From a Single Sensor Monitoring to Multi Sensor Analysis

Introduction

Engine Monitoring as it is known today is mainly a single sensor affair. A sensor is inserted in the machinery at a desired location, and the calibrated value is displayed for the operator to see. Naturally, some operations are automatically done with this information. Most important, alarms are issued automatically when this value is outside the limits given by the high or low set points of normal operation. The data can be printed automatically at given time intervals, or kept on the HDD of the work station for future use. Trend in time of this sensor can be calculated and displayed. But it should be emphasized that this operation is limited to a single sensor, while the physics of a complex system cannot be reduced to a single sensor alone. Multi sensor analysis should take us a step further.

But before we start with multi sensors, let us first go quickly over the most common sensors found in the engine room. Those are:

1. Temperature sensors – mainly PT100 sensors for the lower temperature range, Thermo Couples for the high temperature range (200°C and above).
2. Pressure sensors
3. RPM sensors
4. Speed sensors
5. Torque sensors
6. Inclinometers – list and trim
7. Accelerometers – vibrations, pounding

and more. Each of the above sensors is important on its own merit, giving the user specific value for the parameter measured. In this article we will show how we can gain a better insight into the physical behavior of the machinery, as done by Totem Plus IMACS, by performing multi-sensor analysis.

The Multi Sensor concept.

The creation of "calculated" or "virtual" parameters from the multitude of single sensors, can add a new dimension to the engine monitoring process. A simple example of calculated parameters is the mean value of exhaust temperatures and the deviation of each exhaust temperature from this mean value. This type of analysis is already used for many years, but with obvious limitations. In most systems the calculation is programmed into the system in the factory, and the user does not have the facility to define other calculated parameters at will. Such operation should naturally be available onboard to the user, not only at the factory but at any time during the life time of the ship. Other simple examples of virtual parameters can include pressure or temperature difference, trim, deflection, mean draft etc.

But virtual parameters do not give us any information about correlations between parameters, namely the functional dependency of one parameter on several other parameters. Such dependency can be analyzed on-line, from actual parameters monitored at that moment, or from history. And talking about history, we also want to see the time dependence – over many months – of any parameter in a multi parameter system: a clear example can be mean temperature under normal cruising conditions.

IMACS : Engine Monitoring with data analysis.

IMACS, short for Integrated Monitoring, Alarm and Control System, was developed by Totem Plus using COTS (commercial off the shelf) hardware. The system is using well proven electronics such as the Simatic-S7 PLC, off-the-shelf PC computers etc. that guarantee easily available and affordable spare parts anywhere in the world. System design with full CPU redundancy (hot stand by) and double bus architecture ensures full reliability even if one PLC fails. Additionally, the advanced features of the software give the user much more functionality. Alarms and single sensor monitoring: welcome to the world of data analysis.

Fig. 1: Full CPU redundancy with 2 Simatic S7-412 PLC's.

Fig.2: Engine Monitoring with built in data analysis.

Data Analysis

The term Data Analysis refers to the analysis of monitored points, usually measured by analog sensors on the Main Engine or other machinery elements. Analysis of such data involves readout of data recorded over large periods of time, with the Time stamp being an important factor. Totem Plus IMACS system, for example, records the whole data block every 10 minutes and stores it for the lifetime of the vessel. The analysis of such data was considered until recently very difficult online, due to the powerful computer power

6 Hanevi'im St., Ramat Hasharon 4727908 Israel T:+97235497295 F:+97237602722 Email: totemplus@totemplus.com http://www.totemplus.com

needed. A lot of time was required for the complex calculations involved and the time wasted to read the data from the magnetic media. The rapid increase in computer power during the last decade made it possible to have such analysis in real time, while still not interrupting the normal functional performance of the system. Hence such analysis is not restricted to shore office personnel using powerful computers.

