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DEREL: A Diesel Engine Reliability Database for the U.S. Coast Guard

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Abstract

The Coast Guard utilizes several factors in the determination of when a diesel engine should be overhauled. These factors include the results of the Diesel Engine Monitoring Program, Navy Oil Analysis Program, and Full Power Trials. However, currently the decision to overhaul an engine is based primarily on engine operating hours.

In an effort to reduce costs, the Coast Guard is considering shifting their preventative maintenance to a condition based system to reduce unneeded labor and downtime. To accomplish this goal, an analysis of the criteria used to indicate when a diesel engine should be overhauled must be performed. Specifically, a procedure is needed to select the overhaul timing policy which produces the minimum expected cost for Coast Guard cutters operating throughout the year.

Before any statistical analysis can be conducted an extensive amount of data must be collected on main diesel engines. A computer database is required to store and process this data. The database must be created in a easy to use format and with common data fields applicable to all cutter types.

This report will address the problem of creating a computer database to collect engine failure data for the USCG. A review of several current shipboard reliability databases will be conducted along with a look at modern developments in this area. The objective of this review is to build a knowledge base of current practices in marine reliability data. This knowledge will be used to benefit the creation of a fully functional USCG prototype database using Microsoft Access 95 software called DEREL (Diesel Engine RELiability database). The DEREL database will be implementable immediately in order to speed the initiation of data collection for future uses. The report concludes with a discussion of issues relevant to the implementation of the DEREL in the U.S. Coast Guard naval engineering system.

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Introduction

To remain competitive in global markets, businesses today are focusing on quality improvements. Total Quality Management is being taught at every business school in the country and as one of the world's premier maritime services, the U. S. Coast Guard has embraced TQM philosophies. Ship operations management is a major area in which the Coast Guard can focus its quality initiatives. The effective control of reliability of ship machinery, such as main diesel engines, will determine vessel response reliability. This reliability of response to distress calls or law enforcement operations is important for maintaining the Coast Guard's high level service to our country. In addition, the prediction of engine reliability problems will reduce the cost associated with engine failures at sea.

Marine diesel engines must be overhauled periodically to maintain optimum performance levels and to guard against engine failure. The determination of when to complete the overhaul is a matter of significant importance to any ship owner. The goal of overhaul scheduling is to minimize maintenance costs by reducing unneeded labor and downtime. Internal components should be used for as long as possible without sacrificing overall engine performance or incurring a high risk of engine failure.

The Coast Guard utilizes several factors in the determination of when a diesel engine should be overhauled. These factors include the results of the Diesel Engine Monitoring Program, Navy Oil Analysis Program, and Full Power Trials. A detailed summary of these programs is presented in the first section of this paper. In addition, the Naval Engineering Manual [1] suggests exactly when to perform major overhauls of a cutter's main diesel engines based on engine operating hours. However, the Coast Guard is looking to shift preventative maintenance to a condition based system in an effort to reduce unneeded labor, downtime and cost. The intended goal in setting up this new maintenance system is to determine exactly what must be done to ensure that the diesel engine continues to operate at an expected level of performance. In other words, the service's maintenance philosophy is shifting toward reliability centered maintenance (RCM) [2].

The benefits of RCM were first realized by the airline industry in the 1970's. A report prepared by United Airlines in 1974 described the maintenance programs used in the civil aviation industry [2]. The study reported two rather surprising conclusions:

- Scheduled overhaul has little effect on the overall reliability of a complex item unless it has a dominant failure mode.
- There are many items form which there are no effective form of scheduled maintenance.

The preventative maintenance programs used by the airlines prior to the report were organized and defined as reliability centered maintenance. To this day, RCM is used to develop and refine maintenance programs for all major types of aircraft [2].

Many other industries, such as the nuclear power industry, have utilized RCM techniques to improve reliability at reduced cost. For example, the Institute of Nuclear Power Operations was formed shortly after the Three Mile Island disaster to promote safety and reliability. The resulting maintenance and repair data collection system has been successfully used by the entire nuclear power industry for years[3].

In any application, a condition based maintenance program comprised of online monitoring, periodic testing, and failure prediction analysis is used to accomplish the goals of RCM. Three key parameters used to gauge the performance of equipment using this approach are Reliability, Availability, and Maintainability (RAM). A formal definition of reliability is the probability of a device performing its purpose adequately under stated conditions for the period of time intended. Availability is defined as the probability of finding the equipment operational at a specific time instant. It is used to identify the most effective actions available to keep equipment operational. Maintainability indicates the ability or likelihood of being able to repair the equipment [4]. RAM statistical techniques are used in maintenance support and operations to determine such things as time between overhauls. They have the potential to improve the prediction of maintenance and repair requirements reducing total operating costs over the life of a ship.

A preliminary requirement for RAM techniques to be successfully applied is the collection of supporting data in a standard format. The creation of a database to collect, process, and store diesel engine failure information is an essential first step in the Coast Guard's effort to shift to a condition based maintenance system. This data must be collected before any analysis tools can be implemented or organizational procedures changed.

What are the specific benefits of a reliability database to the Coast Guard? For the Engineer Officer onboard a ship, access to electronic, not paper machinery failure data for his vessel is the big advantage. This means the Engineer can make better decisions on allocating scarce resources toward the maintenance of equipment on his ship. The need for spare parts can be better forecasted and timing of repairs anticipated more accurately. Also, onboard data analysis may alert the Engineer to the need for more detailed data comparison with other ships containing the same equipment. The benefit for the Coast Guard's maintenance managers is the ability to access fleet performance data for trend analysis. The database will enable the comparison of ships of the same class or any ship containing identical equipment. This has the obvious advantage of inducing more informed decisions on the optimization of equipment repair, replacement, and maintenance. The shore based maintenance managers will be able to achieve the lowest vessel life cycle cost given a required level of vessel reliability.

This paper will present a prototype database for the collection of failure data of USCG main diesel engines. This prototype named the Diesel Engine Reliability Database (DEREL) was designed to be compatible with current USCG information systems. It is meant to be a model for the extension of database collection tools for all fields of USCG maintenance, not just main diesel engines. A brief outline of the paper is as follows: First, a literature survey of diagnostic systems and marine databases currently in use is offered as background information. Second, the detailed methodology for creating the new USCG database is presented including discussions of data field inclusions and data integrity and quality. Lastly, the DEREL database is described with visual screen images and sample tables and reports.

Literature Survey

General

In the following subsections, a discussion is presented on diagnostic systems and reliability, availability. and maintainability techniques for analyzing marine diesel engines. In particular, several examples of engine diagnostic systems and engine failure databases currently in use are presented. This is necessary background information for the development of a reliability database. The material for this discussion was obtained through a literature survey of SNAME and IEEE engineering journals and through phone conversations with industry representatives.

Diagnostic Systems

Some ship owners utilize electronic monitoring of shipboard systems to aid in maintenance decision making. In these ships, monitoring and engine alarm systems gather data from sensor instrumentation throughout the plant. These sensors are attached to critical components of the engines and their auxiliaries to diagnose faults. A fault may be defined as something relatively minor like a reduction in fuel efficiency or something much more severe like damage to the engine itself.

The monitoring of engine parameters such as pressures, temperatures, flow volumes, and noise levels are the basis of fault diagnosis techniques. Any deviation from normal conditions can be recognized and discrepancies associated with specific faults identified [5]. In addition, nondestructive techniques such as oil analysis, vibration monitoring, ultrasonic wave transmission, radiography, and corrosive monitoring are used to provide information about the health of the engine [6].

The value of any machinery monitoring system is dependent upon the accuracy of the measurement instruments and the ability of the shipboard engineers to utilize the information provided by the system. An engineer must possess detailed knowledge, plant specific experience, and the discipline to work through tedious calculations to process detailed engine performance data. In some cases, the lack of one or more of these abilities may result in an undiagnosed engine problems that will affect engine reliability. The reliance on ship engineers to analyze the data may hamper efforts to improve maintenance management effectiveness because of lack of trend analysis expertise [7].

One of the first efforts to create a monitoring system that also analyzed the data it collected was a cooperative research agreement between Lykes Lines, MAN/B&W, Det Norske Veritas, and MACSEA LTD. The research, started in June 1987, focused on using computer technology to develop an onboard system to assist ship engineers in diagnosing existing or impending problems with diesel engines [7]. The result of this research was a system that analyzed parameter data and recommended maintenance actions.

Today, the most modern automated fault diagnosis systems accept data directly from the ship's engine monitoring computers and return performance assessment and trouble shooting advice. One such expert system has been developed by MAN B&W for their two-stroke and four-stroke engines. The system provides continuous real time condition monitoring, diagnosis, and trend monitoring through correlation of physical characteristics of the system. It alerts the operator to immediate maintenance requirements with regard to injection, combustion, wear components, and turbocharger operation. Specifically, diagnostic information is given by the system in the event of: contamination of the air intake filter, incorrect combustion, deterioration of the fuel injection pumps, loss of turbocharger efficiency, or when other operating parameters exceed permissible ranges. In addition, the system can provide valuable input to preventative maintenance programs through trend analysis of historical data [8].

The MAN B&W diagnostic system runs on a DOS based PC. It is very flexible and can be tailored to receive data typed manually from a PC keyboard or, in its most current software version, is network connected to the engine monitoring computer to provide totally automatic service.

Another expert diagnostic system offered by a major diesel engine manufacturer is New Sulzer Diesel's MAPEX system. MAPEX (Maintenance Performance Enhancement with Expert Knowledge) consists of a piston ring wear detection module that measures and trends piston ring wear. There is also a module that monitors liner wall temperature, cylinder wall temperatures, scavenging air temperatures, engine speed, and load. The system provides trend graphs while operating on a standard PC [9].

Wartsila Diesel also offers several expert systems for diagnostic analysis. FAKS (Fault Avoidance Knowledge System) receives sensor readings from the engine every 15 minutes and identifies fault possibilities. The system displays the output data in graphical and digital form. Analysis is made based on a knowledge base of hundreds of conditions and thousands of correlations. Another Wartsila system, The Engine Condition Evaluation System was developed to process manually inputted conditions for further processing. The system, which runs on a McIntosh computer, also offers compressed video clips that show how to perform various maintenance procedures [9].

Reliability and Availability Techniques

Most of the fault diagnosis programs presented above are effective and efficient. They are valuable in improving the planning and scheduling of preventative maintenance procedures. This planning is dependent on the frequency of faults, or component and system reliability, diagnosed by these expert computer systems. Therefore, engine diagnosis techniques should be used in conjunction with reliability techniques to minimize overall maintenance and repair costs [5].

The U. S. Navy has extended RAM analysis from its beginnings in electronic and aviation applications into the shipboard field. An interesting example is a study conducted by the Naval Sea Systems Command in 1983 on the age reliability analysis of shipboard equipment. The research consisted of the collection of failure and overhaul data from 22 equipments in the DDG-2 and AFS-1 class ships. The conditional probability of failure for each type of equipment was calculated and plotted to determine optimum overhaul timing. The overall conclusion from this study is that the Navy's maintenance schedule requires too frequent overhauls on many equipment resulting in wasted time and money [10].

Several papers have discussed the failure causes and statistical distributions for marine diesel engines. A series of studies conducted by Hashimoto in conjunction with other authors have examined and compared failure data for marine diesel engine components [11][12][13][14]. They first began by analyzing the failure characteristics of exhaust and fuel valves by using the Weibull failure distribution. They next studied the failure trends for diesel engine components from 1965 to 1980. An significant increase in the mean time between failures for this time period was noticed for exhaust, fuel, starting, and safety valves. In addition, Hashimoto and Ishizuko obtained failure rates for several types of marine propulsion subsystems resulting in the identification of the main engine as one of the most troublesome units [14].

More recent studies into marine diesel engine RAM analysis have been conducted by Perakis and Inozu [5][15][16][17]. Their research centered around the maintenance and replacement problem for Great Lakes shipping companies. This differs from the same problem for oceangoing ships in more than one respect. Primarily, the existence of a winter lay-up season allows most maintenance to be done in three months conserving the other nine months of the year for operating. The authors had access to voluminous failure data for six Colt-Pielstick PC2-400 16 cylinder marine diesel engines for analysis.

A failure modes and effects analysis and fault tree analysis were introduced for the engines as a first step in the RAM analysis process. Next, field censored failure data for components for six identical engines were analyzed. The Weibull and exponential distributions were utilized for the cylinder pistons, heads, jackets, liners, O-rings, connecting rod bearings, fuel cams, and turbochargers. Reliability and hazard functions were produced for these components. A final step in the research was the creation of optimal repair and replacement model for a one and two engine Great Lakes marine diesel ship. The authors used a semi-Markov competing process approach process in their models. An efficient enumeration procedure was presented to select the replacement policy which produced the minimum expected cost for the operating season [16].

RAM Databases

The reliability methodology mentioned above has been available for many years. The problem, first mentioned during the 1963 conference on Advanced Marine Engineering Concepts of Increased Reliability, is the lack of data [18]. In other industries, RAM databanks have been in use for years worldwide. The aerospace, nuclear power, and aviation industries were among the first to develop RAM data banks due to obvious safety concerns. Recently RAM analysis has spread to other industries and the advent of advanced computer technology has made the use of data banks more practical.

There are numerous examples of RAM data banks in the marine industry today. The U.S. Navy has collected data in their 3-M (Maintenance and Material Management) data base since 1963. The current form of the database resides on a client server network using a Hewlitt Packard HP9000 miniframe computer. It is ANSI (American National

Standards Institute) compliant using a structured query language database management system. It is designed to report preventative and corrective maintenance and allow fast and easy access to the information. Currently the 3-M database stores over nine million records of maintenance events [19].

There are two primary manual forms in use by 3-M database users. The first and most important is the Ships' Maintenance Action Form, OPNAV 3790/2K. It is used for the manual reporting of information and contains the same data elements as the computers at automated data entry sites. The shipboard personnel fill out the blocks of the 3790/2K form and it is mailed to the Naval Sea Logistics Center where the information is entered into the master 3-M data bank. A blank Ships' Maintenance Action Form is shown in appendix (5).

The second important form is the Ships' 3-M Data Request Form presented in appendix (6). This form is filled out by any Navy command or contractor desiring a report of information stored in the database. The 3-M system offers numerous report options such as; fuel reports, reliability reports, material histories, and ship's maintenance reports. The requester must fill out the request form completely providing the necessary parameters to build the report.[20]

In conjunction with Newport News Shipbuilding, the 3-M data has been used in a wide variety of programs including: maintenance forecasting programs, logistics support analysis, reliability trend analysis, and the performance monitoring program [21]. The 3-M data provides for the calculation of numerous RAM parameters such as: mean time between failures, mean down time per failure, mean time to repair, and mean time to failure.

One of the first marine diesel engine failure information databanks was developed at the University of Michigan for the Interlake Steamship Company in 1984. The system stored and retrieved data concerning the maintenance of six Colt/Pielstick engines on three ships. The data could be retrieved in various forms to provide machinery history or current status information [22].

