Improving Machinery & Equipment Life Cycle Management Processes

Thomas Koch, Atlantec Enterprise Solutions GmbH, Hamburg/Germany, thomas.koch@atlantec-es.com
Matthew Smith, Lloyd's Register EMEA, Southampton/United Kingdom, matthew.smith@lr.org
Kim Tanneberger, Lloyd's Register EMEA, Southampton/United Kingdom, kim.tanneberger@lr.org

Abstract

Life cycle management of ship-board machinery & equipment is frequently based on planned maintenance concepts. Condition-based maintenance has the ultimate goal to eliminate nugatory maintenance, reduce down time, inspection and repairs. Taking this concept a step further can result in predictive maintenance regimes. This requires very large amounts of data to be acquired, stored, processed and analysed.

We present some potential solutions to allow this, enabling stakeholders to employ them ship-board and shore-side during operation, for arranging maintenance and inspection tasks. We take a closer look at how state-of-the-art IT technology is used to achieve the goal and how this enables advanced decision support tools.

1. Machinery & Equipment Life cycle

Ship Safety related to Machinery is regulated by 1974 SOLAS Convention, *IMO (1974)*, enforced by the Flag Administration of the specific ship, the Classification Society (Class) acting as a Recognised Organisation (RO) that verifies compliance; as a minimum a Planned Maintenance System must be in place (ISM Code, *IMO (1998)*). Class has in addition to the statutory requirements its own standards, i.e. Rules in place. Over and above the basic Rule compliance additional voluntary Class Notations can be applied for. (Note: in this paper the definition of the term Classification has dual use: Classification Societies and Classification as a means to establish a data taxonomy.)

Naturally, Condition Monitoring can be applied on ships without Class involvement. Owners/Operators may choose to apply Condition Monitoring on equipment critical to their operation in order to:

- Reduce down time
- Increase the efficiency regarding spares and service overhauls
- Adhere to a better standard in order to be more professional and attract more business

The additional benefit Class involvement presents is that some invasive inspections can be dispensed with on the basis of the measurements taken being acceptable.

Generally, installation costs for Condition Monitoring Solutions are minimised when being installed during the ship new construction phase. The cost of retrofitting the sensing equipment can be forbidding; especially when the aim of the data collection through such equipment is to reduce operational cost. Potential for these operational cost reductions has been shown for in other industries, *Davies (1998)*.

Classification Societies today are primarily concerned with the safety of the vessel, notwithstanding this Lloyd's Register (LR) Rules Part 5 Chapter 21, *LR (2014a)*, identify the requirements for voluntary Condition Monitoring and Machinery Condition-Based Maintenance Systems. The following examples only show LR requirements, it is to be noted that other Classification Societies may have different requirements.

The notations can be applied for as appropriate to the owners' operational requirements. The Machinery Planned Maintenance Scheme (MPMS), *LR (2014b)*, is an alternative means for ship operators to meet Class requirements for their ship's machinery, through alignment and integration with their existing machinery maintenance programme. Chief Engineers are authorised to inspect certain items of machinery, the inspection reports are then reviewed by Class thus removing the need for invasive Class inspections.

Machinery Condition Monitoring (MCM) and Machinery Condition Based Maintenance (MCBM), *LR (2014a)*, may be incorporated as part of the approved Machinery Planned Maintenance Scheme. The operator decides on the criticality of their systems and implements Condition Monitoring techniques as appropriate. Selected machinery may be credited for survey on the basis of on-condition data without the need for opening up. The MCBM process utilises a systems approach to asset management which will include assessment of an asset's criticality and probability of failure, assessment of the consequences of asset failure and development of a strategy to minimise the risks associated with asset failure. This then allows for implementation of the appropriate methods so that the operator can build up their knowledge of the performance of the system and improve on their maintenance cycles and spares holding.