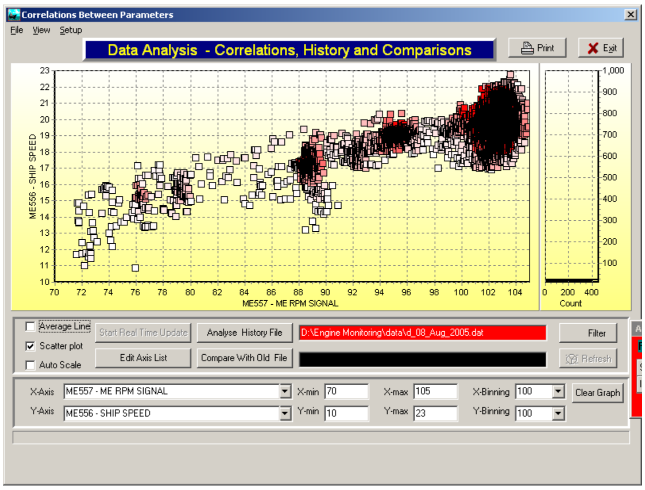


Fig. 3: Speed vs. RPM, no Filter

<u>Implementing Useful Filters</u>

To understand how several sensors are combined to represent a physical system, we can start with a simple plotting of speed vs. RPM. The dependence of these two parameters will vary, naturally, on other parameters such as displacement, trim and possibly other factors such as weather, hence the term "multi sensor". The correlation plot of the above two parameters shows a wide range of speed for each RPM value, as can be seen as a big blob in figure 3. We can, however, use the other parameters as well using the "filter" feature. Let’s assume that we want to see the above relation (speed vs. RPM) but without the smearing due to displacement: we can filter occurrences (events) in which the draft was within a certain region. As can be seen in Fig. 4, the correlation of the two parameters for the same period of time looks different when the filter is activated.

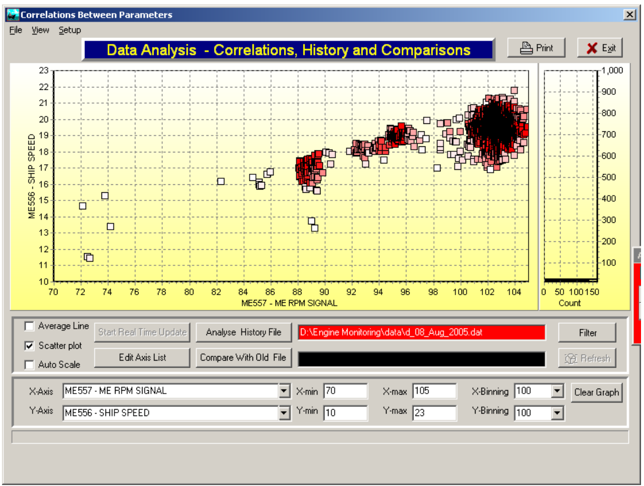


Fig. 4: Speed vs. RPM, with filter on draft – greater than 8.5 meters.

A typical filter is shown in fig. 5, where only draught amidships was checked. However one can choose any sensor onboard into the filter list and set the limits of that parameter that best suit his condition.

6 Hanevi’im St., Ramat Hasharon 4727908 Israel T:+97235497295 F:+97237602722 Email: totemplus@totemplus.com http://www.totemplus.com