The first major effort to form a large scale RAM data bank for merchant vessels got underway in 1978 when the Swedish Ship Owners union began collecting data in 1978 with the help of funding from the Swedish government. After ten years the government support was discontinued and data collection stopped. The data collected during this period included failure rate data for various ship types including tankers, containerships, ro-ro's and general cargo ships [21].

An ongoing attempt at a large scale merchant vessel RAM data bank is being conducted by the Japan Foundation for Shipbuilding Advancement. It was established by the Ship Reliability Investigation Committee (SRIC) to study the equipment and systems reliability of an unmanned engine room ship. The data collection started in 1982 with a testing population of 128 Japanese ships of all types. The failure data collected was used to improve the corrective and preventative maintenance practices primarily for diesel engines and generators. The great benefits realized from this program have led the Japanese Ministry of Transportation to expand the data collection to more types of ships [23].

Another example is the OREDA (Offshore Reliability Data) project launched in the early 1980's by the Norwegian Petroleum Directorate. The objective was to collect reliability data for safety studies on the equipment of 8 participating oil companies in Europe. Originally the data was needed for risk and availability studies in the concept phases of an offshore development. The project was later expanded to collecting in-depth inventory and failure data from different platforms and merging them into a common database. OREDA data has been used by participating companies for internal analysis and external comparison. The design and engineering phases have been the primary areas of use followed by maintenance and operations. In addition, OREDA projects have spawned other activities such as the development of standards for collection of reliability data and the development of software for collection and analysis of data. The OREDA project continues to expand with the fourth phase initiated in 1994. In this phase the data collection is automated whenever possible and the range of equipment classes has been expanded [24].

In this country, a major effort to form a RAM data bank for merchant ships was undertaken in 1993 [21][25][26][27]. ARCO Marine, Energy Transportation Corporation, and Sea Land Service joined forces with the Maritime Administration and NOAA to form the Ship Operation Cooperative Program (SOCP). Any U. S. vessel operating organization or industry is eligible for SOCP membership. At the time of this writing there are 21 members of the SOCP.

The goal of the SOCP is to create an international network to collect RAM data and share this data to promote continuous improvement in reliability and cost effectiveness for the entire life cycle of the ships [26]. The first project in pursuit of this goal was to build a RAM database to compile and disseminate field data from merchant ships. The primary benefit of the database would be to provide performance feedback for each SOCP member and eventually share the information with other members for benchmarking purposes. Other advantages of the shared database would include the use by regulating agencies to assist in revising rules and feedback to engines manufacturers and ship designers [26].

The development of the SOCP's shipboard data entry program included the examination of operational procedures and format information for various existing reliability databases. In addition, common data collection formats and procedures were studied for different forms of shipboard equipment reliability data. Data entry fields and RAM performance indicators were developed and the final software product, called DATE, was completed in 1996. The program runs in conjunction with Oracle 7 in a workstation environment and allows the shipboard engineers to collect equipment failure data in a standard format. Also, the Chief Engineer can view basic equipment information, machinery history, and failure data for items on his ship [27].

USCG Diesel Engine Overhaul Planning Programs

The three overhaul planning programs outlined below are used in combination by U.S. Coast Guard maintenance managers to monitor engine performance and establish maintenance intervals. The shipboard engineer officers are responsible for providing the material (oil samples, engine parameter readings, etc.) to keep the programs functioning properly. Each program is described in detail as a source of necessary background to the development of the DEREL program. The information for this section was obtained from the Coast Guard's Naval Engineering Manual [1].

The Navy Oil Analysis Program

The U.S. Coast Guard participates in the Navy Lube Oil Analysis Program (NOAP) for all cutters greater than 65 feet in length. The program has numerous benefits such as detecting build-up of wear metals, determining harmful changes in viscosity, and detecting fuel dilution and water leaks.

The program consists of drawing periodic oil samples from machinery and testing them with a spectrometer and by other means for their physical properties. Examples of the equipment sampled on the various USCG ships are:

<u>WAGB (POLAR CLASS)</u>
Main Diesel Engines
Main Gas Turbines
Reduction Gears
Controllable Pitch Propeller Systems
DC Propulsion Motors
Ship Service Diesel Generators
Central Hydraulic System

<u>270 WMEC</u>
Main Diesel Engines
Ship Service Diesel Generators
Emergency Diesel Generators
Reduction Gears
Controllable Pitch Propeller Systems
Fin Stabilizer Hydraulic Systems

The samples must be drawn from running machinery at normal operating temperatures. In addition, each sampling point must be approved by the cutter's maintenance command to avoid contamination of the sample. There are strict published guidelines on the proper sampling procedures.

There are three primary factors that influence the value of a given sample. First, the oil must circulate in the system long enough to accumulate wear metal concentrations indicative of the system's condition. Second, the fluid must be representative of the fluid circulating in the system. Lastly, the prescribed sampling intervals and procedures must be followed. In general, samples are taken every 250 operating hours or quarterly, whichever occurs first. After an engine overhaul, oil samples are taken after 1, 25, and 50 hours and thereafter at the regular 250 hour interval. Also a sample should be taken after a major casualty to help in the predication of future casualties.

The samples are submitted to the proper participating laboratory accompanied by the "Oil Analysis Request" form shown in appendix 1. The detailed instructions for completing the form will be omitted in this discussion for obvious reasons but care must be taken when filling out the form or a correct evaluation of the oil sample may be impossible. Any error in information submitted to the laboratory may make the oil evaluation useless. In addition, feedback information is an essential part of submitting oil samples so that the laboratory is made aware of maintenance action taken and can ensure that decision making criteria are updated.

The Navy Oil Analysis laboratories provide the following services to Coast Guard engineers.

Spectrometric Analysis This procedure detects trace metals of the following elements:

- Iron
- Silicon
- Lead
- Magnesium
- Copper
- Titanium (gas turbines only)
- Chromium
- Molybdenum
- Aluminum Nickel
- Silver
- Tin

An emissions spectrometer is used for identifying the above elements. The data is recorded in parts per million (ppm) and abnormal results will be transmitted by message to the respective ships. An equipment history is also sent to the unit for each sample sent.

The basis for spectrometric analysis is the fact that moving contact between metallic components wears away fine metal particles. This particles are carried in suspension in lube oil. The laboratory technique of reading the amount of particles in suspension is accurate but interpretation depends on many variables, including the details of the sampling process. Before 1976, the laboratory technicians manually recorded and interpreted spectrometric data. This lead to obvious problems of human error and lack of understanding. The interpretation required a knowledge of normal and abnormal quantities, threshold limits, trend tables, decision guides, and metallurgy.

Today, spectrometric data has been interfaced directly with an automated laboratory system. The ppm data is stored electronically and analysis is performed automatically including, trend tables, limits, and decision guides. An example of this trend analysis is shown in appendix (2). The automated system generates a equipment history and selects the appropriate laboratory advice. The system has been used to develop threshold values by equipment manufacturer and model. The threshold value is the amount of trace metal concentration (in ppm) at which abnormal level evaluation starts. These threshold values are automatically adjusted as the size of the database increases. The latest wear metal threshold limits are shown in appendix (3).

Physical Properties Test The physical testing of the oil samples is the most important aspect of the oil analysis program for identifying causes of potential machinery failure. The tests are conducted by the laboratory to determine:

- viscosity

- fuel dilution
- suspended solids
- nonsuspended solids
- water
- total acid number (gas turbines)
- flash point
- acidity

The automated laboratory system sends result of the oil analysis tests in the form of a message or a report. The message informs the ship that an oil sample has tested abnormally by the spectrometer or by physical tests. The laboratory advises the ship to re-sample or inspect the equipment and suggest possible sources of the problem.

It was stated above that the evaluation of the spectrometric data is automatically performed by the system. The laboratory generates advice codes for each sample depending on which wear metals have extremely high readings. A summary of these advice codes is shown in table1 below.

ADVICE CODES	WEAR METAL MONITORING
A1	Normal wear. Continue normal sampling.
B1	Abnormal wear. Resample after 50 operating hours.
C1	Abnormal wear. Resample after 25 operating hours.
D1	Purify oil and change filter. Resample after 50 operating hours.
F1	Unit "wear-in" indicated. Resample after 25 operating hours.
G1	Unit "wear-in" indicated. Resample after 50 operating hours.
H1	Resubmit another sample as soon as possible.
J1	Lube oil pump wear indicated. Inspect pump and report findings to laboratory.
K1	Abnormal bearing wear indicated by (element)(ppm). Inspect bearings and report finding.
L1	Abnormal bushing or wrist pin wear indicated. Remove head and inspect.
M1	Abnormal ring, piston, or cylinder liner wear. Check exhaust temp and firing pressure.
N1	Abnormal rocker arm, camshaft, or pushrod wear indicated. Inspect and report findings.
P1	Abnormal gear wear in governor or accessory drive indicated. Inspect and report findings.
R1	Thrust bearing wear in turbocharger indicated. Inspect and report findings.
S1	Cooling system leak indicated by (Mg/Cr). Report findings to laboratory.
T1	Critical wear indicated. Impending failure indicated. Inspect and report findings.
A2	Oil condition normal. Continue normal sampling.
B2	Abnormal fuel dilution. Do not change oil. Check injector, fuel lines etc., for cause.
C2	Excessive fuel dilution. Inspect fuel system, change oil and filter.
D2	Critical fuel dilution. Recommend stop all but emergency operations and change oil.
E2	Abnormal amount of fresh water. Check for leak. Purify/change oil.
F2	Excessive fresh water. Inspect cooling system. Inspect for worn gasket and cracked block.
H2	Abnormal abrasive material in oil. Check air induction system and filter for source.
J2	Excessive abrasive material in oil. Check air induction system. Change oil/filter.
L2	Excessive solid material. Critical condition exists. Inspect and report findings.
M2	Acid number too high. Change oil and continue normal sampling.
N2	Viscosity ( ) @ 100 degrees F. Below minimum requirements. Oil too fluid.
P2	Abnormal viscosity increase. Purify/change oil and check filter.

Table 1 Advice Codes for Wear Metal Monitoring

To make sound engineering decisions, the results of the Navy Oil Analysis Program must be taken in light of all other known factors such as trend analysis and engine performance monitoring. The key to the success of the oil analysis program is the evaluation of the program's recommendations for preventative maintenance. The shipboard engineers submitting the oil samples are ultimately responsible for this evaluation.

Full Power Trials

The full power trial (FTP) is a test of a cutter's propulsion plant operated at maximum rated power. The purpose of the test is to advise the cognizant commands of the operational characteristics of the cutter. In addition, if a deviation from the desired standard performance is detected, corrective action can be addressed.

A full power trial is required at the following times: within the first six months after a new cutter has been delivered and within six months of completion of alterations that affect the propulsion capabilities of a cutter. Upon completion of a FTP, a test report is submitted to the appropriate engineering command where the trial data is compared to original or updated standards. Any problems causing unsatisfactory performance are resolved as quickly as possible. Substandard FTP performance is one factor that impacts the diesel engine overhaul schedule for a cutter.

Diesel Engine Maintenance Program

The Coast Guard Diesel Engine Maintenance Program provides detailed maintenance scheduling requirements for main diesel engines. The operating interval between overhauls is function of several factors such as:

1. Quality of original or replacement components.
2. Operation conditions of the engine and variations in the load and speed.
3. Operation in corrosive or abrasive environments.
4. Quality of the workmanship during an overhaul.
5. Operating within recommended limits of temperature and pressure.

The hourly intervals shown in appendix (4) were generated to provide a basis for planning maintenance time and center section overhauls. After 80 percent of the time to next overhaul has elapsed, the shipboard engineers should evaluate the condition of the engine to identify the need for an overhaul. This evaluation should include information provided by full power trials, Navy Oil Analysis Program, trend analysis, and physical component inspection. These tools help to determine the internal condition of the engine's center section without opening it up. If any indication from these aids shows that an overhaul is necessary prior to the interval outline in the figure above, appropriate maintenance action should be taken.

To clarify terminology, the center section of an engine includes all cylinder assemblies and related components, plus crankshaft and camshaft assemblies, including bearings. All attached pumps and other components are not included. When an overhaul is required the ship orders a overhaul kit created by the Coast Guard's Supply Center Curtis Bay which includes all components necessary to complete the overhaul.

A table included in reference (1) dictates which engine trend monitoring readings must be taken for every engine type. These readings are taken at the specified time intervals of operating time and are compared with previous values. There are seven readings required under this program.

1. Cylinder compression pressure
2. Cylinder firing pressure
3. Cylinder exhaust temperature
4. Crankcase vacuum
5. Intake manifold pressure
6. Exhaust back pressure
7. Lube oil consumption

In addition, if exhaust pyrometers are installed on each engine cylinder then the exhaust temperatures are to be monitored. A brief explanation of each type of reading follows.

1. & 2. Cylinder compression pressure and firing pressure If possible, both individual and average cylinder readings should be observed. These readings provide a good indication of the power balance between cylinders and total power output of the engine. These values should remain relatively constant until the engine approaches the time for an overhaul. At this point both pressures will drop off rather quickly indicating that the rings are sticking, broken or beginning to wear. It also may indicate that the valves are not functioning properly, a piston has cracked, or the liner is beginning to score.

3. Cylinder exhaust temperature A drop in the exhaust temperature and firing pressure only indicates a problem in the fuel system. If the problem is isolated to a small number of cylinders the cause could be faulty injectors. The problem is evident in all cylinders, the problem is more likely to be in the fuel pump or distribution system.

   A rise in exhaust temperatures may indicate faulty injectors but most likely the fuel control system is sticking or excess fuel is being fed to the engine to bring it up to standard operating speed. Also, carboning of exhaust ports or valves could cause the temperature rise.

   The other cause of an unusually high exhaust temperature is a faulty pyrometer. This can be easily remedied by repair or replacement of the pyrometer.

4. Crankcase vacuum After an overhaul, crankcase vacuum is relatively steady until the engine approaches another overhaul interval. As wear occurs between ring, piston, and liner the crankcase vacuum will slowly decrease. As blow-by begins, the high pressure combustion gases break down the protective film on the cylinder walls causing metal to metal contact. Further wear increase the blow-by effect and the

engine sump temperature rises causing vapors to form. Eventually, the combustion gases heat the sump vapors to the point of a crankcase explosion.

Another cause of decreasing crankcase vacuum is a problem with the operation of the crankcase scavenging system. It should be noted that changing the size of the orifice plate on an engine only treats the symptom and not the problem itself.

5. Intake manifold pressure This pressure is an excellent indicator of the condition of the intake valves and the general condition of sealing in the cylinder. It is important to duplicate rpm and load setting when taking intake and exhaust manifold pressures. A change in pressures may be due to carboning of the turbocharger.

6. Exhaust back pressure Any rise in exhaust back pressure should be investigated. It may be caused by fouling of the exhaust manifold or leakage of combustion gases past the exhaust valves. Different engines will have significantly different mufflers or exhaust port arrangements that cause an increase in back pressure when fouled. Piping diameters and bend vary greatly in some cases. In any case, increased back pressure should be monitored closely because it will reduce engine efficiency.

7. Lube oil consumption After an overhaul, initially high consumption is due to unseated piston rings. It will level off as the rings seat and remain constant until the rings and liners begin to wear and the engine reaches its overhaul time. Any unusually high consumption of lube oil should be evaluated as a generalized indicator of internal and external engine condition.