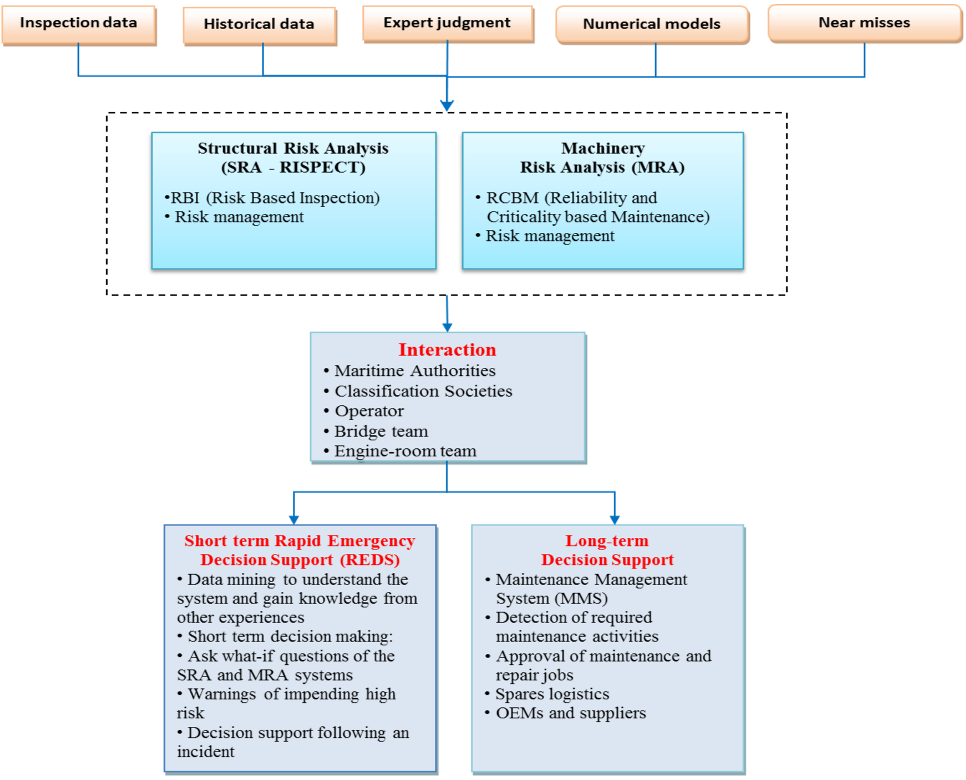

Fig.1: INCASS Risk Analysis, *INCASS (2013a)*

These notations allow Classification Surveys to be less invasive and time consuming by providing evidence that the system is in working order, that an oncoming failure can be detected and prevented by a timely intelligent intervention. With periodic maintenance it could be that the system had to be stopped due to calendar based maintenance and survey at two different points in time. With MCBM the system will only be stopped if the function goes out of acceptable operation limits. Individual items are credited for survey based on the collected data (rather than invasive inspection) and evidencing at the same time that the condition monitoring regime/scheme is operating correctly i.e. monitoring of trends and making sure that appropriate action is taken. It is expected to see deviation on the data and how these deviations have been dealt with. The measured data and trends are reviewed and analysed, but the data is currently not collected by Class, *LR (2014a), LR (2014b), IACS (2009), IACS (2006)*.

System reliability and performance data is commercially sensitive; an unreliable vessel could be seen as a non-preferable option in the chartering market. Also performance data could be used to compare commercial competitiveness. The same can be said for equipment manufacturers, as data proving that equipment is unreliable is likely to lead to loss of orders, or at least a loss of reputation and brand image. At the same time through life costs are an important selling point for manufacturers, the ability to show reliability and maintenance savings via Condition Monitoring can all enhance the manufacturer's reputation. The question here is how the industry shows that the manufacturer's claims are valid and the statistics are not simply designed to gain future sales income, or that maintenance schemes are overly cautious, thus creating additional maintenance related income. Nevertheless, equipment manufacturers, ship owners and operators are measuring and collecting machinery and equipment condition and performance data, the information gained and the deep understanding of the information is greatly increased if the vessel and system as a whole is interpreted rather than looking at individual equipment in isolation.

The analysis could be conducted over a wide range of fleets and operators. In order to for this to be possible it is essential the data is collected in a manner that makes this kind of analysis possible (rather than for the individual interests only) i.e. a common data format. Taking into account the commercially sensitive nature of the information, this data needs careful handling. For hundreds of years Classification Societies have had the status of a trusted third party to allow for exactly this to happen; the learning across fleets for the benefit of the industry.

2. New concepts, regulations and corresponding requirements

Stemming from two previous successfully concluded European Research Projects RISPECT (Risk-based Expert System for Through Life Ship Structural Inspection and Maintenance and New-build Ship Structural Design, FP7) and MINOAS (MARINE INSPECTION ROBOTIC ASSISTANT SYSTEM, FP7), the aim is to build a full ship risk model and decision support system for structural as well as machinery risk.

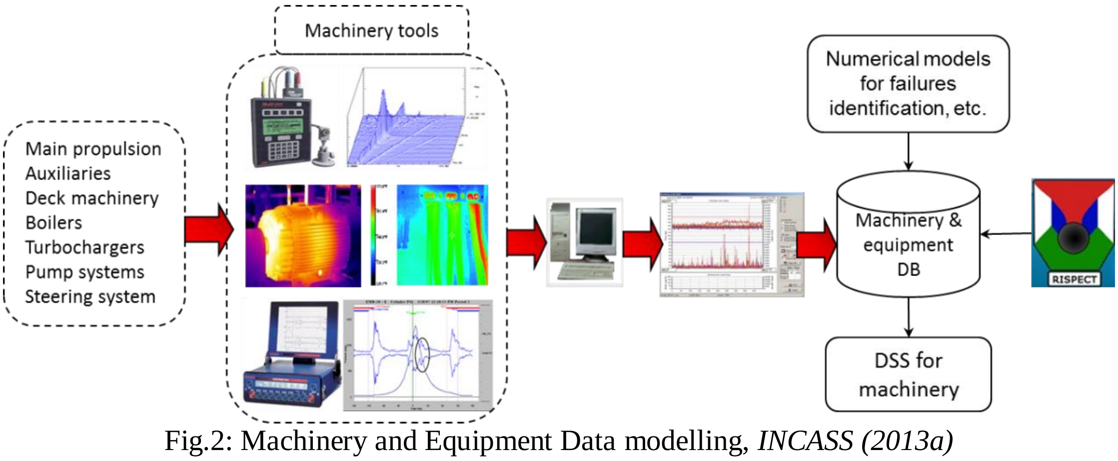

Fig.2: Machinery and Equipment Data modelling, *INCASS (2013a)*

The INCASS (Inspection Capabilities for Enhanced Ship Safety) project is aiming to develop the methodology and tools to collect and analyse such data on a ship specific and fleet level. This requires:

1. The identification of critical items,
2. The collection of data,
3. The appropriate analysis methods, and lastly
4. The communication of the results.

The focus of this paper will be the second point; the collection of data. It is clear that the measurement techniques to monitor machinery health and performance are in existence and are already being applied. These can range from simple temperature measurement to complex measurements such as vibration, *INCASS (2014a)*.

The INCASS strategy to collate all data generated in one database searchable and updateable, allows for a new level of understanding of such Condition Monitoring data, *INCASS (2013b)*.

This system means that a subset of critical information can be used to perform standardised reliability analysis and recommend actions to be taken based on the results. Equipment control panels, platform management systems, condition monitoring systems, voyage data systems all need to be producing data that can be interpreted by a common data base/data collection system i.e. a common data format to allow the exchange of data may need to be defined.