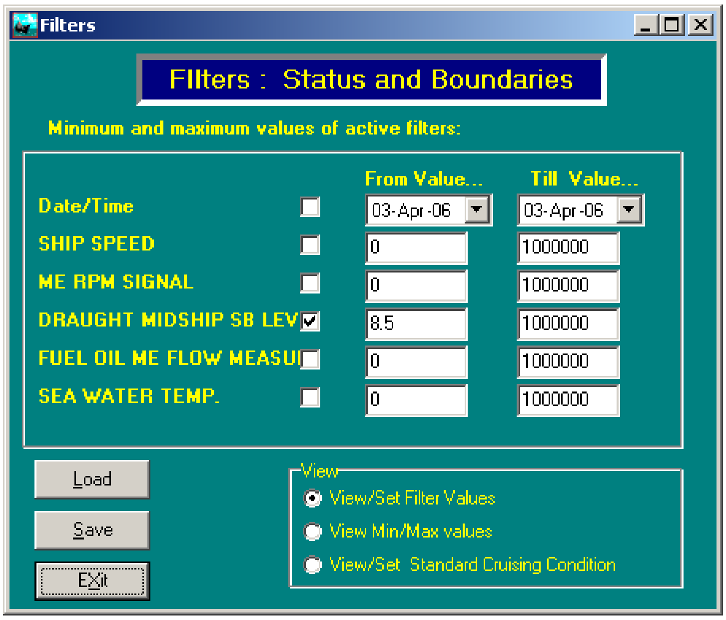


Fig. 5: Using filters.

Blobs to Graphs

Back to the correlation plots, blobs are not so useful for decision making. Hence a better way to present the relation between the plotted parameters is to show the average speed value for each RPM, or the average speed in the corresponding range of speed, as can be seen in Fig. 6 for the same correlation plotted in fig. 3. Similarly, Fig.7 shows the average dependence of speed on RPM with the same draft filter used in Fig.3. A close look in the two correlation plots shows that the speed at 102 RPM was dropped by 0.4 Knots when restricted to high displacement only.

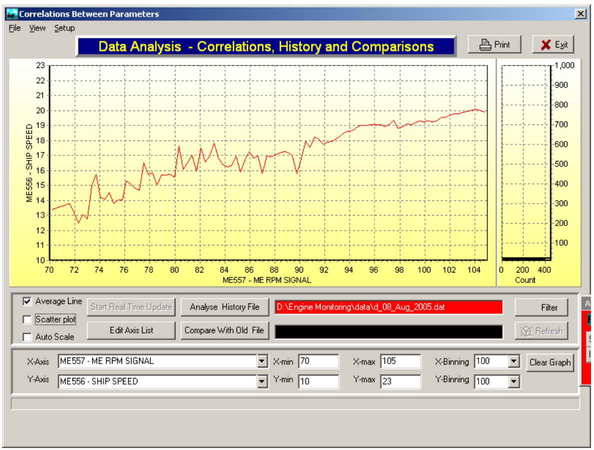


Fig. 6: Speed vs. RPM, average value, no Filter

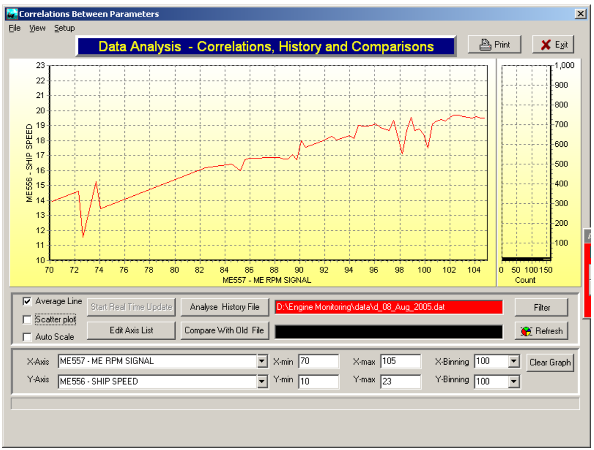


Fig. 7: Speed vs. RPM, average value, with filter on draft – greater than 8.5 meters.