Summary

The senior engineering management within the service have decided that the Oil Analysis Program, Full Power Trials, and the Diesel Engine Maintenance Program are no longer sufficient to provide the most cost efficient maintenance plan possible. Evidence of this is the chartering of "Tiger Team" working groups to improve the service life of a particular type of engine. These teams are made up of maintenance managers from around the country who study the maintenance processes of only one manufacturer's model of an engine. They are tasked with beginnging the process of shifting the Coast Guard from a platform based maintenance system to a equipment based management system. One example is the ALCO Tiger Team that has produced important policy changes and recommendations including an Equipment Support Plan that defines the overall process for the systematic support of all ALCO engines installed on U.S. Coast Guard Cutters.

The three programs outlined above represent the way the Coast Guard previously monitored engine performance and determined maintenance intervals. In the past, most Coast Guard policies involved numerous manual inspections performed by the ship's crew or shore-side support personnel. The labor was relatively less expensive than the engine parts and so it made sense to open and visually inspect components before replacing them. However, today's labor, even sailors', is more expensive that engine parts. Therefore, it is more economical to shift to a condition based maintenance system. The Coast Guard intends to create a system where an engine component is used for a known period of time and then replaced. The engine continues to run, virtually maintenance free for another known period of time until the component is replaced again. This system drastically reduces the number of open and inspect evolutions saving labor costs.

It should be noted that any new maintenance philosophy created must continue to endeavor to balance engine reliability, lost cutter days to maintenance, available resources, funds, labor, and sound engineering practice. The overall operational capabilities of the cutters cannot be degraded under any circumstances. As discussed in the introduction of this paper, the concept of Reliability Centered Maintenance, has been proven effective in other industries. The Coast Guard now begins the process of introducing the system into their own maintenance organization.

DEREL - Diesel Engine RELiability Database

Introduction to Database Concepts

A database is a collection of related information called data. Many common databases are used daily such as a telephone book, a calendar, or a card catalog. A database may be paper-based but many are electronic today. The main advantage of electronic database management systems is that they can store very large amounts of data and make it much easier to extract that data.

A telephone book is a perfect example of a database for defining most database terms. For example, a single page of a telephone book contains a listing of people's last names, first names, addresses, and phone numbers. A page of this information can be thought of as a **table** in database terminology. Each column of information on the page contains a single kind of data (last names, first names, addresses, etc.) In a table, each column of data is called a **field**. Each row contains one piece of data from each field relating to a single residence. In a table, each row of data is called a **record**.

Most electronic databases include tools for viewing and working with the data in the tables. This is a primary advantage of computerized databases over paper-based databases where each record must be manually searched and re-written. For example, **forms** let you see data however you want, rather than in just rows or columns. They can be used to view only certain fields, or to display one record at a time. **Reports** provide the best way to present the data as a printed document They allow you to specify which fields to print, sort records, group records, or calculate summary information. Lastly, a **query** lets you ask questions about data. The query itself is the question that is asked, not the information produced from the database when the query is run. For example, a query could be run to generate a list of how many people have the last name Smith in a telephone book.

To summarize, a database is a collection of related information. The data is stored in tables. Tables contain columns of information called fields, and rows of related field information called records. Forms, queries, and reports are tools for viewing and manipulating the data in the tables. Understanding the definitions of these terms is vital to following the description and presentation of the DEREL database on subsequent pages.

Description of the DEREL Database

DEREL was created using Microsoft Access 95 software on a desktop PC. The Coast Guard currently uses the two programs, ORACLE and Access, for all database applications. Access 95 was chosen for this application primarily because of its window based design and availability to the programmer. Also, the size and scope of the DEREL database is well within the limits if Access' capabilities. The DEREL database consists of four related database tables: an Equipment Information table, a Preventative

Maintenance table, a Corrective Maintenance table, and a Failure Information table. The ingredients of each table is described below.

The Equipment Information table contains a description of each engine for which data is to be collected. The description includes information such as equipment identification code, ship hull number, engine model, and serial number. Each engine's equipment information file is stored as one record in the Equipment Information table.

The Preventative Maintenance table contains information about actual preventative maintenance carried out on each engine. Examples of preventative maintenance actions stored in the table are center section overhauls, partial overhauls, and scheduled services or inspections. The Preventative Maintenance table is referenced to the Equipment Information Table by engine serial number.

The Corrective Maintenance table contains information about the corrective maintenance following an engine failure. For obvious reasons, the Corrective Maintenance table is referenced to the Failure Information table. Sometimes, one failure may lead to more than one corrective action. This may happen if the first corrective action did not adequately solve the problem and another corrective action is needed to bring the engine back to operational condition. The Corrective Maintenance Table is designed to handle this possibility.

The Failure Information table stores information about the engine failures. There are three types of failures defined as degraded performances, incipient failures, and complete failures. The table contains a record of the severity of the failure, the failure's effect on ship operations and the cause of the failure. Each failure record is linked to the corrective action or actions that remedy the situation.

The four tables described above are linked in a combination of one-to-many and many-to-many relationships. For example, the Equipment Information table is linked to the Preventative Maintenance table in a one-to-many relationship. For every engine in the first table there can be zero, one, or, many rows of information in the preventative maintenance table. Another, more complicated, relationship exists between the Equipment Information table and the Corrective Maintenance table. They have a many-to-many relationship that can only be modeled in Access 95 by breaking it down into multiple one-to-many relationships. For example, an engine can have multiple failures and each failure require multiple corrective actions. The Failure Information table acts as a linking table between the Engine Information table and the Corrective Maintenance table. The entire database structure and the relation between the different information files is shown in figure 1.

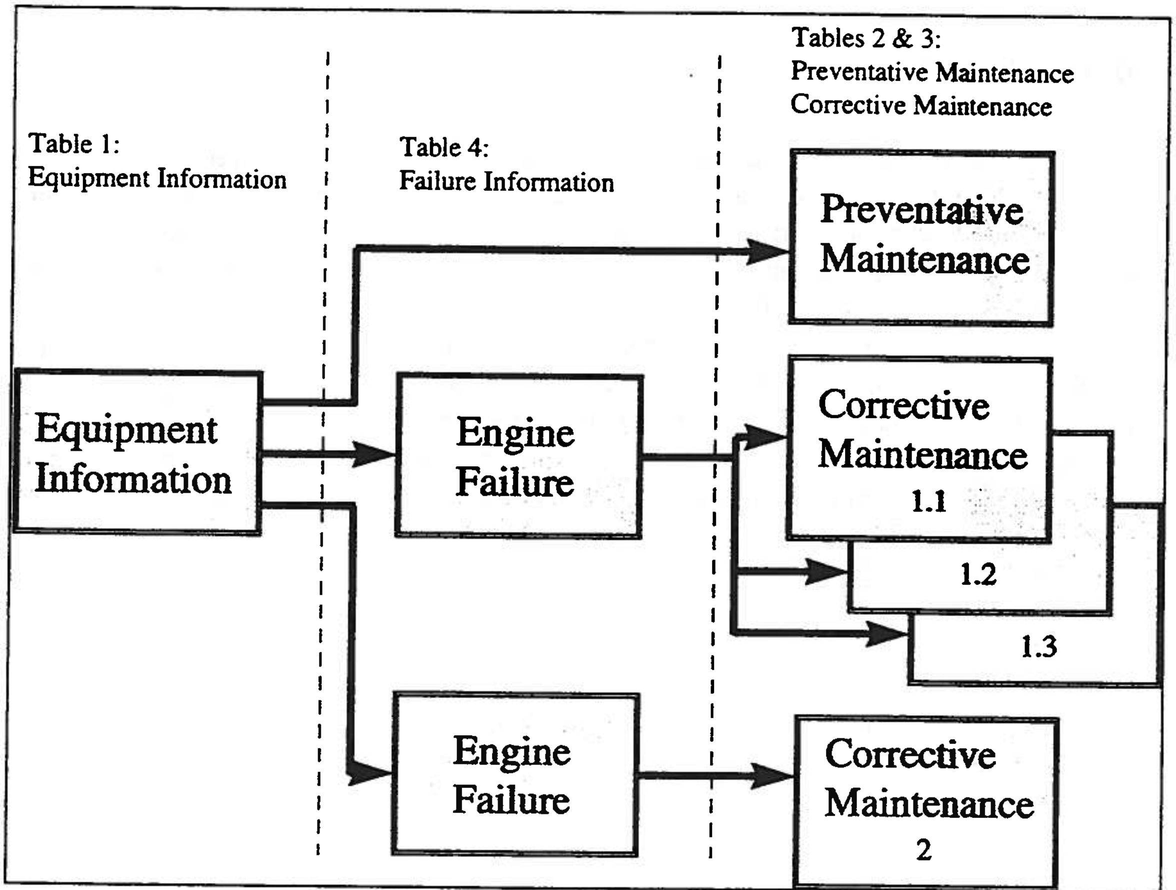


FIGURE 1 DEREL DATABASE STRUCTURE

DEREL Data Fields

The fields of a database determine the kinds of data that are stored. Each column of information in a database is a field. The data fields of the DEREL database are outlined below. Each field is bulleted with the data entry choices for a given field are preceded by arrows (>). The intent of this section is to present a complete view of the types of data collected and stored by DEREL.

A comprehensive glossary containing the definitions of the data fields and other terminology in the DEREL database is found in appendix 7. The data term dictionary is a crucial part of any database design because it defines the data to be collected and provides a resource for the user to answer questions about the data requirements. Also, a complete listing of maintenance and failure action codes is presented in appendix 8.

<u>Table 1 - Equipment Information</u>

- EIC
- Hull Number
- Engine Model: select one **Note: This list will include all USCG engine types.*
    >ALCO 251B
    >FM 38TD8
    >Cummins V12-525M
    >CAT D-311
    >Detroit Diesel 6V53
- Serial Number
- Installation Date

<u>Table 2 - Preventative Maintenance</u>

- Cumulative Operating Hours
- Operating Hours
- Maintenance Manhours
- Type of Maintenance Completed: select one
    >Center Section Overhaul
    >Partial Overhaul
    >Scheduled service/inspection
    >Replaced - same model
    >Replaced - different model
    >Other
- Maintenance Code

<u>Table 3- Corrective Maintenance</u>

- Corrective Maintenance Start Date

- Repair Manhours
- Repair Performed by: select one
  >Ship's Crew
  >Contractor's Crew/Shipyard
  >Technical Representative
- Reason for Repair: select one
  >Complete Failure
  >Degraded Performance
  >Incipient Failure
- Corrective Action Details

<u>Table 4- Failure Information</u>

- Date Failure Occurred
- Date Failure Recognized
- Cause of Failure: select one
  >Connecting Rod
  >Cylinder Head
  >Cylinder Liner and O-ring
  >Cylinder Piston
  >Crankshaft
  >Fuel Pump
  >Salt Water Pump
  >Turbocharger
  >Operator Error
  >Other
- Failure Code
- Trouble Isolation Time
- Failure Criticality: select one
  >critical
  >major
  >minor
- Effect on Ship's Operations: select one
  >No effect on operations
  >Reduced ship speed
  >Reduced mission capability excluding ship speed
  >Dead in the water

Development of DEREL

The goal of designing any database is to take a real world system and model it in a database. The process consists of deciding which tables to create and which columns they will contain, as well as the relationships between the tables. The thought process followed during the development of the DEREL database is described below.

It has been said that designing a database is more of an art than a science. Often real world problems are not easily represented in a database. There are, however, two major principles that should be followed to achieve a properly designed database [28]. First, the database should conform to the relational model. This is a basic idea which simply means that the database should be a series of unordered tables that can be manipulated using nonprocedural operations. Access 95 is compatible with most aspects of the relational database model.

The second key to a successful database design is the principle of normalization. It is the process of simplifying the design of a database so it achieves the optimum structure. Normalization theory consists of normal forms which are a linear progression of rules you apply to the database. Each higher normal form achieves a better, more efficient design. DEREL conforms to the following three normal forms:

- First Normal Form - This means that for every row-by-column position, there exists only one value, not an array or list of values. If lists of values were stored in a single column, there would be no easy way to manipulate the values.
- Second Normal Form - The tables should store data relating to only one entity (a diesel engine), and that entity should be fully described by a primary column (engine serial number). In other words, every column of a table is dependent on the engine serial number.
- Third Normal Form - This means all columns must be mutually independent of the primary key (serial number). No columns containing calculations should exist in the table. Dependencies cause problems when you add, update, or delete records because you may have to input several values for each record being updated.

The detailed approach to designing DEREL began with a concerted effort to learn the system to be modeled. The USCG diesel engine overhaul programs were studied (see section 2) and numerous phone conversation made with cutter maintenance managers to determine their idea of the ideal database capabilities. In addition, several databases already in use such as OREDA and SOCP's DATE program were analyzed to understand the typical data fields used in modern reliability data banks. An informal list of requirements of the system was developed such as "Must be able to track an engine failure's effect on the ship's operational performance."

Next, the data tables were roughed out on paper. Normalization theory was kept in mind at this point to make sure that each table describes a single entity. After initial drafting, the data field list was refined after review by several prominent USCG maintenance managers. In addition, changes were made based on reference searches on the subject of database design. For example, the "reason for repair" field was changed to include only three selections; complete failure, degraded failure, and incipient failure. This decision was made because most reliability data banks distinguish these three failure modes for maintenance engineers, component designers, and risk/reliability analysts [29].

The tables were then created in Access 95 making sure the three rules of normalization were followed. The type of data for each field was determined. Text, numbers, dates, and memo format were used in various fields as appropriate. The specific contents of each table and the arrangement of the data fields was determined based primarily on the way most diesel engine maintenance is performed in the Coast Guard today. A thorough understanding of the system to be modeled made this process relatively simple. The decisions were made to split the data into four tables and link them with the relationships described earlier. The use of related tables has made the database very efficient because a person can enter only the information necessary for a certain maintenance action without having to repeat entries or enter unnecessary data.

One of the most important features of a normalized database is the use of primary keys in each table. A primary key is any field or combination of fields in a table that uniquely identifies each table record. Access 95 will not allow you to enter records with duplicated values in the primary key. The primary key is used as a main index to speed data retrieval from large tables much like the index at the back of a large reference book. The tables of the DEREL database each have a primary key to help define the relationships between the tables. The engine serial number is used as the primary key in both the Equipment Information and Failure Information tables. The Preventative Maintenance and Corrective Maintenance tables use an auto-number primary key. Auto-numbers are sequential numbers that are automatically inserted when a record is added.