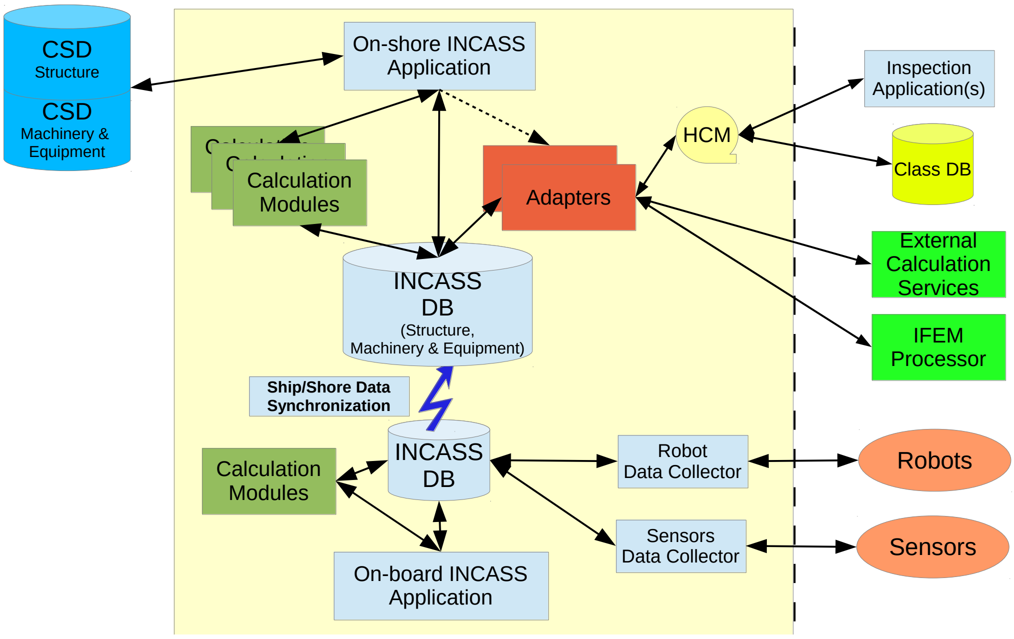

Fig.3: INCASS system architecture, *INCASS (2013a)*

Relating to measurements, which can be taken to allow a judgement of the performance status of a machine or system, there are a multitude of existing techniques, some continuous some manual. The same applies to the measured value to be transmitted, some may be online, and some may be manual. We list some of these techniques to show the diversity.

On the simpler side of online measured parameters, which are often not taken for Condition Monitoring purpose, but to control the process are **pressure, flow, temperature.** These sensors can be installed in the system and their output can be connected directly with a data acquisition system, for example a pressure transducer transforming a mechanical pressure into an electrical signal, but there is also the manual option should a mechanical pressure gauge be present in the system to collect such information manually.

Client Name:	Lloyds Register	Vessel:		IMO:	xxxxxxx
Machine ID:	REDUCTION GEAR 3	Sampling Point:	STARBOARD INNER	Make:	Not Stated
Model:	Not Stated	Sampled Date:	04/02/14	Report Date:	17/02/2014
Serial Number:	Not Stated	Report ID:	xxxxxxx	Unique ID No.:	xxxxx
Brand:	MOBILGARD 1 SHC SAE 40			Grade:	40

Diagnosis — Diagnostician: Danny Shorten

The oil is in a clear condition with negligible water. The viscosity is close to the new oil value and the oil is suitable for continued service. Elemental analysis of the wear elements shows these to be remaining at very low levels. There is no evidence to indicate that any undue wear is occurring. ✓

Results		Current Sample	Historical Samples
Sample No		4614123	
Status		✓	
Sampled		04/02/14	
Fluid Age			
Unit Age		6893	
Fluid Condition			
Viscosity @ 40 °C	mm²/s	114.8	
Appearance	-	Dark	
Additives			
B (Boron)	mg/kg	184	
Ba (Barium)	mg/kg	0.7	
Ca (Calcium)	mg/kg	6444	
Mg (Magnesium)	mg/kg	38	
P (Phosphorus)	mg/kg	100	
S (Sulphur)	mg/kg	6408	
Zn (Zinc)	mg/kg	118	
Contamination			
Water	%	<0.1	
Na (Sodium)	mg/kg	8.0	
K (Potassium)	mg/kg	0.4	
Si (Silicon)	mg/kg	8.4	
Li (Lithium)	mg/kg	0.0	
Wear Metals			
Ferrous Debris (PQ)	-	10	
Al (Aluminium)	mg/kg	1.7	
Sn (Tin)	mg/kg	1.2	
Pb (Lead)	mg/kg	0.0	
Cu (Copper)	mg/kg	1.4	
Fe (Iron)	mg/kg	5.0	
Cr (Chromium)	mg/kg	0.1	
Mo (Molybdenum)	mg/kg	0.1	
Ag (Silver)	mg/kg	0.1	
Ni (Nickel)	mg/kg	0.5	
Mn (Manganese)	mg/kg	1.1	
Fluid condition & other tests			
Neut No.	mg KOH/g	1.44	

Normal | Caution | Serious

Fig.4: Oil Analysis Report

On the more complex side of measurements stand the following:

Combustion performance monitoring of thermal engines - The operation of a diesel engine is affected by many parameters such as air intake temperature and pressure, fuel temperature and pressure, injection timing and instantaneous fuel injection rate and the cylinders characteristics. These parameters are measured to assess combustion performance. The measurement is often conducted at one point in time manually by handheld equipment, but newer machines can have inbuilt sensors to allow the online collection of such data.