Determining time trends

Now that we understand the correlation plot of a multi sensor system, we can enter a very important parameter – the time. We can compare such plots for different periods, and see what deterioration or change occurred from the first period to the other. The first example displayed in fig. 8 shows the speed dependence on RPM for two periods of one month, using adequate filter, the first (in red) for June 2005 and the other (in black) for Nov. 2005. As expected, 5 months are not enough for the vessel to develop

6 Hanevi'im St., Ramat Hasharon 4727908 Israel T:+97235497295 F:+97237602722 Email: totemplus@totemplus.com http://www.totemplus.com

significant marine growth such as affect the vessel performance: but for the first time this can be judged analytically, and not by "gut feeling". It would be interesting to see such plots after a period of, say, 24 months. In fig. 9

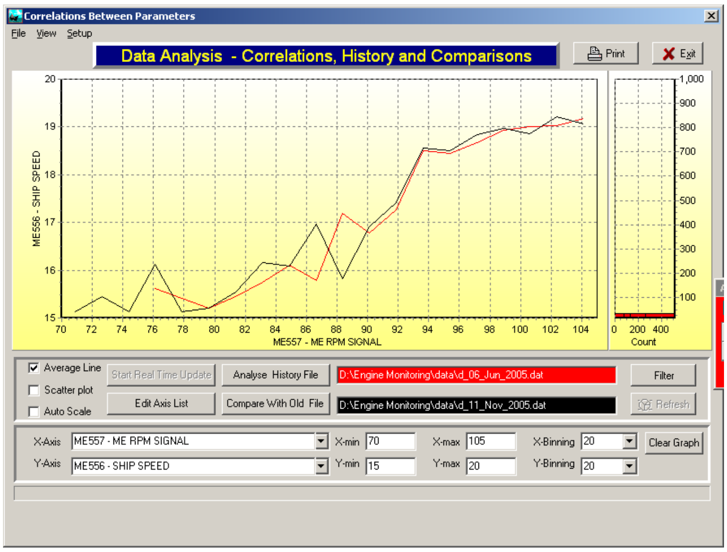


Fig. 8: comparison of two periods, speed vs. RPM.

we present the increase in fuel consumption, as

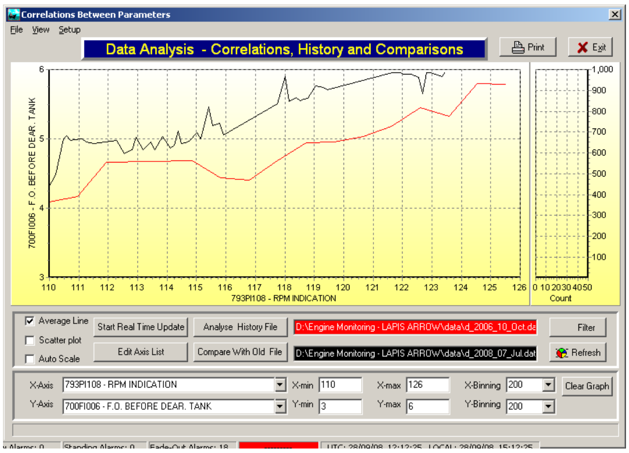


Fig. 9: Fuel consumption, filtered by draught.

measured by a flow meter, between October 2006 and July 2008, taken at the same draft.

But not all is the same after several months, as we can see from the plots in Fig. 9 and 10, showing the dependence of the Main Engine Exhaust gas temperature of Cylinder 6 on RPM for the two periods of October 2005 and December 2005. In Fig. 9 we see that the temperature dropped in average by 7 degrees, but when we impose a new parameter such as the sea water temperature we see that the drop is somewhat more pronounced and is roughly 10 degrees.

Correlation plots are not restricted to RPM dependence (although a very important parameter in engines), but can show other dependencies as well. It is up to the user to define his own multi sensor dependencies that will suit his goal, out of the multitude of sensors available.

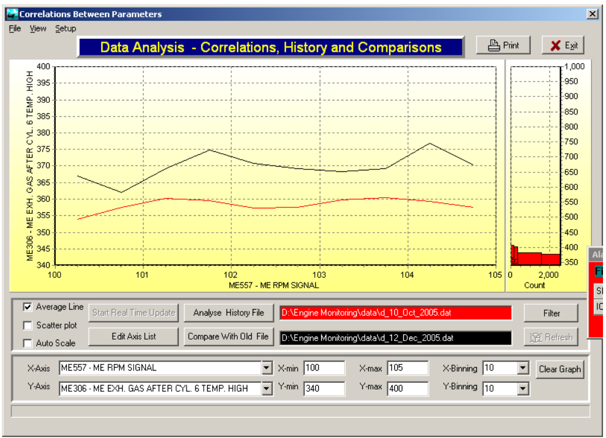


Fig. 10: Mean exhaust gas temp, filtered by draught.