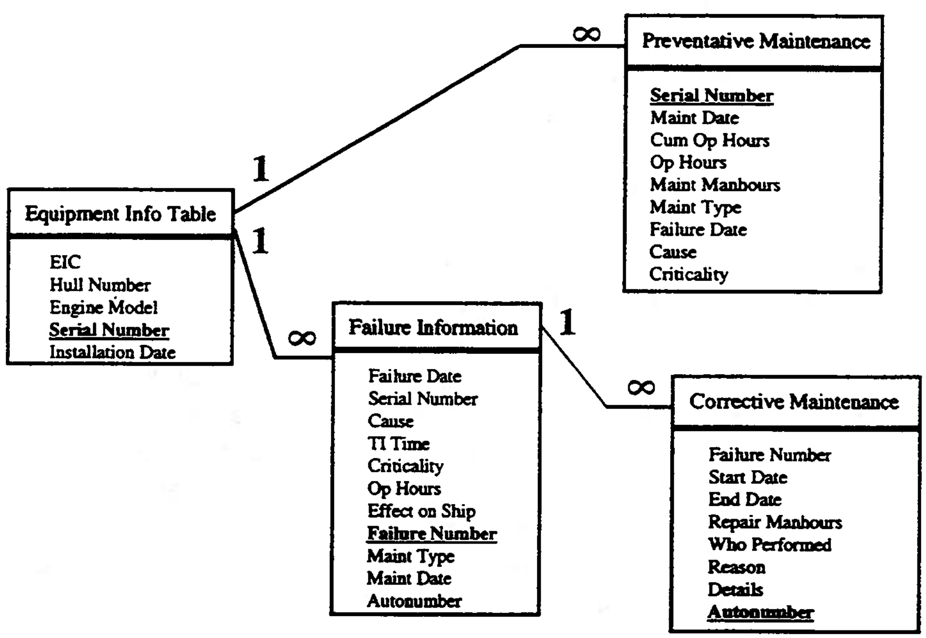


Figure 2 Primary Key Relationships

This allows for multiple maintenance entries to be indexed to the same engine serial number. Figure 2 displays the relationship layout of the DEREL tables. The data fields are listed for each table with the primary key underlined. The one-to-many relationships described previously are denoted by the numeral one and infinity symbol above the lines connecting the tables.

Next, prototype queries, forms, and reports were created. While designing these objects, design deficiencies became obvious and were corrected. For example, a report may have called for a maintenance history arranged chronologically where the table it calls upon does not store a date entry. Subsequently, a maintenance date field was added to that table.

The last steps in the initial design of DEREL was to solicit the opinions of USCG maintenance managers as to the content and structure of the database. The data fields and structure layout were distributed for review by the customer. Responses were received and changes to design made accordingly. The final refined DEREL database design is presented in the following section of this paper.

Data Integrity

Data integrity has become a very important feature of any modern reliability database. Without the specification and enforcement of data integrity rules, bad data will get into a database. The old adage "garbage in, garbage out' applies aptly in this case. Without standardized data forms, analyses of trends and mathematical calculations become virtually impossible. There are several integrity rules that are a necessary part of any database [28].

The DEREL database was designed to conform to these rules as much as possible. The first rule of data integrity is called the entity integrity rule. It simply states that primary keys cannot contain missing data. This should be obvious because you cannot uniquely identify or reference a row in a table if the primary key of that row can be empty. Fortunately, Access 95 automatically enforces this rule when a primary key is set.

The referential integrity rule states that a primary key value cannot be entered into a second table unless the referenced value exists in the referenced table. This prevents any unmatched primary key values in a database. The "enforce referencial integrity" option was activated for the four tables of DEREL along with the "cascade update related fields" option. This means that for update changes, the change is cascaded to all dependent tables. For deletions, the rows in all dependent tables are deleted.

There are other database integrity rules that are commonly called business rules. This type of rule is specific to each database and comes from the rules of the system being modeled by the database. The enforcement of these business rules are just as important as the enforcement of the general integrity rules discusses above. DEREL was designed with many examples of business rules to ensure data integrity. Many of the data fields do not allow blank entries (in addition to primary keys). In fact, only the memo fields that contain repair narratives are allowed to be entered as empty records. Another example of a business rule in DEREL is the rule that the Cumulative Operating Hours must be greater than or equal to the Operating Hours. This follows directly from the definitions of these fields in the data dictionary. This rule was added to the program to ensure that these two vital pieces of information are not confused or entered in error by the shipboard personnel.

Data Security

It is envisioned that the DEREL database will be used primarily by USCG maintenance managers for detailed trend analysis. The data records will be entered at the ship crew level and compiled, in one location, into a master database containing the entire fleet's data. There are obvious data security concerns at multiple levels. Who enters the data on the ship? How is the data sent to the master database and who controls the administration of system. These questions will be answered in the future by senior USCG maintenance managers if the decision to bring DEREL online is made. In the following discussion recommendations are made as to how to set up Access 95's security features to best protect the data from tampering.

During the design of DEREL the a simple database password security setup was used. This involves setting a single password for the entire database that all users must know to open the database. This system is very easy to implement and use but it is also easily compromised because all users use the same password. Access 95 offers more complicated security techniques that will be necessary for the DEREL database.

A workgroup based security model will be ideal for the DEREL database. Access 95's workgroup based security is based on users and their permissions, not passwords.

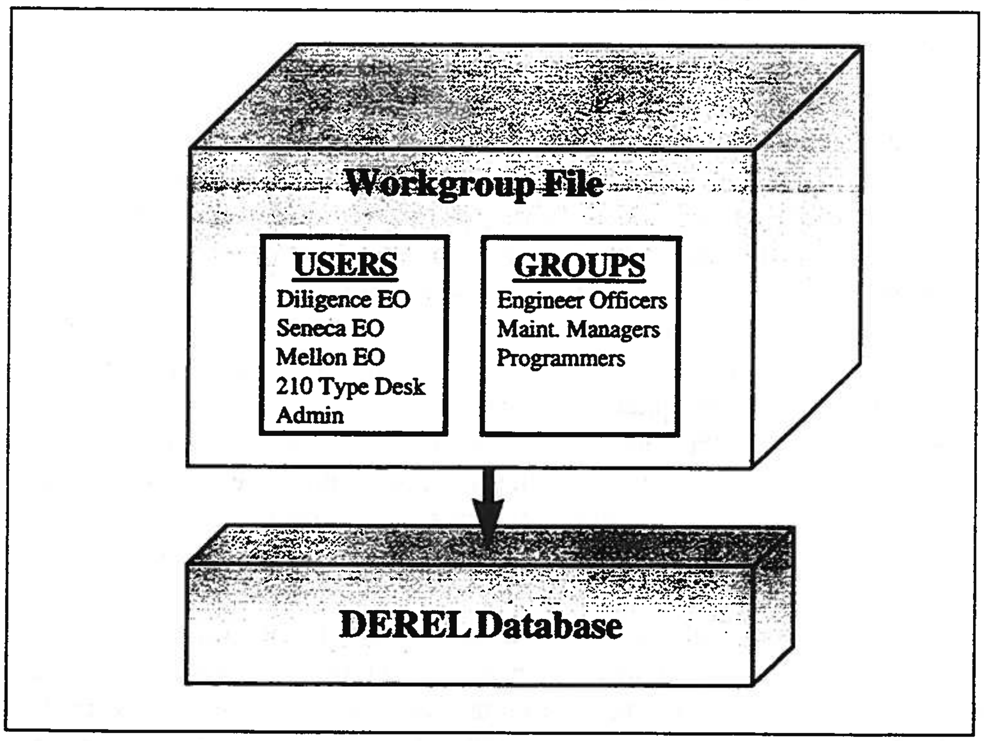


Figure 3 Security System for DEREL

This system requires each user to have both a user name and password. Each user controls their own password and can change it at any time without affecting other users. The passwords are more secure because they are not shared by a lot of users. User and group accounts and their passwords are stored in the workgroup file. The potential workgroup file for the DEREL database is shown below in figure (3). The workgroup file contains the user accounts and their passwords (Diligence EO, Seneca EO, etc.) and the three group accounts (Engineer Officers, Maint. Managers, and Programmers). It stores a number of pieces of information including: user account names and passwords, information about which users belong to each group, and various user preference settings. The groups are simply a collection of users with the same security permissions. The DEREL user groups would include all cutter engineer officers, and maintenance managers since they would all have approximately the same use requirements for the database.

Each user and group of an Access 95 database can have different levels of permission to work with a database. The administrator can assign the permission settings for each object in any combination seen in the chart below.

OBJECT	OPEN/ RUN	READ DESIGN	MODIFY DESIGN	ADMIN	READ DATA	UPDATE DATA	INSERT DATA	DELETE DATA
Table		X	X	X	X	X	X	X
Query		X	X	X	X	X	X	X
Form	X	X	X	X				
Report	X	X	X	X				

Table 2 Permission Sets for Each Type of Object

The DEREL database would logically allow the shipboard personnel to update data only without the ability to modify the design of the tables or forms. The maintenance manager would need permission to open and read the database but would have no need to update data under normal circumstances. Lastly, the programmers and administrator would require access to all of the databases features. Every user's permission set could be tailored to their job category specifications.

A special user group is the Admin user group. Access 95 always requires that there be at least on person in the Admin group. This requirement makes it impossible to have a workgroup without an administrator. Admin members can grant themselves permission to any database object. In addition, members of Admin always have the ability to manage user and group accounts in their workgroup. Any time a new object is created, the Admin group gets full permission to the new object. The DEREL database would require an administrator, probably at the Engineering Logistics Command, to control access to and design characteristics of the database.

Presentation of DEREL

The DEREL database was designed to be as "user friendly" as possible for the shipboard personnel using the program. Considerable effort was made to make it easily navigable within the point and click windows-based system of Access 95. The best way to become familiar with the capabilities of DEREL is to view the actual screens presented by the program. The following discussion presents the working elements of DEREL with a discussion of their capabilities and uses.

A session in the DEREL program is started at the Main Menu screen shown in appendix 9. The Main Menu is a form designed to help the user navigate the database. There are two primary way to use DEREL; to input new data or to view a report of existing data. The Main Menu is divided into halves for each of these uses. The left side of the main menu gives the user options for inputting new data. The right side gives the user options for viewing a report of existing data. One distinguishing feature of the Main Menu is the existence of seven command buttons. Command buttons are used on forms to start an action or set of actions. They are used in conjunction with subroutines, called macros, to perform numerous actions when they are clicked with the mouse pointer. These macros automate repetitive tasks and help ensure that those tasks are performed consistently and completely each time. The Main Menu contains six command buttons that open other forms and the "Quit DEREL" button that saves all changes made to table entries and immediately closes Access 95. The user is sent back to the original desktop view of their computer.

Inputting New Data

The first command button on the input side of the Main Menu is the "New Engine" button. It opens the Equipment Information Entry Form and allows the entering of engine specific information for a new engine only. This section should only be accessed once for each engine. Once an engine has its equipment information entered into DEREL, it will never change until the engine is replaced at which time an original equipment information entry is made for the new engine. Appendix 10 shows the screen view of the Equipment Information Entry Form. Data must be typed into the EIC, Serial Number, and Installation Date while the Engine Model and Hull Number information may be entered with the help of a list box. The list box provides all possible answers to the question and allows the user to simply pick the correct one. This technique allows the fast and accurate entry of complicated text information. Once a new engine has been entered, the user should use the "Save Current Entry" button to save the record. Lastly, the return to the Main Menu form is facilitated through the use of the "Return to Main Menu" command button.

The Equipment Information Entry Form enters information into the Equipment Information Table. This table contains the actual location and layout of the data stored by DEREL. The table stores the information within DEREL and is not actually seen by the common user. An example set of data in the Equipment Information table is seen in the table below.

EIC	Hull Number	Engine Model	Serial Number	Installation Date
1234567	WAGB-10	ALCO 251-B	28354	9/5/90
1234567	WHEC-717	FM 38TD8 1/8	19654	6/6/91
1234567	WMEC-901	ALCO 251-B	17293	8/25/89
1234567	WHEC-726	FM 38TD8 1/8	18654	7/9/88

Table 3 Sample Equipment Information Table

The second command button on the input data side of the Main Menu is the "Preventative Maintenance" button. It opens the Preventative Maintenance Entry Form seen in appendix 11. Serial Number and Engine Model are carried over from the Equipment Information Table and do not need to be entered. The bottom of the form is used to enter Cumulative Operating Hours, Operating Hours, Maintenance Manhours, and Maintenance Type. The Maintenance Type entry is made easier by the existence of a list-box control. The "Save Current Entry" command button saves the current record into the Preventative Maintenance table. An example set of data in the Preventative Maintenance table is seen in the table below.

Serial Number	Maint Date	Cum Op Hours	Op Hours	Maint Hrs	Maint Type
17366	8/1/97	5000	2000	8	Scheduled Service/Inspection
17366	8/10/97	5100	2100	6	Scheduled Service/Inspection
17366	8/15/97	5150	2150	20	Partial Overhaul
17293	8/1/97	8000	8000	25	Center Section Overhaul
17293	8/20/97	8200	200	5	Scheduled Service/Inspection
17293	8/22/97	8300	300	15	Partial Overhaul

Table 4 Sample Preventative Maintenance Table

The Preventative Maintenance Entry Form is a special kind of Access 95 form that also contains a subform. It takes advantage of the fact that if you have a one-to-many relationship you can use a main form and a subform within a single form window to view both sides of the relationship. A single engine can have multiple preventative maintenance entries and the Preventative Maintenance entry form allows you to see all of these records together. In this case, the engines serial number and model are shown in the main form, while the preventative maintenance information is entered into the subform. Access 95's subform feature is intelligent because as you move from engine to engine in the main form, it automatically applies a filter to the subform so that the latter only displays records relevant to the main form's current engine. When Access displays a main form and subform, it provides two sets of record navigation buttons that enable you to scroll through both forms independently. This allows the user to scroll through records to find the engine on their ship instead of having to enter the serial number and engine model. The main form's navigation buttons are at the bottom of the form window, and the subform's navigation buttons are at the bottom of the subform itself.

The final command button located on the input side of the Main Menu is the "Failure/Corrective Action" button. It triggers a macro that sends the user to the

Failure/Corrective Action Information Entry Form seen in appendix 12. This is another form that contain a subform. The main form allows for entry of the failure information such as Failure Date, Op Hours, Trouble Isolation Time, Cause of Failure, Effect on Ship, and Criticality. This information is saved in the Failure Information Table. A sample set of data in the Failure Information Table is seen below in table 5. An interesting note on

Failure Date	Serial	Cause	Op Hours	TIT	Criticality	Effect on Ship	Code	Failure
8/10/97	17293	connecting rod	2000	2	major	reduced ship	501	7
8/21/97	17293	fuel pump	2100	3	minor	no effect on	510	8
9/5/97	17293	turbocharger	2150	5	major	reduced mission	512	9

Table 5 Sample Failure Information Table

this table is the existence of the Failure Number data field. This field contains auto-numbers which are sequential numerals automatically inserted when a new record is added to the table. In this case, as a new failure record is entered, Access assigns an auto-number to the record. Table 5 displays failure numbers seven, eight, and nine for the engine with serial number 17293. The auto-number is used to link the failure with it's corrective actions.