Vibration analysis - in isolation it is a powerful tool which given suitable operator training and experience can be used to identify the condition of rotating machinery without the requirement for invasive inspection. Due to high sampling rates and large data quantities it is often the case that overall velocity alarms are dealt with on the vessel by constant monitoring and alarms, and detailed analysis of the Full Fourier Transform data is conducted remotely by third party analysis companies where the data is routinely transferred when band width is available.

Thermography - can be particularly useful as the results are instantly available to the user, with limited requirement/benefit in post capture analysis. Thermal images are taken of a particular item to identify hot, or in some cases cold, spots relative to the surrounding environment. In order to allow accurate temperature to be displayed an instant calibration may be needed.

Electrical signal analysis - can be performed to detect issues in electric machines or cabling. Some of these measurements such as insulation resistance would be conducted offline at one point in time, whereas others to detect harmonics for example would be conducted online for differing operating conditions of the system.

Laboratory **oil analysis** is conducted on samples taken to assess properties of the oil and wear/contaminant levels. Modern condition monitoring systems can also include in-line wear scanners which constantly monitor debris levels. A laboratory oil analysis report is shown in Figure 4 above.

From all of this it is clear that the data that requires collection is diverse and any database which is to store such needs to allow for this diversity.

3. Data acquisition and management

To realize the system architecture depicted above, the system has to build on a stable environment for acquisition and management of all data required. It therefore needs a platform which is able to handle the variety of data sources.

Monitoring of equipment requires collection of a considerable amount of measured data and observation information in order to provide sufficient insight for condition assessment and to identify trends regarding safety and reliability. This is particularly demanding for overall vessel condition assessment. Various requirements result from the approach discussed here and need to be taken into consideration.

Data volume - The total data volume collected over time from vessels in operation is substantial. It starts with the creation of a vessel profile, which includes a detailed equipment list. During operation, monitored data is being added continuously. A combination of data filtering, compression and post-processing is being employed to reduce the amount of low level, high granularity data items that need to be stored. Nevertheless, the analysis processes of the proposed approach require a massive amount of information to be stored. Consequently, tools for rapid search, retrieval and access are needed to create a system that offers the capabilities required in a production environment. In particular, the analytic processes and decision support systems tend to put a high load on the underlying data management infrastructure.

The system is being designed under the following assumptions:

- several hundred vessels to be maintained
- up to a few hundred major or relevant equipment items, this includes relevant system sub-structures such as cylinders, pumps etc. on a diesel engine or hydraulic components on a steering gear
- on average, several dozen sensor data streams per item being tracked
- various analytical models employed per equipment item and vessel
- results of analysis calculations being performed in the past are stored and available
- stochastic characteristics are derived and extracted from analysis calculations
- logged suggestions generated by decision support components are archived

All in all this results in an expected data volume of 10-30 GB per vessel through life, mapping into a total data volume of several TB for a production environment.

Sensors - To observe and monitor equipment, sensors of various types are the most prevalent means of data acquisition today. More and more equipment items are delivered with a considerable number of such devices. The arrival of smart sensors as an advanced form of Internet-of-Things items is starting to provide very powerful data sources that already include a growing part of the data processing chain for acquired raw data. A key characteristic of data sets acquired by sensors is the packaging as n-channel time series. A corresponding requirement is the capability to group incoming data by equipment, physical quantity and to be able to merge time series to provide consistent full life-cycle recordings. Sensors appear in a huge variety of implementation forms and data output formats. It is essential to be able to process all these potential data sources.

Calibration of sensors is essential for most devices for reliable data readings. It is therefore necessary to be able to track the calibration history and to have access to the determined correction and adjustment parameters.

The typical content of sensor data records will often include:

- Sensor identification – mandatory in order to be able to trace back the actual data item to its original source.
- Time of Measurement – mandatory information, though no special requirements exist with regard to precision (i.e. a granularity of minutes seems to be appropriate except for dynamic measurements)
- Actual value – depending of the capabilities of the data source this may still be in raw format, i.e. some voltage or plain count number. If this is the case, the corresponding scale and offset values must be specified along with the measurement type and unit information.
- Location – not mandatory for all types of data items, but commonly applicable. For example, strain gauge measurements will be related to some location and orientation. The actual data being transferred may not require this information in detail – instead the sensor or data source identification will be sufficient, provided that some initial setup can be established that relates the data source to some location.
- Coordinate system, where applicable
- Orientation – similar to Location, only applicable to select types of measurements
- Measurement type and unit – mandatory data which is required to correctly interpret the actual values. Assuming that data sources are not capable of range switching, this information can also be provided as part of an initial setup as is discussed for Location data. Depending on the actual data source capabilities, further details about scaling and offset values may be required.
- Calibration information – frequently sensors will require regular calibration. Information about the actual state of calibration and even calibration history must be accounted for. This will provide insights into the actual operational status of the sensor in question.

A wide range of measuring devices has to be supported, ranging from simple raw value streams to smart sensors that incorporate complex data processing capabilities including screening and filtering of the data. Furthermore, as more advanced sensors become available, future devices will be able to provide additional properties, context information and be able to perform more advanced pre-processing operations. Sufficient flexibility is needed to be able to accept data from such sources.

Robotics - A further possible source of information is found in the data collected or produced during inspections. Today, such inspections are to a large extent still being carried out manually. These are expensive activities, particularly when access is difficult or special precautions are needed due to a hazardous environment. Our investigations include evaluation of robotics equipment, that can be used to collect data e.g. when operating in submerged condition, crawling to remote positions, in hazardous environments etc. While the current focus of such investigations is structural assessment, the same technology will soon be applicable, e.g. *Navy (2015)*, to equipment condition assessment, e.g. to get rapid access to a restricted or hazardous space or to generally automate regular time-consuming but non-critical inspection tasks.