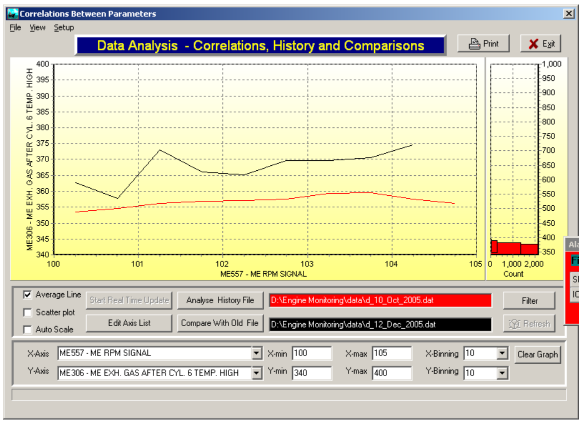
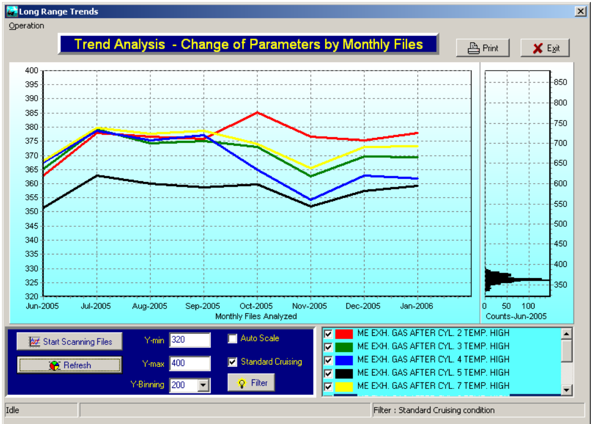
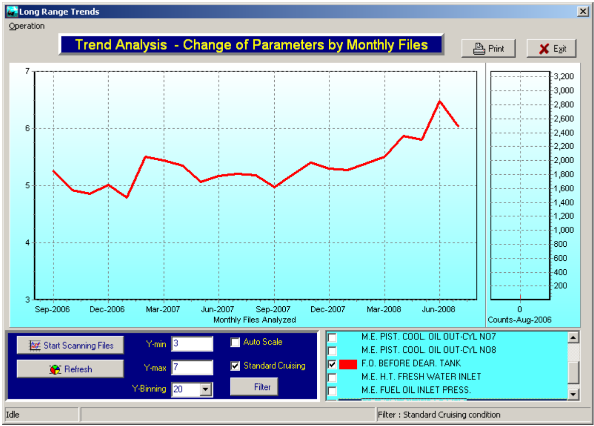


Fig. 11: Mean exhaust gas temp, filtered by draught and sea water temperature.

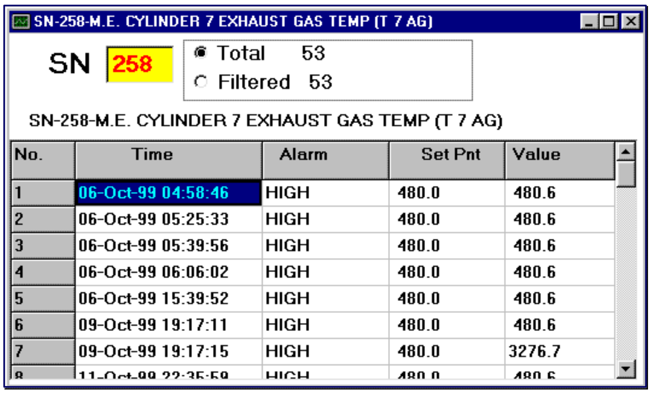
Using the same concept of multi-sensor analysis, the trend in time of the monthly averaged values (for which a "Standard Cruising Condition" applies) can be calculated. As seen in fig. 12, the trend in time of any parameter (e.g. Exhaust gas temperatures of individual cylinders, or fuel consumption) can be plotted. The cruising condition defines the average RPM, draught, sea water temperature and possibly other parameters relevant to this vessel. This trend is calculated over many months, and it gives the change in time of the average monthly value of this parameter during similar cruising or working conditions. Such long term, multi-dimensional trends (in this example for 23 months), are a vast improvement from the short period, single sensor trends available today.