The subform of the Failure/Corrective Action Information Entry Form is the Corrective Maintenance Entry Form. It allows for the entry of Start Date, End Date, Repair Manhours, Repair Performed By, Reason for Repair, and Details for a given corrective action. The form is designed such that the user can enter multiple corrective actions for a single failure. A typical example of this is seen in the Corrective Action Table below. Failure number seven has multiple corrective actions listed. The first

Failure	Start Date	End Date	Repair	Who Performed	Reason	Details
7	8/10/97	8/11/97	10	ship's crew	degraded	Con rod replaced
7	8/11/97	8/12/97	8	ship's crew	degraded	Incorrect first
7	8/15/97	8/20/97	25	contractor/shipya	complete failure	complete overhaul
8	8/21/97	8/21/97	2	ship's crew	incipient failure	pump replaced
9	9/5/97	9/7/97	12	ship's crew	degraded	leak weld repaired

Table 6 Sample Corrective Maintenance Table for Serial #17293.

attempt at repairing the connecting rod was completed incorrectly causing the repair to be unsuccessful. This required a second attempt on 8/11/97 and finally a complete overhaul by a shipyard starting on 8/15/97. All of the corrective actions remain linked to the original failure number until the repairs return the engine to running condition. This allows a maintenance manager to easily trace chronic engine problems with complicated repair histories.

The Failure/Corrective Action Information Entry Form contains a "Save Corrective Maintenance Information" button to save the newly entered record to the Corrective Maintenance Table. Also, a "Return to Main Menu" command button exists to send the user back to the Main Menu when data entry is complete.

Viewing a Report of Existing Data

The first of the command buttons on this side of the Main Menu is the "Failure Data with Corrective Action" button. It triggers a macro that initiates a sequence of events which generate a report. The macro first asks the user for the engine serial number and then for the beginning and ending days of the time period on which to search for data. The Failure Table and Corrective Action Table are then queried with the resulting data summarized in the format shown below in figure 4. Information from both tables is

Failure Information plus Corrective Action

Serial #	Fail Date	Cause	TI Time	Code	Criticality	Effect on Ship	Start	End	Mhrs	Who Performed	Reason
17293	9/5/97	turbocharger	5	502	major	reduced mission	9/5/97	9/7/97	12	ship's crew	degraded
17293	8/21/97	fuel pump	3	510	minor	no effect on	8/21/97	8/21/97	2	ship's crew	incipient failure
17293	8/10/97	connecting	2	512	major	reduced ship	8/15/97	8/20/97	25	contractor/yard	complete failure
17293	8/10/97	connecting	2	512	major	reduced ship	8/11/97	8/12/97	8	ship's crew	degraded
17293	8/10/97	connecting	2	512	major	reduced ship	8/10/97	8/11/97	10	ship's crew	degraded

Figure 4 Sample Failure Data with Corrective Action Report

combined and presented in an easy to read format. The purpose of the report is to provide a summarized view of failure data for an engine and the ensuing corrective action used to correct the problem. The report can be regenerated repeatedly for any engine serial number and any combination of dates.

The second command button on the viewing a report side of the Main Menu is the "Open Operating Hours Summary Report" button. It triggers a macro that opens a report summarizing all failure and preventative maintenance actions. A sample of the Operating Hours Summary report is seen in figure 5. This report can be used by the shipboard engineer to view the engine history of all of the engines on the ship. Figure 5 displays an engine hours history for two fictitious engines with serial numbers 17293 and 17366. This form will print out all of the information the database holds on any engines on file for a complete history every time the command button is activated. The Operating Hours Summary Report gives a concise summary of an engine's history, chronologically by Operating Hours, so that the preventative maintenance proceeding a failure is easily recognizable.

Operating Hours Summary

Serial Number 17293

Op Hours	Failure Date	Cause	Criticality	Maint Date	Maint Type
3000	9/5/97	turbocharger	major		
2200	8/21/97	fuel pump	minor		
2150				8/15/97	Partial Overhaul
2100	8/10/97	connecting rod	major		
2100				8/10/97	Scheduled Service/Inspection
2000				8/1/97	Scheduled Service/Inspection

Serial Number 17366

Op Hours	Failure Date	Cause	Criticality	Maint Date	Maint Type
8000				8/1/97	Center Section Overhaul
300				8/22/97	Partial Overhaul
200				8/20/97	Scheduled Service/Inspection

Figure 5 Sample Operating Hours Summary Report

This report was created using a special kind of query called a union query. This means that records from two separate tables were combined and sorted. In this case, information from the Failure Information Table and the Preventative Maintenance Table were combined with Operating Hours being the common field. To do this, Structured Query Language (SQL) was programmed into the macro. This is a popular form of a data access language which instructs Access to perform complex operations not featured in the normal pull down menus of the program. The actual SQL statements are shown below.

```
SELECT [Serial Number], [Op Hours], [Failure Date], [Cause], [Criticality], [Maint Date],[Maint Type]
FROM [Preventative Maintenance]

UNION ALL SELECT [Serial Number], [Op Hours], [Failure Date], [Cause], [Criticality], [Maint Date],
[Maint Type]
FROM [Failure Information]
ORDER BY [Serial Number], [Op Hours];
```

Figure 6 The Operating Hours Summary Report' SQL Statements

They tell Access to select all records in the fields listed in brackets from the Preventative Maintenance Table and combine them with all the fields listed in bracket from the Failure

Information Table. In addition, Access is instructed to sort the records that are returned from the initial query first by serial number and then by operating hours.

The last command button on the right side of the Main Menu is the "Summary Report for an Engine Model" button. It triggers a macros that first asks the user for the engine model to be summarized. Special care must be taken to enter the engine model information exactly as it is presented in the list-box if the Equipment Information Form. The macro is sensitive to any difference in letter case or spacing. The user may need to refer to the Equipment Information Form to make sure they have the correct syntax for and engine model. Next, the user is asked to provide a beginning and ending date for the time period of information to be summarized. Access activates a query and produces a report in the format shown in figure 7. The sample report summarizes fictitious information for the ALCO 251-B engine model in the month of August 1997. The purpose of this report is to provide the maintenance managers with a summarized view of

Engine Model Summary

EngModel	Fail Date	Serial #	Cause	TI Time	Criticality	Effect on Ship	CumOpHrs	OpHours	MaintType
ALCO 251-B	8/21/97	17293	fuel pump	3	minor	no effect on ops	5150	2150	Partial Overhaul
ALCO 251-B	8/21/97	17293	fuel pump	3	minor	no effect on ops	5100	2100	Scheduled Servic
ALCO 251-B	8/21/97	17293	fuel pump	3	minor	no effect on ops	5000	2000	Scheduled Servic
ALCO 251-B	8/10/97	17293	connecting rod	2	major	reduced ship speed	5150	2150	Partial Overhaul
ALCO 251-B	8/10/97	17293	connecting rod	2	major	reduced ship speed	5100	2100	Scheduled Servic
ALCO 251-B	8/10/97	17293	connecting rod	2	major	reduced ship speed	5000	2000	Scheduled Servic

Figure 7 Sample Engine Model Summary Report

failure information for any particular engine model. The information presented here can be used to look for trends and evaluate the general reliability characteristics of an engine model across the entire USCG fleet.

Another feature of Access that will be very useful for the Coast Guard's maintenance managers, is the ability to easily create a query that selects records based on any criteria desired. This feature allows the database to be simplified by eliminating the need for records to be coded for sorting. Access will search for and summarize records based on specific criteria without these codes. For example, the records of the failure information table include a field containing "critical", "major", or "minor". It may be desired to view a summary of all engine failures that are considered "critical" for a certain engine type. The DEREL user can create a query to search the database for any record that include the information "critical" in type of failure field. Another example would be to summarize all of the records that have the same type of engine failure, such as crankshaft failure.

The steps to create a query are very simple, especially for a routine user of the program. Access provides a user-friendly environment to learn the details of designing queries, with the aid of any program user's guide. The maintenance managers will use this feature the most and should be familiar with the design of basic queries. Once a query is created it can be saved for repeated searches in the future. Needless to say, there are numerous combinations of criteria that can be used for a query of DEREL and so no attempt is made here to design the queries to satisfy every possible situation.

Implementation Issues

There are numerous implementation issues that must be addressed prior to the introduction of the DEREL database throughout the Coast Guard fleet. Most of these issues are related to the logistics of the launch itself and the preserving data quality once the program is in use. Both are vital aspects of successfully utilizing DEREL and will be discussed in turn.

Logistics

As with any new Coast Guard initiative, the DEREL database will require extensive planning and coordination to get off the ground. The central issues are personnel related. The actual dissemination of the program and its policies can be handled very inexpensively by mailing diskettes to the ships on the fleet along with instructions for installation and operation. There are almost no other logistic costs associated with the implementation of DEREL.

An important issue that must be addressed is the transferring of information between the collection sites and the DEREL master data bank. In other words, how do the ships transfer data to the DEREL administrator? The most efficient technology for this would involve the Internet. E-mail from the ship would be received by the administrator and the new data up-loaded into the master DEREL file easily. Access 95 offers a simple pull down approach to doing this. If Internet technology is not available or practical, the data files can be saved on a diskette and mailed to the DEREL administrator on a monthly or quarterly basis.

The central issues regarding the launching of DEREL involve personnel. There are some very important tasks that must be completed prior to initiating DEREL into the family of naval engineering maintenance tools. First, DEREL must be converted to Access 2.0 format. The University of Michigan is equipped with the more advanced Access 95 version of the Microsoft product. All indications are that the transition will be smooth, but any unforeseen glitches must be ironed out by a knowledgeable Access programmer.

Also, a comprehensive guideline manual for data collection must be written for DEREL. This "user's guide" is essential to successfully training shipboard personnel on the use of the program. At a minimum, it should contain installation instructions for the program and a detailed tutorial that presents all of the capabilities of DEREL. Subsequent revisions of the manual must be issued as necessary. The manual must be authored by the same person who converted the program to Access 2.0 because of their familiarity with the software.

Another logistics issue that must be thoroughly thought out is the definition of security permissions. This issue was addressed previously in the Data Security portion of this paper but requires another mention here. The actual user group names, passwords, and permissions must be determined and programmed into Access. Care must be taken to ensure that the security system is set up properly to provide untainted data without making the system unmanageable.

The person to complete the conversion, writing of the user's guide, and programming of security permissions would, most logically, become the DEREL Administrator discussed in the security portion of this paper. The administrator would update the master data file at one location and make any changes or additions to the program required. The logistics of the launch of DEREL would have to be the administrator's primary responsibility. Also, the details of the DEREL database program must be outlined in a detailed Coast Guard Instruction for reference by the entire fleet. It seems apparent that the administrator position will require significant time sacrifices in, at least, the first few months of the program. In fact, if the Coast Guard desires a rapid launch, the duties of the administrator may require a two or three person staff working full time at the beginning. The issue of who the administrator will be, who he/she will work for, and where the central data bank of DEREL data will be kept are all essential questions that must be answered.

Data Quality

Another aspect of the implementation of DEREL that is vital to its success is the maximization of data quality. This means getting the maximum quality of data from all the sources available. The first step in this effort is the creation of a thorough user's guide outlined above. Second, there must be a close communication system between the data collector's and the project management as to the procedures and interpretation rules. Also, the software must contain built-in consistency checks in the data collection modes. DEREL does this more than adequately as discussed in the data integrity portion of this paper.

The quality control of the data itself should be carried out in several steps [30].

1. The individual data collectors on the ships must be trained to recognize appropriate DEREL database data points and correctly record them as necessary.
2. The engineer officer must check the data accuracy upon entering it into the program onboard their ship.
3. The DEREL Administrator should perform periodic random spot checks of data from all sources.
4. Final verification of data quality of the complete database should be made by the senior maintenance management.

It is anticipated that there will be two major challenges in the quality assurance process of the DEREL database. The harmonization of rule interpretations and quality standards between data collectors will be difficult. Also, dealing with changes in the software, guidelines, or data definitions in the life of the DEREL project will present numerous obstacles. These can be overcome with forethought and dedicated effort to smooth coordination between the DEREL administrator and the shipboard engineers.

Topics of Further Research

The conversion of DEREL into Access 2.0 and the development of the user's guideline manual present possible subjects for further study by graduate level Coast Guard students. In addition, the specifics of the security system must be programmed into the database and field tested.

However, an academically more interesting project would be the utilization of data stored by the DEREL database in developing a model for engine replacement practices. A very similar project was completed by Perakis and Inozu (reference 17). Building on their approach to creating a reliability model that rationalizes winter lay-up practices for Great Lakes marine diesel ships, a future student could use DEREL's data to improve the Coast Guard's replacement practices. A prerequisite to this research would be the accumulation of sufficient data (approx. 5 years worth) in the DEREL system to support the necessary calculations. Given that the derivation of a similar reliability model was completed by Perakis and Inozu, the project would be feasible for a M.S.E student or team of students.

References

1. Commandant Instruction M9000.6B, Naval Engineering Manual, U. S. Coast Guard, September 1993.

2. Moubray, J., Reliability-centred Maintenance, Butterworth-Heinemann Ltd, Oxford, 1991.

3. Rees, J. V., Hostages of Each Other: The Transformation of Nuclear Safety since Three Mile Island, University of Chicago Press, 1994.

4. Billinton, R., and Allan, R. N., Reliability Evaluation of Engineering Systems, Concepts and Techniques, Plenum Press, 1992.

5. Perakis, A. N., and Inozu, B., "Reliability Analysis of Great Lakes Marine Diesels: State of the Art and Current Modeling," Marine Technology, Vol 27, No. 4, July 1990.

6. White, M. F., and Rasmussen, M., "Vibration Diagnosis Data Bank for Machinery Maintenance," Norwegian Maritime Research, No.3, 1984.

7. Dabbar, J. M., Ward, D. A., and Logan, K. P., "Expert Performance Diagnostic System for Marine Diesel Engines," in SNAME, 21st Century Ship and Offshore Vessel Design, Construction and Operation Proceedings - Ship Technology and Research Symposium, April 12-15, 1989.

8. "A Diagnostic Approach to Engine Health," The Motor Ship, Vol. 70 No. 830, September 1989.

9. Story, D. S. and Story, M. E., "A Standard Method for the Integration of Engine Diagnostic Systems," in Proceedings, SNAME, 1994 Ship Operations, Management and Economics Symposium, U. S. Merchant Marine Academy, Kings Point, N.Y., May 12, 1994.

10. Prichard, J. W., "Equipment Age-Reliability Analysis," Proceedings - The 20th Anniversary Technical Symposium, Association of Scientists and Engineers of the Naval Sea Systems Command, 1983.

11. Horigome, M. and Okawara, I., "Statistical Characteristics of Maintenance of Main Diesel Engine Systems," Bulletin of Marine Engineering Society of Japan, Vol. 7, No. 1, March 1979.

12. Horigome, M. and Umemoto, S., "Valve Replacment on Marine Diesels," Bulletin of Marine Engineering Society of Japan, Vol. 11, No. 2, 1983.

13. Hashimoto, T. et al, "Evaluation of Reliability and Maintainability of Marine Engine Subsystems," Bulletin of Marine Engineering Society of Japan, Vol.9, No. 1, March 1981.

14. Hashimoto, T. and Ishizuka, K., "Consideration for the Initial Failure of Marine Engine," Bulletin of Marine Engineering Society of Japan, November 1973.

15. Inozu, B. and Perakis, A. N., "Statistical Analysis of Failure Time Distributions of Great Lakes Marine Diesel Engines Using Censored Data," Journal of Ship Research, March 1991.

