. All data is printed out, including the tank loading statement, cargo summary, draft and trim, and transverse stability as well as a shear force and bending moment's tabulation. A simplified shear and bending moment graphical plot is also furnished. Loadline calculations for various temperature zones can be performed throughout the voyage. The system can be used to plan for multiple pick-up and discharge ports. For product carriers, rearrangement of cargo is so simple that several trial loadings can be accomplished with little effort, more efficiently loading the ship yet insuring trim and safety.

DIGILOAD can be expanded to meet various additional ship requirements. The following options may be added to the basic system:

- The use of ullage and temperature transducers to provide load monitoring at pre-set time intervals during loading, enroute and while unloading.
- Load and/or ballast sequencing analysis.
- Stress gauges and back up alarm sub-routines for load monitoring.
- Dynamic enroute stress calculations using strain gauges and wave measurements using transducers.

Computerized loading reduces operator involvement, which minimizes possible errors as well as increasing loading safety and speed. Loading reports are routinely prepared. Use of the more precise digital computer eliminates use of arbitrary safety factors to take care of analogue computer inaccuracies. This allows full loading of the ship in accordance with classification requirements. Cargo distribution can be optimized and real time load monitoring and overstress warning can be provided for extra safety.

DIGIPAY

DIGIPAY is an administrative system that uses the computational capability of either the DIGILOT or DIGINAV computer for payroll accounting and/or ship inventory control. A remote control console, and input/output terminal are added for the administrative programs, which are customized to each owner's needs.

OTHER FUNCTIONS

Obviously major fleets have their own particular shipboard computer requirements which can be readily met by customized input/output and programs to solve the myriad other problems considered economically beneficial for ship operations.

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