Alarm Analysis

Alarm analysis (sometimes called Fault Analysis) involves the statistical analysis of the alarms. Modern vessels today have a vast number of alarms, and the analysis of their occurrence can be very



No.	Time	Alarm	Set Pnt	Value
1	06-Oct-99 04:58:46	HIGH	480.0	480.6
2	06-Oct-99 05:25:33	HIGH	480.0	480.6
3	06-Oct-99 05:39:56	HIGH	480.0	480.6
4	06-Oct-99 06:06:02	HIGH	480.0	480.6
5	06-Oct-99 15:39:52	HIGH	480.0	480.6
6	09-Oct-99 19:17:11	HIGH	480.0	480.6
7	09-Oct-99 19:17:15	HIGH	480.0	3276.7

important. For example, the number of times for which each alarm happened can be counted and sorted, either for one arbitrary period or month by month (fig. 12). Naturally, such presentations can be misleading if some alarm is repeatedly happening in a short time. Such repetitions can come either from a faulty sensor or from a repeated genuine alarm, and to avoid such occurrences a filtering mechanism is required. The filter is used to avoid multiple counting of alarms that are repeated within a very short period of time. The filter is a standard feature in the Totem Plus Fault Analysis system, and the filter time can be adjusted by the user.

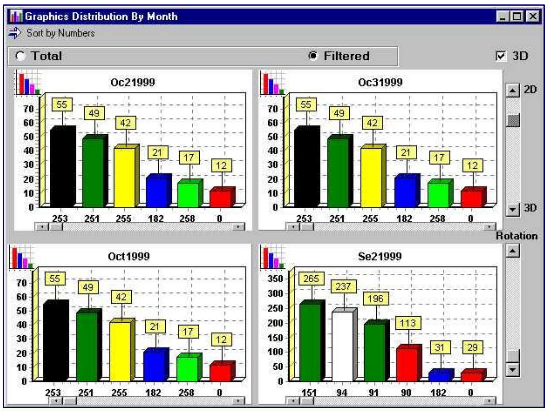
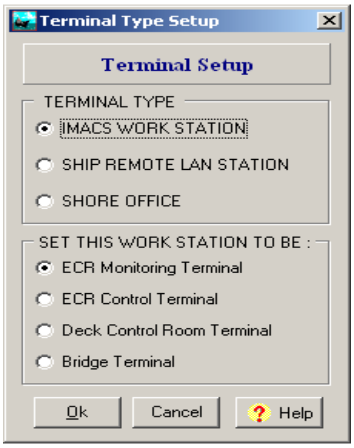


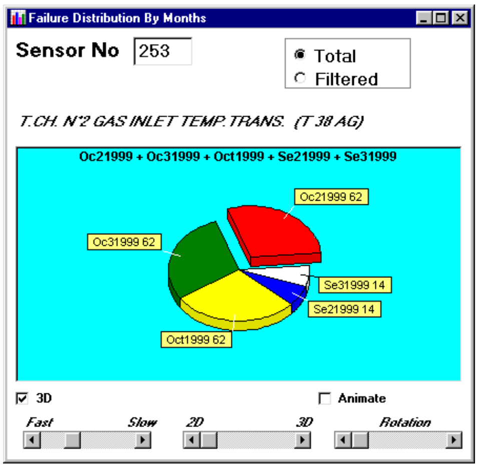
Fig. 12: Most frequent alarms per month.