Robotic platforms can support a wide range of data sources ranging from imaging, acoustics and vibrations to specific sensing technology. From the data processing perspective, inspection based data sources do not fundamentally differ from the continuously operating monitoring devices.
The main difference is that it will typically be packaged as snapshots containing many data points at a given instance in time. Other differences may result from to the level of local intelligence for data processing and screening as well as details of the data packaging and transmission. Once the collected data is uploaded, it can be processed in similar fashion as the sensor data using the same grouping and merging techniques.

Voyage recordings - All ships are tracking their voyages at least for management purposes. However, this data can also provide insights into loading conditions due to the cargo loading condition, sea state, course and direction and weather conditions to determine the overall operating conditions of the vessel. The range of information available for this class of data varies widely from brief noon reports to full scale sensor-based tracking information. This also applies to the actual data recording techniques which range from paper-based or simple document type information to be submitted manually to full data records provided automatically at regular time intervals.

Image data - With the wide-spread availability and ever-growing use of imaging devices, images and video sequences are becoming more and more a means of documenting inspection observations. Image data can only be fully explored, if it is accompanied by sufficient meta-data describing the location, view direction and camera orientation, time stamp and other useful annotations. For on-board imaging, a precise definition of the location is needed. Therefore, regularly some reference marks or other stable reference points will be required. As imaging technology is advancing rapidly, very useful information is expected to be gathered from selected wave-length techniques such as thermographic imaging.

Imaging data can occur in various forms such as “simple” photographic images or video streams to specialized imaging like thermographic images or post-processed images that have been modified using sophisticated processing chains e.g. for detection of defects, *Bonnin-Pascual (2014*).

Data transmission - Data transmission channels depend on the mode of transmission. For example, for most robotic equipment some intermediate storage exists, from which data will be uploaded after a single mission or campaign has been completed and most likely post-processed. In such a configuration, data can be provided in some data container holding all the results from a single mission.

For continuously operating sensors, often some intermediate collection device is employed as well. Uploading of data collection batches would also occur in some data container. The actual transfer can occur either by actively importing containers via an application or by uploading/copying a container to some pick-up location where an automated process will detect the new data and import it.

Storing of engineering data - Data describing objects from engineering domains have some challenging properties, when trying to handle those using established, traditional data management technology such as relational systems. Only a small fraction of the data shows a referential topology that fits well into table-oriented structures. Engineering data is mostly graph-structured and multi-dimensional. Therefore, navigation and search will expose particular properties. That being said, some specific areas are of a clear tabular nature, such as time-series resulting from measurements.

Another difficulty is the wide range of data granularity observed with engineering data. This is often addressed by clustering of data such that small data items occurring in large quantities are closely tied to the target object they are supporting. This allows efficient retrieval of complex data sub-networks.

Identification of data items is yet a further topic that needs to be dealt with. Primary key generation often applied in database systems does not work well for engineering data. It usually results in a complex and arbitrary name-to-id mapping layer that needs to be maintained.

All of the issues become real obstacles when moving into larger scale data volumes. A possible solution is to apply graph-oriented storage technology, which has recently gained wide recognition in the context of “big data” applications. The Topgallant® Information Server, which is used in our implementation, provides a graph-oriented data management platform, which addresses these issues, *AES (2015).*

Equipment Data Model - For our purposes, a data management arrangement is needed that is capable of storing life-cycle information for all equipment components considered to be critical functional units. Life-cycle related information includes properties for identifying systems under investigation. Moreover, stored information will provide a sufficient collection of mostly technical but also some administrative properties maintained by systems recording performance data, collected by sensors or sampled during inspection and maintenance processes. The data management should also allow maintaining links to other information derived from different parts, machinery and systems.

There already exist approaches defining data organisation principles for storing data related to equipment components, part lists or catalogues. Many of these are either proprietary, focus primarily on administration and logistics requirements or are limited in scope and have never gained any substantial ground. We researched various projects and existing standards that are closely related to the shipping domain in order to identify requirements and features that would contribute to a good solution. The approaches include *coding* systems such as yard-specific systems, established *classification* systems (classification meaning the type identification and purpose of equipment – not to be confused with the work of Class Societies) such as SFI, *SpecTec (2005)* or NORSOK, *NORSOK (1996)*, international standardisation efforts for design data like ISO 13584 ("P-LIB"), *PLIB (2004)*, including combination with ISO 10.303-227 IS Plant Spatial Configuration, *ISO 10.303-227 (2005)*, or (withdrawn) proposals for standardization such as ISO 10303-226 WD Ship Mechanical Systems. Furthermore, results from logistics oriented research efforts such as CPC (Common Parts Catalogue), *NSRP (2010)*, were considered. A summary of results from this research is provided in *INCASS (2014b)*. From this investigation, the solution described below has been developed.

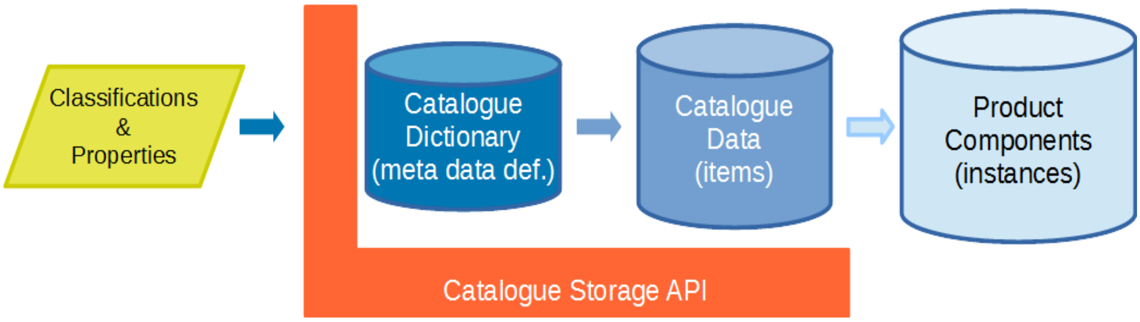

Fig. 5: Catalogue data management component

Concept for M&E database standardization - Analysing the different approaches and defining storage and indexing principles for components, the following observations have been made:

- Conventionally, structuring large amounts of information items have been organized by using explicit coding systems. These coding systems are used to locate the information item. Frequently, the coding scheme follows some information carrying principles in itself (e.g. acronyms or "speaking numbers") which help the user to extract key search criteria from the coding.
- However, in many cases access to an information item using a coding system involves two steps: (a) first look up the code from the key word catalogue, (b) use the code to locate the information item. Today, this sort of indexing is clearly a function that can be completely hidden from users by software. The most general example is the typical web search, where a vague combination of key words leads to a correspondingly long list of matching information items.
- For technical systems, a practical solution lays between those two extremes setting a useful approach. This is typically implemented as a catalogue system, which involves the definition of an extendible dictionary (holding the available set of key words for item classification). This makes searches for information items more specific than for instance a web search avoiding the static-ness of coding systems.
- To support broad-scale analysis across multiple ships, systems and potentially many components, efficient search functions are very important. This in turn requires the dictionary to be capable of efficiently tracking and enumerating all properties available for the description of components.
- Classifications of components will constantly evolve. New types of products will appear on a regular base, which should not lead to a rapid invalidation of a system.

- Licensing and Intellectual Properties issues must not interfere with the operation of the system, otherwise the use will become either impractical, expensive or both. Dealing with this issue, a flexible method of linking to licensed coding systems is needed.

Taking into account the above considerations in terms of standardised systems and approaches, the developed concept leads to maintaining a component instance repository that includes a catalogue based system providing dictionaries to define and maintain the classification system and catalogue implementations based on a dictionary.

The chosen catalogue approach provides support for different hierarchies such as by system, by function, arbitrary number of levels, efficient support of search and retrieval as well as update of catalogue dictionary (i.e. migration of dictionary versions). Furthermore, the dictionary supports an unlimited number of properties of defined type (e.g. boolean, integer, double, measure (with units), range, enumeration, string, uniform resource identifier (URI), etc.).

The data model design of the dictionary includes classifications (item classes) and property definitions. Item classes define the classification and inheritance aspects of equipment types to be captured in the catalogue. Item classes represent a collection of properties, which define all captured state values of an equipment item.

Item class definitions support single inheritance (all properties of super classes are inherited), e.g. an classification "Engine" can be further refined into a "Diesel Engine" and further into "Four Stroke Engine" and "Two Stroke Engine", where the latter will hold all properties defined for "Engine" and "Diesel Engine" plus any further specific ones defined for the "Two Stroke Engine" class. As can be inferred from this, the commonly established rules for object oriented design are applicable to the design of the classification hierarchy.

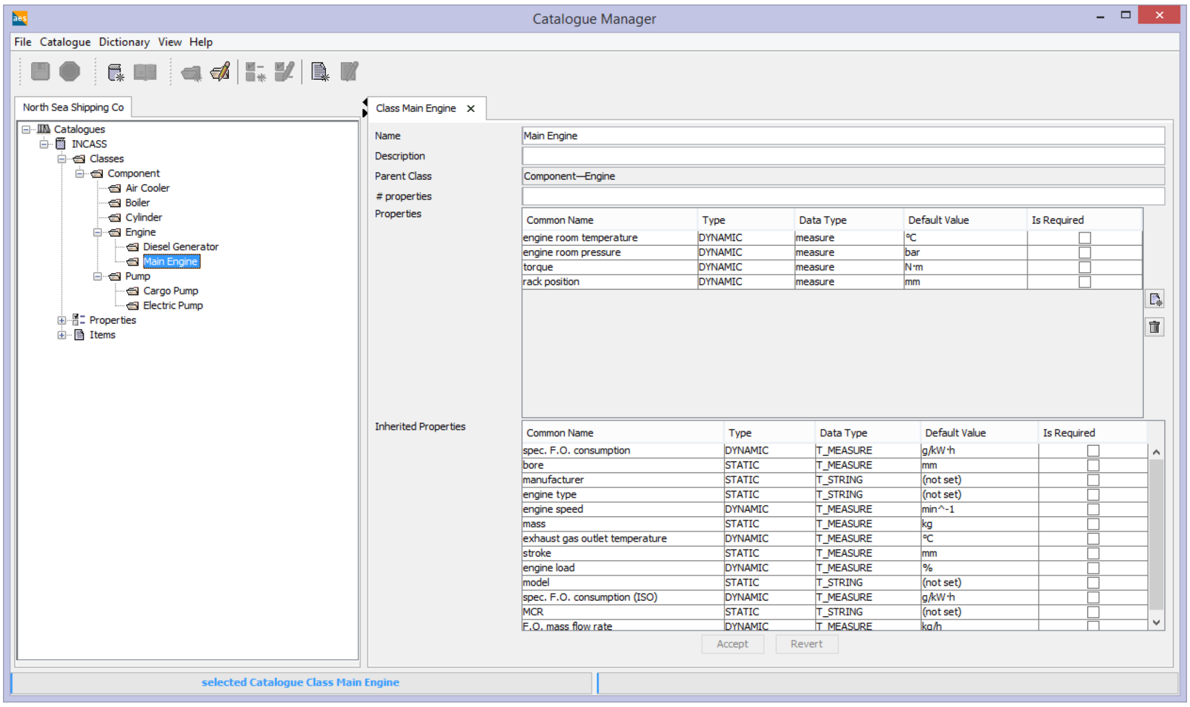

Fig.6: Defining an item classification in Catalogue Manager

Properties are characterised by a behavioural type: ***Static*** properties are those who will be immutable throughout the life time of an equipment item (e.g. maker, empty mass). Static properties are fixed for an equipment item specification (i.e. the data provided by the manufacturer as a fixed given design value of an identifiable equipment model). ***Configurable*** properties are fixed throughout the life time of an equipment item but depend on the actual configuration at configuration or delivery time of the actual component instance. ***Dynamic*** properties represent the values can be monitored over time and depend on actual operating conditions of the component item. Such properties are recorded as time series.