16. Inozu, B. and Perakis, A. N., "Reliability-based Replacement Algorithms and Applications to Marine Diesels," presented at the Operations Research 1990 International Conference, Vienna, Austria Aug. 28-31, 1990; published in Proceedings, German/Austrian Operations Research Societies, Spring Verlag, Berlin.

17. Perakis, A. N., and Inozu, B., "Optimal Maintenance, Repair, and Replacement for Great Lakes Marine Diesels," European Journal of Operational Research, Vol 55, December, 1990.

18. Bazovsky, I., "Reliability Mathematics as Applied to Shipboard Machinery," Proceedings of the Conference on Advanced Marine Engineering Concepts for Increased Reliability, February 1963.

19. Ship's 3-M Database Course Manual, Vol 3.0, Naval Sea Logistics Center, 1996.

20. OPNAV Instruction 4790.4C, Ships' Maintenance and Material Management (3-M) Manual, U.S. Navy, November 1994.

21. Inozu, B. D., Aksoy, Y., and Bulgak, A. A., "Ship Reliability Data Banks and Their Uses in Ship Operations Management," in Proceedings, SNAME, 1994 Ship Operations, Management and Economics Symposium, U. S. Merchant Marine Academy, Kings Point, N.Y., May 12, 1994.

22. Nikolaidis, E. and Parsons, M. G., "Marine Diesel Maintenance Management System for the Interlake Steamship Company," Department of Naval Architecture and Marine Engineering, The University of Michigan, Ann Arbor, Mich., 1984

23. Hashimoto T., "The Introduction of SRIC Database in Japan and Estimation of Reliability and Maintainability for Marine Engine System with its Database System," Proceedings of ISME'95 - Fifth International Symposium on Marine Engineering, Volume II, pp.473-492, Yokohama, Japan, August 17-21, 1995.

24. Santorv, H. A., Hokstad, P., and Thompson, D. W., "Practical Experiences with a Data Collection Project: the OREDA Project," Reliability Engineering and System Safety, Vol. 51, 1996. Pp.159-167.

25. Inozu, B. D., Schaedel, P. G., and Karaszewski, Z. J., "Reliability, Availability, Maintainability (RAM) Database/Shipnet of the Ship Operations Cooperative Program: A Status Report from Panel M-41," in Transactions, SNAME, Vol 104, 1996. Pp.451-473.

26. Inozu, B. D., Schaedel, P. G., Molinari, V., and Roy, P., "Implementation of a Shared Reliability, Availability, Maintainability (RAM) Database for Ship Machinery to Improve Cost Effectiveness and Safety," presented at the 1997 Transportation Operations, Management and Economics Symposium at the Meadowlands Hilton Hotel, May 14-15, 1997.

27. Inozu, B. D., Schaedel, P. G., and Karaszewski, Z. J., "SOCP's RAM Database/SHIPNET: A cross functional Network for Ship Life Cycle Cost and Safety Decision Support," Proceedings of ICMES'96: Safe and Efficient Operations of Ships - New Approaches for Design, Operation, and Maintenance, pp. 111-121, Trondheim, Norway, June, 1996.

28. Litwin, P., Getz, K. Gilbert, P., Reddick, G., Access 95 Developer's Handbook, Sybex Inc., 1996.

29. Cooke, R. M., "The Design of Reliability Data Bases, Part 1: Review of Standard Design Concepts," Reliability Engineering & System Safety, Vol 51, 1996.

30. Sandtorv, H. A., Per Hokstad, Thompson, D. W., "Practical Experiences with a Data Collection Project: The OREDA Project", Reliability Engineering & System Safety, Vol 51, 1996.

Appendix 1 – Oil Analysis Request Form

OIL ANALYSIS REQUEST						KEY PUNCH CODE
TO: OIL ANALYSIS LAB CHARLESTON NAVAL SHIPYARD NOAP LAB (CODE 134), CHARLESTON, SC 29408						
FROM: MAJOR COMMAND CGD ONE						
FROM: OPERATING ACTIVITY *(Include ZIP Code/APO)* USCGC SPENCER, WMEC 905, BOSTON, MA 02109						
EQUIPMENT MODEL/APL 665360253						
EQUIPMENT SER. NO. 970-873						
END ITEM MODEL/HULL NO. WMEC-905						
END ITEM SER. NO./EIC B101/MAIN PROPULSION ENGINE, DIESEL, MECHANICAL						
DATE SAMPLE TAKEN *(DAY, MO., YR.)* 22-12-82				LOCAL TIME SAMPLE TAKEN 1345		
HOURS/MILES SINCE OVERHAUL 1200 HOURS						
HOURS/MILES SINCE OIL CHANGE 1200 HOURS						
REASON FOR SAMPLE [X] ROUTINE [ ] LAB REQUEST [ ] TEST CELL [ ] OTHER *(Specify)*						
OIL ADDED SINCE LAST SAMPLE *(Pt., Qts., Gals)* 50 GALLONS						
ACTION TAKEN PURIFIED OIL						
DISCREPANT ITEM						
HOW MALFUNCTIONED						
HOW FOUND [X] LAB REQUEST [ ] CREW						
HOW TAKEN [ ] DRAIN [ ] TUBE [X] HOT SAMPLE [ ] COLD SAMPLE						
REMARKS NO.1 MAIN DIESEL ENGINE						
FOR LAB USE ONLY						
SAMPLE RESPONSE TIME						
FE	AG	AL	CR	CU	MG	NI
PU	SI	SN	TI	MO		
LAB RECOMMENDATION						
SAMPLE NO.			COMPONENT CONTROL NO. *(CCN)*			

DD FORM 2026 REPLACES AFTO FORM 110, APR 78, DA FORM 3282, NOV 72,
1 AUG 76 AND NAVMAT FORM 4731/1, FUL 72 WHICH ARE OBSOLETE

Appendix 2 – Wear Metal Trend Example

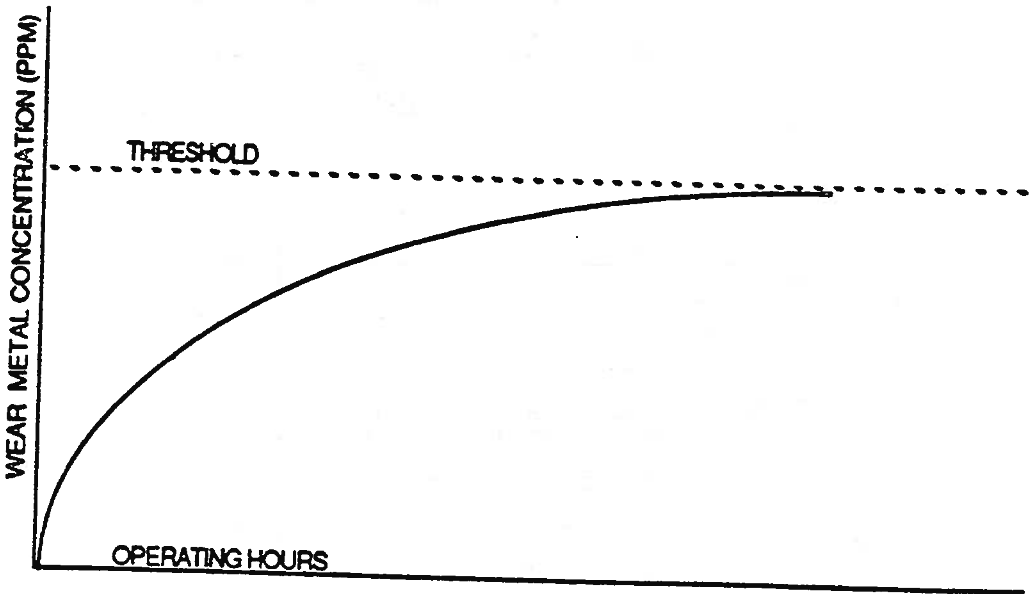
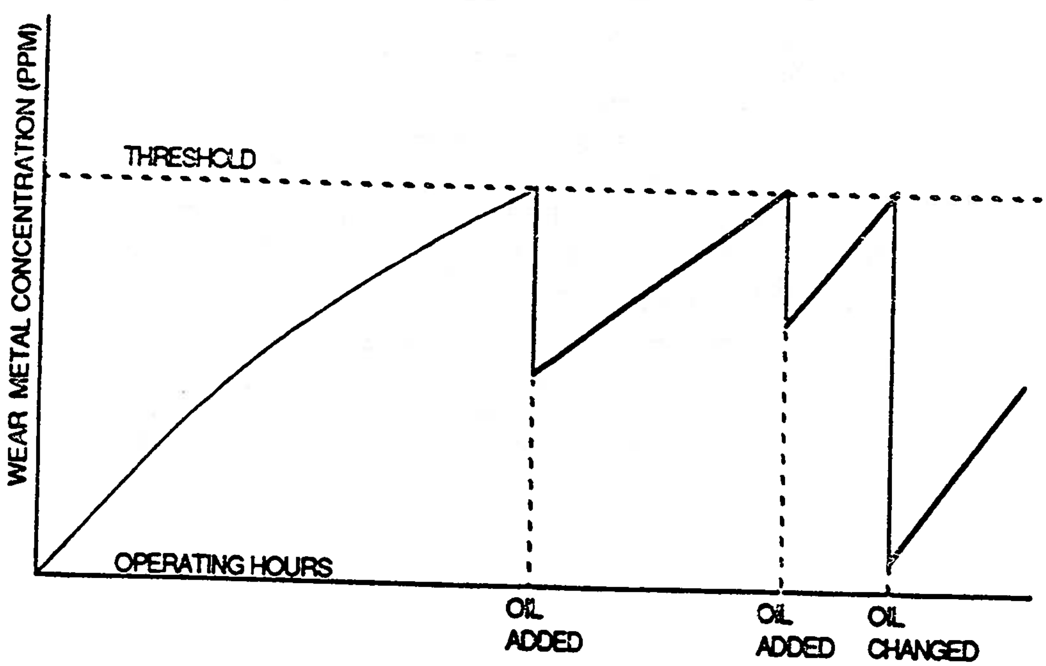


Figure 262-2. Wear Metal Concentration Vs Constant Oil Replenishment



Appendix 3 – Wear Metal Threshold Limits

EQUIPMENT/EIC	Fe	Ag	Al	Cr	Cu	Mg	Ti	Pb	Sn	Ni	Mo	Si
MPE/B101												
ALCO V16-251B	52	0	13	23	33	45	0	10	0	2	2	11
ALCO 18-251-F	51	0	13	23	33	100	0	10	0	4	4	54
CATERPILLAR D-353	57	0	17	7	15	41	0	21	0	2	2	11
CATERPILLAR D-375	57	0	17	7	15	41	0	21	0	2	2	11
CATERPILLAR D-379	57	0	17	7	15	41	0	21	0	2	2	11
CATERPILLAR D-398	57	0	17	7	15	41	0	21	0	2	2	11
CUMMINS V12-525	75	0	15	13	20	40	0	30	15	0	0	12
CUMMINGS V12-600	75	0	15	13	20	40	0	30	15	0	0	12
COOPER-BESSERMER MBm-12	43	0	3	5	14	24	0	10	0	2	2	21
ENTERPRISE DMG-38	43	0	9	25	19	34	0	10	0	1	1	6
FAIRBANKS-MORSE 38TD 8-1/8	39	2	6	53	35	100	0	15	2	2	2	11
GENERAL MOTORS 8-268A	99	5	4	15	105	100	0	90	0	0	0	17
GM 6-71	88	0	27	30	27	100	0	19	5	2	2	17
GM 8-110	140	0	0	30	125	100	0	30	45	0	0	50
GM 16V 149	140	0	0	30	125	100	0	30	45	0	0	50
PAXMAN 16RP200M	85	0	10	50	15	0	0	20	17	0	0	25
WAUKESHA 6NKDBSM	79	4	32	25	60	100	0	59	0	0	0	10
WAUKESHA LRDBSM	79	4	32	25	60	100	0	59	0	0	0	10
WAUKESHA F-1905-DSIM	79	4	32	25	60	100	0	59	0	0	0	10
MEP/C101												
ALCO V16-251F	52	0	13	23	33	45	0	10	0	2	2	11
ENTERPRISE DSR 46	43	0	9	25	19	34	0	10	0	1	1	6
FAIRBANKS-MORSE 38D 8-1/8	65	0	3	12	100	100	0	21	13	2	4	7
CATERPILLAR D-398	57	0	17	7	15	41	0	21	0	2	1	11
COOPER-BESSEMER												
GN-8, GND-8, GSB-8	43	0	3	6	14	24	0	10	0	2	2	21
GM 12-567	84	0	25	27	26	100	0	17	3	2	2	15
GM 8 & 12 278A	99	5	4	15	105	100	0	90	0	0	0	17
INGERSOL-RAND'S	63	4	32	20	60	100	0	35	0	0	0	17
MPE/D101												
PRATT-WHITNEY FT4A-2	39	3	0	4	3	21	4	40	17	3	3	9
PRATT-WHITNEY FT4A-6	39	0	0	4	1	0	0	40	10	2	0	9
PRATT-WHITNEY FT4A-12	39	0	0	4	3	21	4	40	17	3	3	9
RGM/B301												
FARRELL-BIRMINGHAM	50	0	5	2	30	40	0	40	0	2	2	10
LUFKIN HSO 1616	28	0	6	2	33	41	0	43	0	2	2	14
LUFKIN MSO 2724	34	0	6	2	33	45	0	39	0	2	2	14
PHIL-GEAR DHMGS	56	0	5	2	15	28	0	10	0	2	2	17
PHIL-GEAR 75VMGS	56	0	5	2	15	28	0	10	0	2	2	17
PHIL-GEAR 120 DHMGS	56	0	5	2	19	100	9	10	4	3	3	13
WESTERN 46123R	22	2	5	2	19	100	9	10	4	3	3	13
PC/B408												
ESCHER-WYSS 400G	87	3	4	5	23	100	0	12	0	2	3	10
KAMEWA 66/4	23	0	5	2	76	100	1	23	5	2	1	11
PROP SYS PSI 50/3	18	1	2	1	24	1	2	6	7	1	3	10
PROP SYS PSI 63/4	18	1	2	1	24	1	3	6	7	1	3	10
PROP SYS PSI 125/4	18	1	2	1	24	4	3	6	7	1	3	10
PC/C408												
ESCHER-WYSS 'N'	87	3	4	5	23	100	0	12	0	2	3	10
MM/M101												
WESTINGHOUSE S082P046-SSG/3101	20	0	0	4	20	100	0	10	5	2	3	10
ALCO V8-251B	52	0	13	23	33	45	0	10	0	2	2	11
CATERPILLAR D-343	57	0	17	7	15	41	0	21	0	2	2	11
CATERPILLAR D-318	57	0	17	7	15	41	0	21	0	2	2	11
CATERPILLAR D-348	57	0	17	7	15	100	0	10	0	4	4	50
CATERPILLAR D-398	57	0	17	7	15	41	0	21	0	2	1	11
CATERPILLAR 3304	86	0	18	9	28	0	0	51	0	0	0	24
FAIRBANKS-MORSE 38E5-1/4	69	0	8	4	20	100	1	13	6	1	3	9
FAIRBANKS-MORSE 38F5-1/4	69	0	3	3	11	100	1	13	6	1	3	6
GM LL-8-567CR	24	2	5	12	23	100	7	9	0	2	2	12
GM8	110	0	25	20	25	100	0	30	5	2	2	15
GM6061	88	0	27	30	27	100	0	20	5	2	2	15
GM 4 & 6071	88	0	27	30	27	100	0	19	5	2	2	17
GM 3, 6, 8 - 268A	99	5	4	15	105	100	0	90	0	0	0	17