Focusing on a single alarm, a very valuable information source is the log of this alarm. The log (Fig. 13) can help in tracing possible cause for this alarm, by showing the exact times such fault happened. (Old Timers may fondly recall the infamous "Bacon Alarm", which happened every breakfast by the cook activating the Smoke Detector.) Analyzing the log for the monthly statistics of this single alarm (Fig. 14), we can get further insight on the current level of maintenance and possible deterioration over several months.

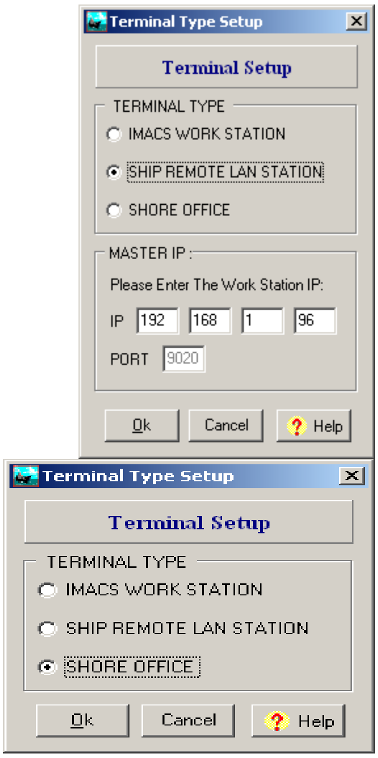
Analyzing data ashore

The Office Version of the IMACS system allows office personnel to monitor vessel condition from shore. Totem Plus is supplying the office version as standard (Fig. 8), and in fact the office program is exactly the same program that runs online but with a different setup of the terminal (see Fig. 15). Replay of data and monitoring the exact condition of the vessel at any specified time is possible with this program at any other computer ashore.

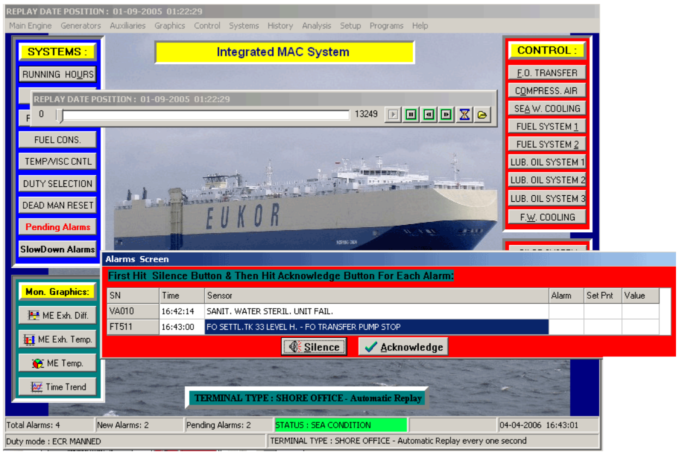




6 Hanevi'im St., Ramat Hasharon 4727908 Israel T:+97235497295 F:+97237602722 Email: totemplus@totemplus.com http://www.totemplus.com



Transfer of data from ship to shore can be done by several methods, varying from real time monitoring by satellite link to monthly transfer of data files on CD. While online link to vessel is still very expensive, Totem Plus IMACS system have the option to send the last hour file to the office by Email at any time. The last hour file (typical size less than 50KB for a big ship) contains all the data and alarms from the last hour, and sending it by Email is inexpensive. This Emailed file allows the shore experts to give better advice to the vessel during emergencies or breakdowns, or have daily supervision of performance from the office.



Summary

In this article we tried to show the powerful advantages that can be gained from analysis of the data stored. IMACS by Totem Plus is a system that can do all this, and help the owners maintain their vessel in a more efficient way.