Catalogue Manager - As part of the prototype system implementation, an application has been developed to support the creating and maintenance of equipment data for ships to be monitored and assessed. This Catalogue Manager helps to establish the dictionary structure of a catalogue in a way that is suitable to capture all information that is required for the risk assessment and decision support system execution. Once the corresponding dictionary has been set up, the actual equipment configuration can be defined and stored. From that point onwards, monitoring data can be received and associated with equipment items, enabling the user to build an equipment monitoring history.

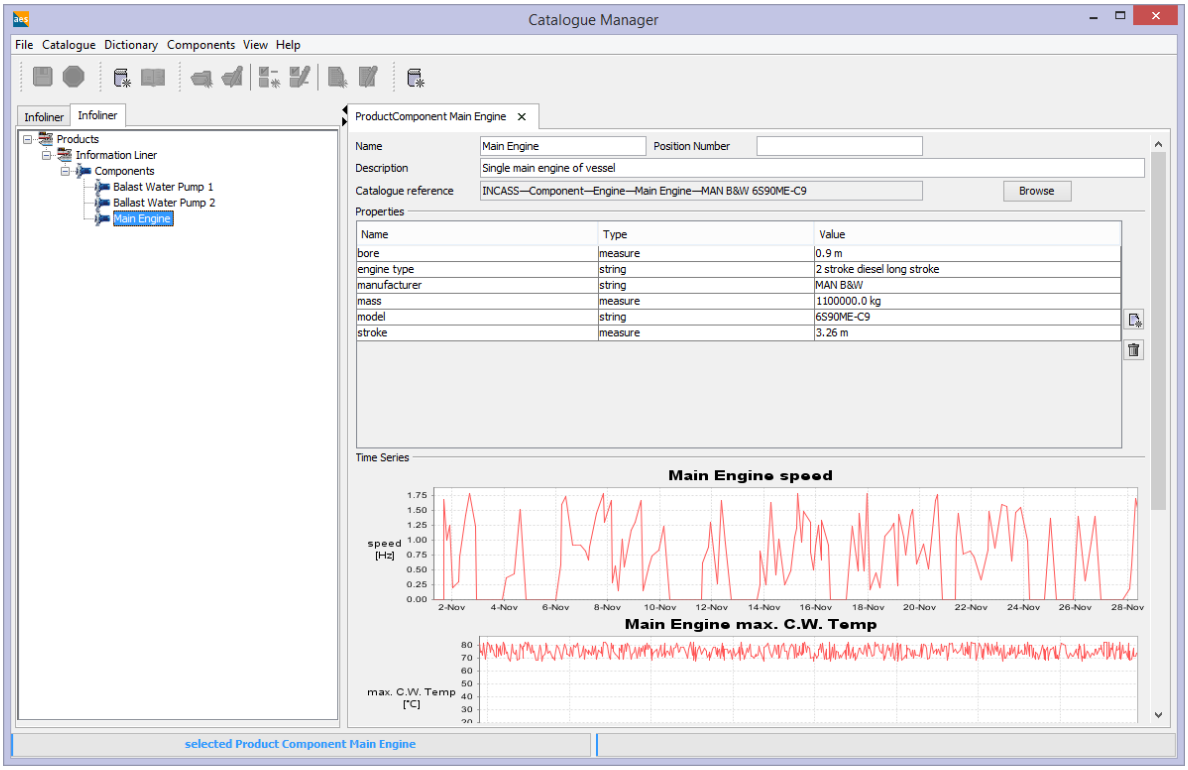

Fig.7: Equipment item properties with collection data

Apart from setting up a catalogue structure and catalogue content, in this application the essential actual equipment items can be defined or managed. This includes:

- Instantiation (registration) of the actual equipment instance related to a specific ship. This model relates to a physical object on-board the vessel, that is uniquely identifiable (e.g. by manufacturer, model, and/or serial number).
- The instance is defined with reference to a catalogue item, which allows tracking of relationships to comparable items (same model, same manufacturer, same functionality)
- An import mechanism is provided to easily import from externally provided material or equipment lists, ranging from simple tabular formats to full-blown CAD model component data.
- For each instance, the *Configurable* properties can be adjusted, matching the actual set-up of the item.
- *Dynamic* properties data (e.g. time series) can be associated with these product components during the whole life cycle of the equipment item.
- Easy lookup of all observation and measurement data available for the item in focus.

4. Data processing

Most of the monitoring information to be analysed is contributed by real-time data acquisition received from either sensors installed on-board or imported as inspection data records. In particular on-board sensors often provide raw data, though the actual collection mechanism depends on the type of sensor or equipment employed. No strict real-time requirements exist for transferring the data to the database and further to calculation modules, following the “eventually consistent” paradigm, *Vogels (2008)*, which matches very well with the incremental processing schedule being used. Analytic processes are executed on the basis of data that is “currently known”. As more data is added, specific parts of the processing will reoccur, thereby including the most recent findings.