Appendix 4 – Engine Application Table

Engine Make and Model	Overhaul Interval Hours *	Oil Analysis	Compression and Firing Pressures	Crankcase Vacuum	Inlet Air Pressure	Exhaust Pressure	Lube Oil Consumed
ALCO							
16-251-B	18,000	X	X	X	X	X	X
16-251-CE	18,000	X	X	X	X	X	X
16-251-F	18,000	X	X	X	X	X	X
18-251-F	18,000	X	X	X	X	X	X
CATERPILLAR							
D-311	12,000	X		X	X	X	X
D-318	12,000	X		X	X	X	X
D-330	12,000	X		X	X	X	X
D-333	12,000	X		X	X	X	X
D-343	12,000	X		X	X	X	X
D-348	12,000	X		X	X	X	X
D-353	20,000	X		X	X	X	X
D-375	16,000	X		X	X	X	X
D-379	20,000	X		X	X	X	X
D-398	16,000	X		X	X	X	X
D-399	16,000	X		X	X	X	X
D-3304	10,000	X		X	X	X	X
D-3412	20,000**	X		X	X	X	X
D-3406B	12,000	X		X	X	X	X
D-3516	12,000	X		X	X	X	X
COOPER-BESSEMER							
GND8-600	7,000	X	X	X	X	X	X
CUMMINS							
V 12-525M	8,000	X		X	X	X	X
VT12-600M	8,000	X		X	X	X	X
VTA12-700M	8,000	X		X	X	X	X
VT 903M	10,000			X	X	X	X
FAIRBANKS-MORSE							
38D 8 1/8	12,000***	X	X	X			X
38TD8 1/8	12,000	X	X	X	X	X	X
PAXMAN****							
16RP200M	18,000	X	COMPRESSION ONLY	X	X		X
DETROIT							
6V53	12,000			X	X	X	X
6V92	12,000			X	X	X	X

Appendix 4 – Engine Application Table

Engine Make and Model	Overhaul Interval Hours *	Oil Analysis	Compression and Firing Pressures	Crankcase Vacuum	Inlet Air Pressure	Exhaust Pressure	Lube Oil Consumed
GENERAL MOTORS							
8-645	16,000	X	X	X	X	X	X
12-567	12,000	X	X	X	X	X	X
12-278	10,000	X	X	X	X	X	X
8-278	10,000	X	X	X	X	X	X
8-268	10,000	X	X	X	X	X	X
6-268	10,000	X	X	X	X	X	X
3-268	10,000	X	X	X	X	X	X
6-110	10,000	X	COMPRESSION ONLY	X	X	X	X
12-V-71	10,000	X	COMPRESSION ONLY	X	X	X	X
8-V-71	10,000	X	COMPRESSION ONLY	X	X	X	X
6-71	12,000		COMPRESSION ONLY	X	X	X	X
4-71	12,000		COMPRESSION ONLY	X	X	X	X
2-71	12,000		COMPRESSION ONLY	X	X	X	X
WAUKESHA							
6NRDBSM	5,000	X	COMPRESSION ONLY	X	X	X	X
6NKDBSM	5,000	X	COMPRESSION ONLY	X	X	X	X
197-DLCM	5,000	X	COMPRESSION ONLY	X	X	X	X

NOTE:

* Engines shall be evaluated at 80 percent of the stated interval as per paragraph D.2. An engine that has already exceeded the stated interval shall have the center section overhauled within the next 2,000 hours.

** CATERPILLAR D-3412 engines on the 82' WPB shall be overhauled at 11,000 hours.

*** 213' WMECs should retain a 16,000 hour overhaul interval.

**** For Paxman engines on 110-foot WPBs, the intervals listed are for engine changeout intervals instead of overhaul.

Appendix 5 – Ship's Maintenance Action Form

OPNAV 4790/2K (Rev. 6-75) S/N 0107-LF-047-8011

SHIP'S MAINTENANCE ACTION FORM (2-KILO)

COMP DEFL

SECTION I. IDENTIFICATION

JOB CONTROL NUMBER

1. SHIP'S UIC
2. WORK CENTER
3. JOB SEQ. NO.
4. APL/AEL
4. SHIP'S NAME
5. EQUIPMENT NOUN NAME
6. WHO
7. STA
8. CAS
9. DFR
10.
11.
12.
8. HULL NUMBER
13. IDENT. EQUIPMENT SERIAL NUMBER
14. EIC
15. SAFETY HAZARD
16. LOCATION *(Compartment/Deck/Frame/Side)*
17. WHEN DISCOVERED DATE YR DAY

CONFIGURATION CHANGE

18. ALTERATIONS *(SHIPALT, ORDALT, Fld Chg, etc.)*

FOR INSURV USE

19. */**
20. INSURV NUMBER
21. SUFF
22. U
23. S
24. P/F

SECTION II. DEFERRAL ACTION

25. S/F MHRS. EXP.
26. DEFER. DATE YR. DAY
27. S/F MHRS. REM.
28. DEADLINE DATE YR. DAY

SECTION III. COMPLETED ACTION

29. ACT. TKN.
30. S/F MHRS.
31. COMPLETION DATE YR. DAY

FOR SELECTED EQUIPMENTS ONLY

32. ACT. MAINT. TIME
33. T
34. METER READING

SECTION IV. REMARKS/DESCRIPTION

35. REMARKS/DESCRIPTION
36. CONT. SHEET
37. CSMP SUMMARY
38. FIRST CONTACT/MAINT. MAN *(Print)*
39. RATE
40. SECOND CONTACT/SUPERVISOR *(Print)*
41. PR
42. T A
43. INTEGRATED PRIORITY

SCREENING

C. DIV. INIT.
D. DEPT. INIT.
E. COMMANDING OFFICER'S SIGNATURE
F. TYCOM AUTHORIZATION
44. IUC
45. TYCOM
46. SPECIAL PURPOSE A. B. C. D. E. F. G. H. I. J. K. L.

SECTION V. SUPPLEMENTARY INFORMATION

47. BLUEPRINTS, TECH. MANUALS, PLANS, ETC.

AVAILABLE ON BOARD YES NO

48. PREARRIVAL/ARRIVAL CONFERENCE ACTION/REMARKS

SECTION VI. REPAIR ACTIVITY PLANNING/ACTION

49. REPAIR W/C
50. EST. MHRS.
51. ASST. REPAIR W/C
52. ASST. EST. MHRS.
53. SCHED. START DATE YR DAY
54. SCHED. COMP. DATE YR DAY
55. REPAIR ACTIVITY UIC
56. WORK REQ. ROUTINE
57. EST. MANDAYS
58. EST. MANDAY COST $
59. EST. MATERIAL COSTS $
60. EST. TOTAL COST $
61. JOB ORDER NUMBER
62. LEAD PBE CODE
63. DATE OF EST. YR DAY
64. FINAL ACT.
65. MHRS. EXPENDED
66. DATE COMPLETED YR DAY

G. COMPLETED BY *(Signature - Rate)*

H. ACCEPTED BY *(Signature - Rate/Rank)*

*U.S. GPO:1987-705-929

Appendix 6 – Ship's 3M Data Request Form

OPNAVINST 4790.4C
7 November 1994

SHIPS' 3-M DATA REQUEST FORM

FROM: ACTIVITY NAME   POINT OF CONTACT: PERSON'S NAME   DATE: ________

ADDRESS: (SHIP'S ADDRESS)   PHONE NR. (AVN) XXX-XXXX   ROUTINE

________   (COMM) XXX-XXX-XXXX   ☐ URGENT

RPT. NR: NAMSO 4790.S 5046   OPTION 12

PARAMETERS: REPORT TIME FRAME FROM 1 Oct 1989 TO 1 Oct 1992

ST/HNR	UIC	EIC	APL	W/C	SN
FFG 33	21058	WOE2	12345678901	WS01	00-010-4960
FFG 33	21058	WOE2	23456789012	WS01	00-020-5071
FFG 33	21058	WOE2	34567890123	WS02	00-030-6182
FFG 33	21058	WOE2	45678901234	WS02	00-040-7293

OTHER: ________

NUMBER OF COPIES: ________   FORMAT: PRINT ☐ FILM ☐ FICHE ☐ TAPE

SHIP VIA: MAIL
☐ FED EXP.
☐ COURIER
☐ PICK-UP

TO: SAME AS ABOVE ☐ OTHER (BELOW)
ADDRESS: ________

NOTE: REPORTS ARE SENT TO CONTRACTORS ONLY AT REQUEST OF USN COMMANDS.

PURPOSE OR INTENDED USE OF THE DATA:

MAINTENANCE ANALYSIS
☐ MATERIAL HISTORY
☐ ENGINEERING ANALYSIS
☐ MANPOWER ANALYSIS

SUPPLY SUPPORT ANALYSIS
☐ CONFIGURATION STATUS
☐ FINANCIAL PLANNING
OTHER (EXPLANATION BELOW)

REMARKS: ________

(ATTACH ADDITIONAL SHEETS IF NECESSARY)

Appendix 7 - Glossary of Database Terms

Center Section Overhaul - The replacement of all cylinder assemblies and related components, crankshaft and camshaft assemblies and bearings. Other components such as attached pumps, vibration dampers, blowers, and turbochargers are inspected and replaced as necessary. The operating hours for the engine a reset zero.

Complete Failure - The condition of the equipment prevents it from operating without repairs. The equipment is in a non-functioning state.

Connecting Rod - The rod connecting a piston to a crankshaft. A possible problem under this subject is damage to the connecting rod bearings.

Corrective Action Details - A sentence form summary of all action taken and the procedures used to repair the engine. The purpose of this entry is to record the details of a repair in order to benefit future engineers with the same repair problems.

Corrective Maintenance End Date - The date when the corrective maintenance is completed and the equipment is placed back into service.

Corrective Maintenance Start Date - The date when the corrective maintenance action is begun.

Crankshaft - The main rotating member in the base of the engine, transmitting power to the flywheel and power train. Possible problem areas that fall under this category are: clogged lube oil passages, cracks, scratches or gouges in the crankshaft.

Critical Failure - Prevents the ship from performing its mission or creates a hazard to the personnel onboard.

Cumulative Operating Hours - The total number of the hours that the engine has operated since it was installed on the ship. When a new engine is installed the cumulative operating hours is set to zero and accumulates thereafter until the engine is replaced.

Cylinder Head - A casting containing the valves and injector that bolts to the top of a cylinder block and seals off the cylinders. Possible problem areas that fall under this category are: carbon build-up in port areas and around valve stems, cracks in valve springs, or other problems in the nozzle cup area, fire deck area, valve seats and disc area.

Cylinder Liner and O-ring - A machined sleeve that is pressed into a cylinder block and which the piston moves up and down. Problem areas include; cavitation damage or excess wear to the outside of the liner.

Cylinder Piston - The pumping device used to generate pressure in the cylinder. The piston may exhibit unusual wear and tear.

Degraded Performance - The equipment will operate, but does not achieve the intended level of performance in at least operating characteristic. The decline in effectiveness does not require an immediate repair.

EIC - The Equipment Identification Code. A hierarchically structured code assigned to equipment that are normally subjected to maintenance. The seven character code identifies a system down to its lowest designated assembly. The first position identifies the category, the second position identifies the subcategory/system, the third and fourth characters identify the system/equipment/set, the fifth identifies subsystem/assembly/unit, sixth identifies subassembly/assembly and the seventh identifies subassembly/component.

Fuel Pump - A device for metering precise quantities of fuel at precise times and rainsing them up to injection pressures. Includes problems with the cross head assembly, the push rod lifter assembly, and the rollers on the liners.

Hull Number - The ship type and hull number of the unit.

Incipient Failure - The signs of malfunction are beginning to appear in the form of intolerable temperature or pressure readings. There is no immediate loss in the equipment's performance level but the signs of malfunction are present. If these warnings are not heeded, degraded performance or even complete failure may follow.

Installation Date - Date engine item was placed in service.

Maintenance Manhours - The total expended manhours for the maintenance action. The number is calculated by multiplying the number of people who worked on the equipment by the sum of the hours that each of them worked. The total time should include any time spent on an activity essential to the completion of the maintenance such as planning, researching, and making special tools.

Major Failure - Degrades the ship's mission capability including reduced speed or efficiency. The non-availability of back-up for critical equipment denotes a critical failure.

Minor Failure - Does not affect the mission capability of the ship. The equipment is not vital to the ship's operation and can be easily done without.

Operating Hours - The number of hours that the engine has operated since the last complete overhaul. If there has been no complete overhaul on an engine yet, operating hours equals cumulative operating hours.

Operator Error - Includes errors of omission or oversight by the engineering personnel which cause failures. Also, the misuse of the engine or its components may lead to an operator error induced failure.

Partial Overhaul - A replacement of only some of the necessary components that constitute a center section overhaul. The operating hours are not reset to zero.

Repair Manhours - The total expended manhours for the repair action. The number is calculated by multiplying the number of people who worked on the equipment by the sum of the hours that each of them worked. The total time should include any time spent on an activity essential to the completion of the repair such as planning, researching, and making special tools.

Replaced - different model - Replacing an engine part with a unit of a different model or manufacturer. Entry of a new serial number is required.

Replaced - same model - Replacing an engine part with a new unit of the same kind. Entry of a new serial number is required.

Salt Water Pump - A accessory driven water pump that provides water flow from the skin of the ship to through the heat exchangers for engine cooling.

Scheduled Service/Inspection - Maintenance that is performed at a given interval in order to prevent a future failure. Some examples are: changing lube oil, lubricating, cleaning or changing filters.

Serial Number - The equipment serial number.

Trouble Isolation Time - The amount of time it took to determine the exact cause of the failure in whole hours.

Turbocharger - A blower driven by the engine's exhaust gas that is used to compress inlet air.

Type of Maintenance Completed - Self explanatory. The list-box available allows a selection of one of the following choices: complete overhaul, partial overhaul, routine service/inspection, replaced - same model, replaced - different model, and other.

Appendix 8 - Maintenance and Failure Codes

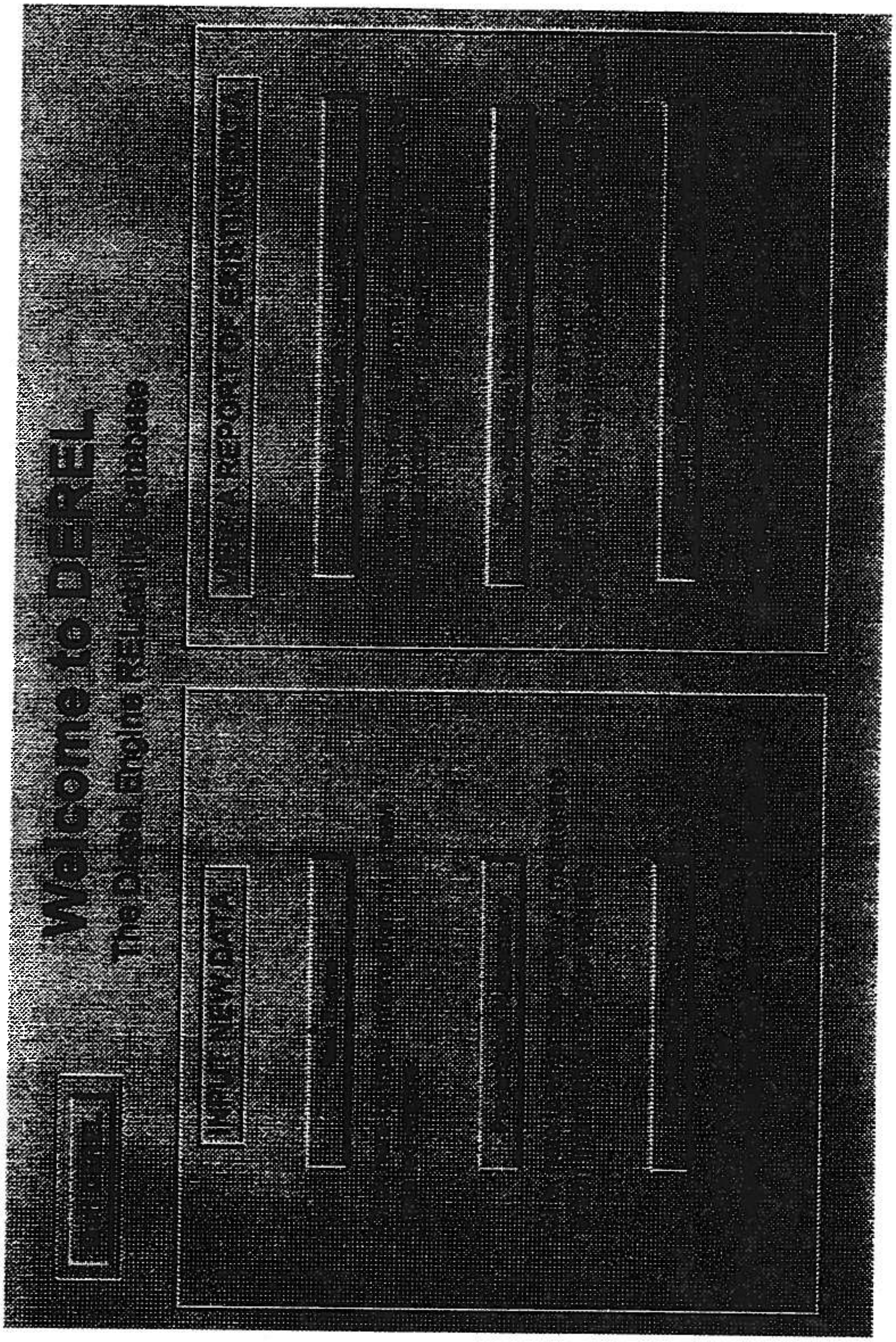
Maintenance Codes

CODE	MEANING
100	center section overhaul
101	partial overhaul
110	replaced engine - same model
111	replaced engine - different model
120	remove, examine, reuse engine part
121	examine in place
122	remove and replace engine part
123	send part to manufacturer for examination
130	install experimental part
131	experimental part examined and found working
132	experimental part examined and found not working
140	other (document specifics in machinery history)

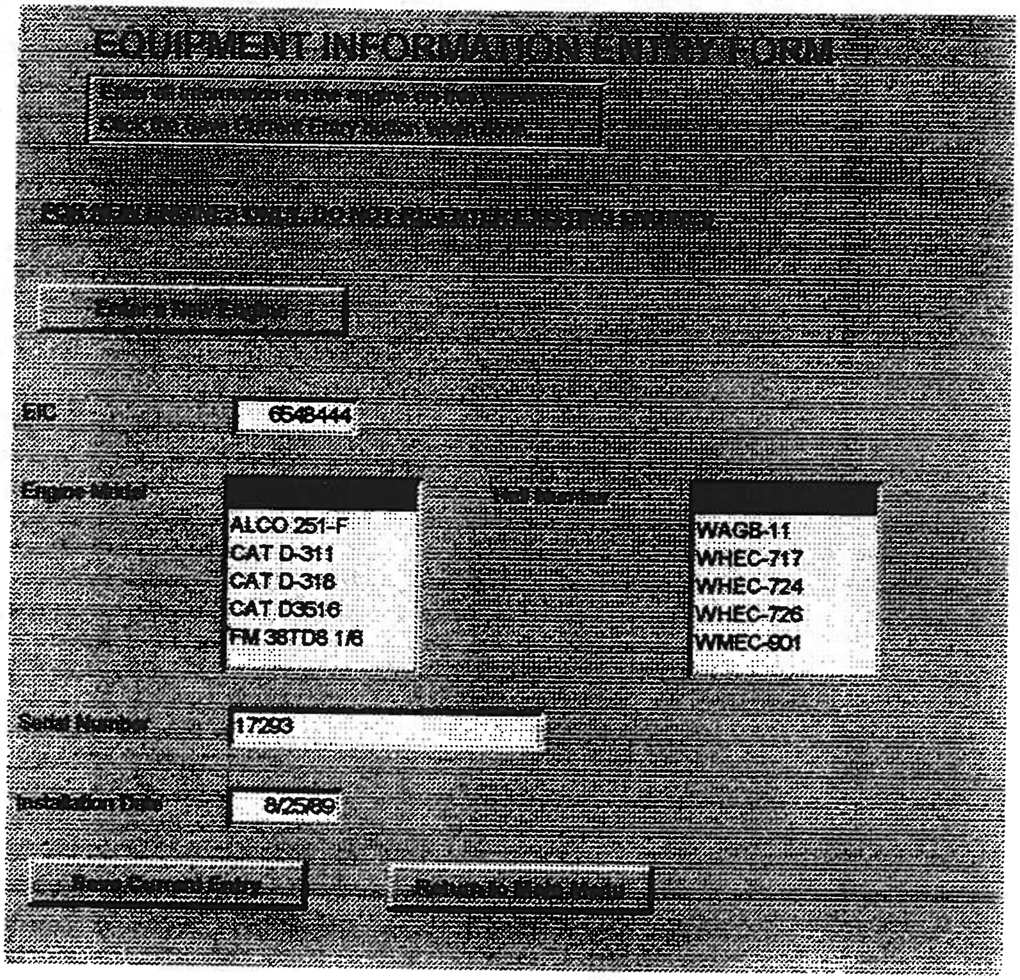
Failure Codes

CODE	MEANING
500	connecting rod failure (bearing failure)
501	connecting rod failure (structural crack)
510	cylinder head failure (excessive wear)
511	cylinder head failure (structural crack)
520	cylinder liner and O-ring failure (cavitation damage)
521	cylinder liner and O-ring failure (excessive wear)
530	cylinder piston failure (excessive wear)
531	cylinder piston failure (structural crack)
540	crankshaft failure (gouging)
541	crankshaft failure (structural crack)
550	fuel pump failure
560	salt water pump failure
570	turbocharger failure (excessive wear)
571	turbocharger failure (structural crack)
580	operator error
600	other (document specifics in machinery history)

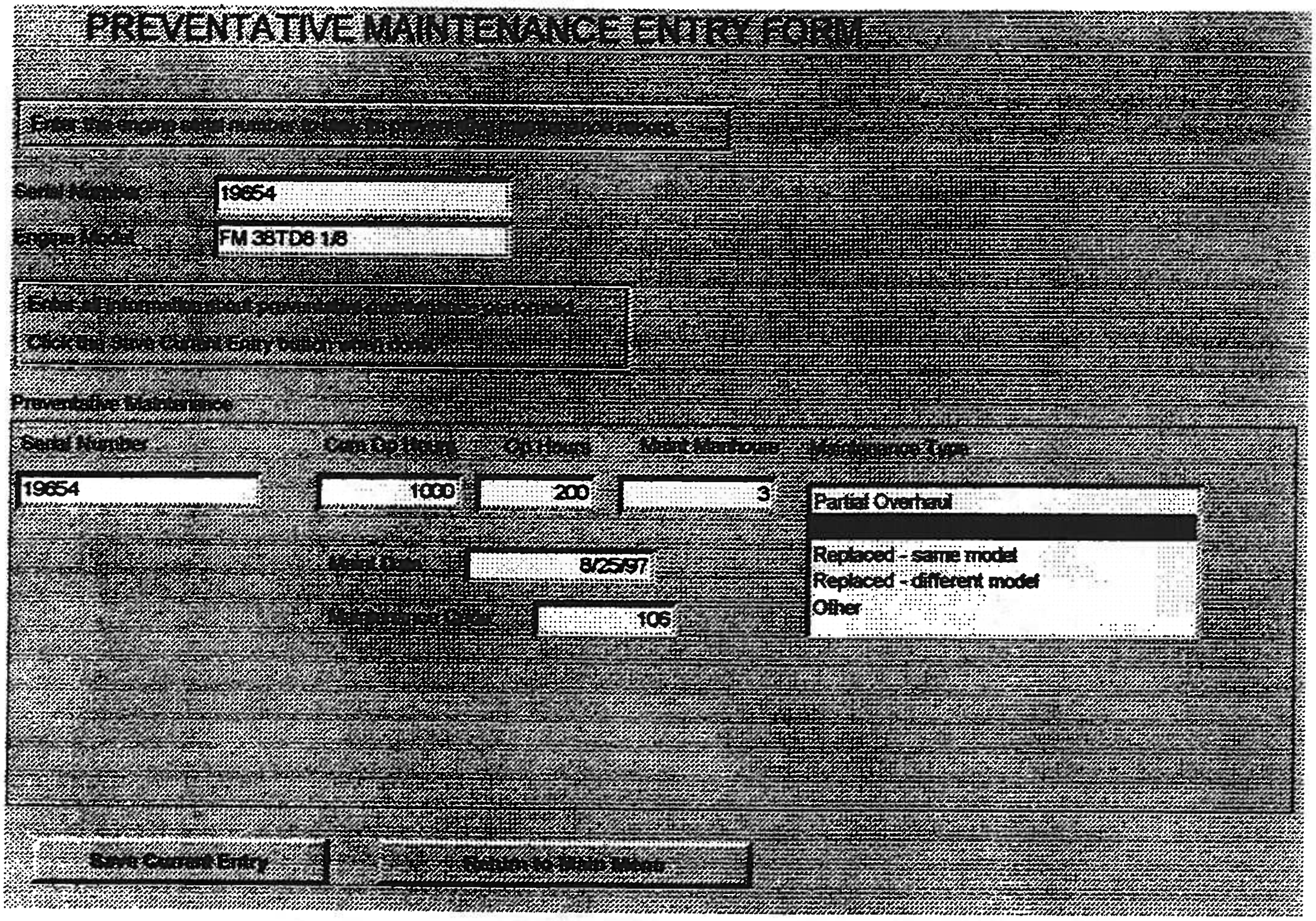
Appendix 9 - DEREL Main Menu



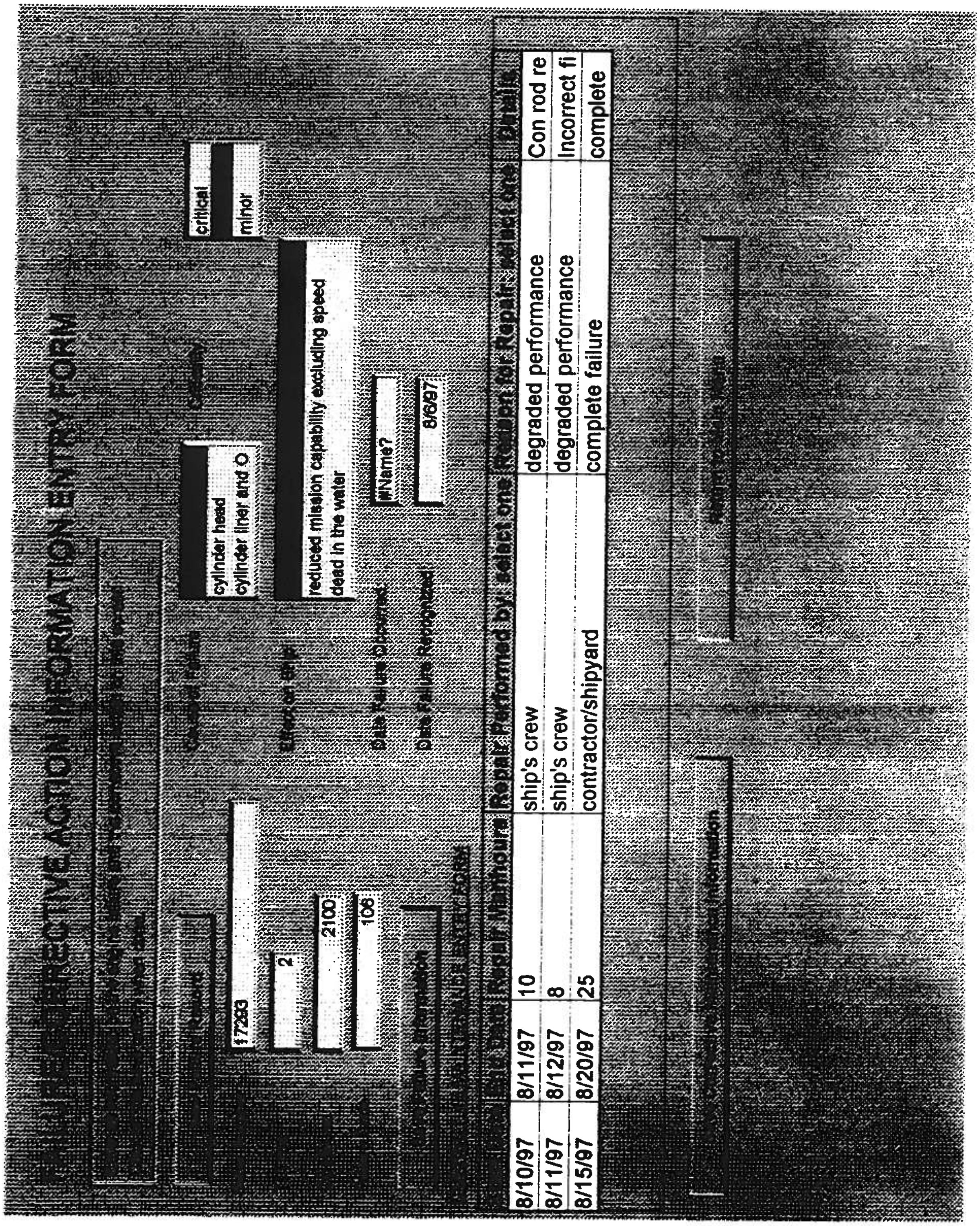
Appendix 10 - Equipment Information Entry Form



Appendix 11 - Preventative Maintenance Entry Form



Appendix 12 - Failure/Corrective Action Information Entry Form



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