The system exhibits the main properties of “*big data”* processing being in focus of many IT developments today, *Marz, Warren (2015)*:

- Observed data is provided as raw data reflecting actual observations. No interpretation towards the conclusions to be drawn by the system has occurred at the data source. For example, sensors to not perform any judgement regarding the significance of the measured data (this requirement does not preclude sensor devices from error checking, though).
- Once data has been received and persisted, it is considered to be *immutable*. No change of observed data recordings are expected to happen.
- As a consequence of immutability, persisted observed data is *eternally* true, thus qualifying as a fact or evidence.
- Along the same lines, no calculation results produced at a certain point in time, which is based on the data available at that time, will change once established. The incremental nature of applied algorithms such as Bayesian Belief Networks will instead lead to updating of results over time through re-evaluation and re-assessment, *Han, Kamber (2006), Downey (2013)*.

Calculation engine framework - The risk assessment and decision support functions of the software system being developed include a considerable number of different sophisticated calculation modules are being provided by many different contributors. Each of these methods works with a flow of execution steps (from simple sequences to more complex transition networks) among provided computational methods.

One of the challenges is to integrate these modules into the overall system environment such that users will be able to utilize them reliably and efficiently. For this reason, the system includes a calculation engine framework that takes care of the task integration. This framework provides the following features:

- A method of specifying computational works flows for the different tasks to be supported.
- An API and tools to activate and execute instances of these calculation work-flows from applications like the Ship Management, which is one of the main user visible interfaces of the system.

To integrate a calculation module, a work-flow is defined by means of a process description. It describes a calculation work-flow as a combination of processes, activities, and transactions and links them to executable units. The model is described using a concise domain oriented language (PDSL – Process Definition Script Language) for work flows which is available in the Topgallant® environment. Once the work flow is defined, an instantiation and execution mechanism in the framework will provide access to the module and generate a corresponding execution user interface within the controlling application, as soon as the corresponding module shall be activated.

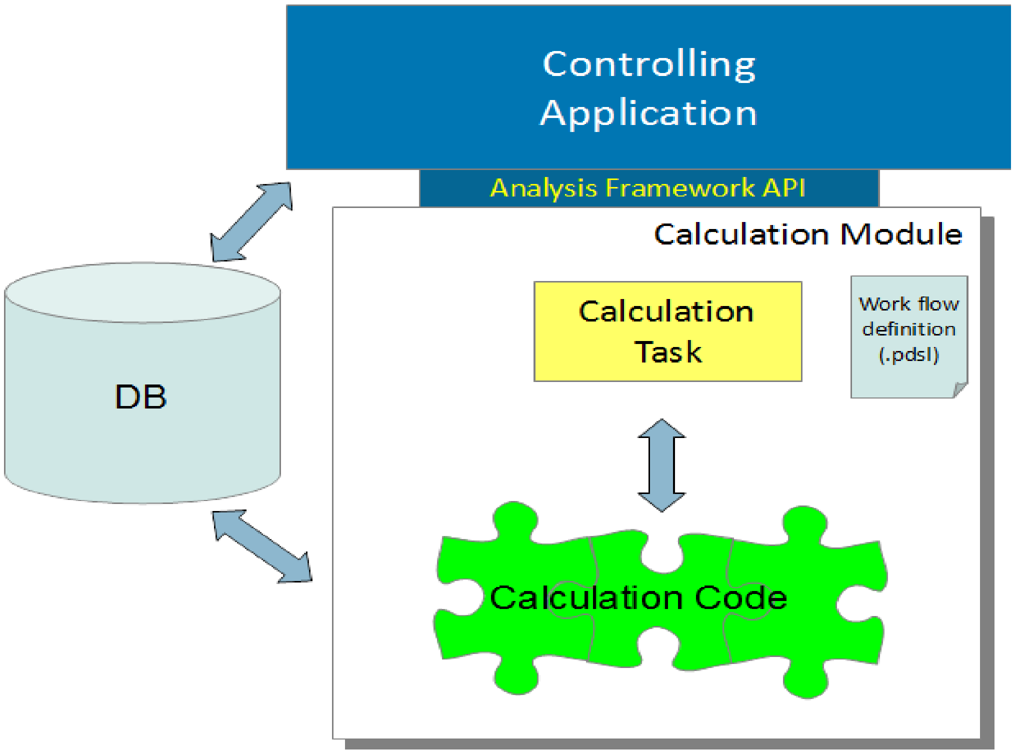

Fig. 8: Calculation Framework

5. Conclusions and Outlook

The vast majority of merchant vessels trading today conduct some form of Condition Monitoring, be that analysis of individual pieces of equipment, thickness measurement campaigns or complex system wide analysis. The approach is entirely dependent on the complexity of the ship and its associated systems and the owners approach to Condition Monitoring. There is currently no defined industry single standard or minimum level. Advances in data handling, computational power and worldwide communication with vessels at sea is opening up new opportunities for the marine industry.

Advanced methods for Condition Monitoring, prediction of risk levels for failures and ultimately providing assistance and guidance in decision making processes related to this domain depends on a solid data acquisition and data management platform. We have presented an approach to capture relevant data efficiently and to prepare the ground for sophisticated further processing using advanced algorithms and strategies. We see this as a powerful “toolbox”, on top of which various computational techniques can be implemented.

There are still challenges that we need to overcome:

- An industry standard data format
- Proven financial benefits for investing in condition monitoring technology
- Commercial sensitivities of both the marine and manufacturing industries, and many more.

However, ground breaking work is being done by projects such as INCASS and by private industry with a view to bringing the performance and Condition Monitoring within the marine industry to the very forefront of technology. It is a common belief that the nuclear and aircraft sectors lead the way in Condition Monitoring and that the offshore industry has the upper hand with respect to risk based maintenance strategies. We believe that the marine industry is on the cusp of a technological revolution that will allow it to proudly stand shoulder to shoulder with its rivals, and has the potential to compete as the technology leader/innovator in this area.

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