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E-Prognostics: A step towards E-Maintenance of Engineering Assets

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Abstract

Reliability of manufacturing or production processes is heavily dependent upon the flawless operation of asset plant and equipment utilised in the processes. Nevertheless, continuous and seamless flow of information, aimed at real time access to process stakeholders provides the foundation for effective management of these assets. An essential requirement in this regard is the continuous availability of the condition monitoring information and its analyses in order to predict failure conditions as soon as the asset starts deviating away from its standard operational behaviour. This paper presents an integrated approach for prognostics based on radio frequency identification (RFID) technology. It presents an architecture aimed at introducing information processing capabilities at the asset level, thereby equipping the asset to be proactive in identifying its maintenance requirements wirelessly rather than relying on human interaction to examine the asset for irregularities.

Key words: Asset Management, e-Maintenance, sensors, RFID, Joint strike fighter.

E-Prognostics: A step towards E-Maintenance of Engineering Assets

Abrar Haider
Andy Koronios

1 Introduction

Modern production or manufacturing environment demands an elevated degree of plant and equipment reliability involved in manufacturing process. Technological advances, on one hand have improved their efficiency, and on the other hand are changing the ways these plant and equipment have traditionally been maintained. Information and communication technologies are fast taking over from the conventional practices of manual plant inspection and reliance of these practices on paper based information acquisition and management. This change is aimed at continuous monitoring of the condition of the asset plant and equipment; so as to sense malfunctioning in their operating conditions, which may have serious impact on other areas of the business. Its importance is dictated by the fact that any changes in the asset condition have a direct impact on critical business aspects such as production, resource planning, and sales and distribution. At the same time, in case of a failure condition developing, it is important to plan maintenance execution and related resources ahead of time such that the asset spends minimum time in idle state. Therefore a sound asset plant and equipment condition monitoring (CM) technique has important consequences for asset management as well as for the entire business.

An asset is a physical component of a manufacturing, production or service facility, which has value, enables services to be provided, and has an economic life of more than twelve months [1]. Whereas, asset management is the set of disciplines, methods, procedures and tools to optimise the whole life lifecycle impact of costs, performance and risk exposures associated with the availability, efficiency, quality, longevity and regulatory/safety/environmental compliance of a company's physical assets [2]. In the context of this paper, the terms physical asset or asset, refer to plant and equipment used by engineering enterprises in manufacturing or production process. These assets range from configurations of oil rigs, power generation and distribution facilities, military hardware, to commercial aircrafts. The types of assets represented here are diverse and their maintenance demands are quite divergent, however to ensure continuous availability and reliability of each of these assets the underlying philosophy is the speed with which irregularity in their operation could be traced. A logical solution to this issue is to introduce certain level of information processing capabilities at the asset level such that each asset is capable of making a diagnosis about its condition itself; a trend that has been termed as e-intelligence.

E-intelligence is defined as the shift from traditional manufacturing philosophy that illustrates factory integration, to an e-factory and e-supply chain philosophy, which progresses towards the goal of global business automation [3]. Such a setting suggests seamless flow of interoperable information that circumnavigates manufacturing, maintenance, and logistics, as well as process integration with suppliers and customers. For asset management it means an integrated environment that not only monitors the condition of an asset but also predicts failure conditions as well as generates relevant maintenance recommendations and work requests. Nevertheless, contemporary diagnostic equipments are ill equipped for the emerging e-intelligent maintenance paradigm [4]. Mostly these equipments identify a failure when the situation is already out of hand, and therefore they serve as tools of failure reporting better than instruments for pre-warning of a failure condition in its developing stages. Condition information is captured through an array of sensors, filed devices and paper based manual inspection systems, which is then collated and analysed to see how the asset behaves over a period of time. This information is not only historic but also lacks quality due to the variety of data acquisition techniques employed. Apart from this, a failure condition that may have been in developing stage at the time of information capturing, by that time has probably resulted in asset breakdown. Another issue is that of locating the exact location of the failure condition. Asset health is measured by the safe levels of operational vital signs, such as temperature, pressure, and light. However, taking these measurements in isolation, not only do not provide the nature of the failure but also do not provide any indication on the location where the failure condition might be developing. For example, just a rise in temperature tells nothing about the condition of an asset, if it is taken in isolation from other condition parameters. On the other hand, rise in temperature along with smoke emission may lead to the faulty seals or oil change of an engine. In the absence of the complete picture it is difficult to find out what is causing the asset to malfunction and by the time the cause is pinned down the failure condition has gone from bad to worse. This is even more cumbersome for complex configurations of assets, such as oil rigs and aircrafts. Therefore, there is a need for a CM apparatus that provides a comprehensive picture of an asset condition, through a single channel, so as to warn of a failure condition in development. The same information could be used to provide a complete prognostic report for asset health management at any point in time for effective asset utilisation and its lifecycle management. Such a CM mechanism is responsive, technologically convergent, and information intensive, aimed at:

a. Continuous monitoring of the operational environment of an asset.
b. Improving asset reliability through efficient prediction of asset failures
c. Integrated planning and scheduling of repairs indicated by CM.
d. Utilising CM information for maximisation of equipment performance and throughput
e. Reducing CM and maintenance costs

This paper outlines an architecture for intergraded wireless asset prognostics using RFID technology. This architecture is based on the idea of mounting a Chipcon CC1010 based RFID on each asset. CC1010 supports an onboard microcontroller, and allows for interface to digital as well as analogue sensors, thus allowing for monitoring of the operating environment as well as condition of an asset. A significant advantage of using RFID technology is the identification of the asset or the particular configuration being monitored. This paper is divided into two sections, in the first section intricacies and challenges posed to asset management paradigm have been reviewed to develop a case for integrated prognostics, and in the second section practical aspects of CC1010 for integrated prognostics are discussed.

2 Asset management paradigm

An asset lifecycle starts at the time of designing the manufacturing or production system, and typically illustrates, stages such as, asset commissioning, operation, maintenance, decommissioning and replacement. Market demand and supply dynamics derive product and services design, and this product and services design derives production. Production specifies the types and design of assets to be used in production along with the operational workload of how much to produce. Operational workload and asset design specify the maintenance demands to keep the assets in running condition, whereas, maintenance determines the future production capacity of the assets. Fundamental aim of asset management processes is the continuous availability of service, production and manufacturing provisions of assets. Asset management is policy driven, information intensive, and is aimed at achieving cost effective peak asset performance as shown in Figure 1.

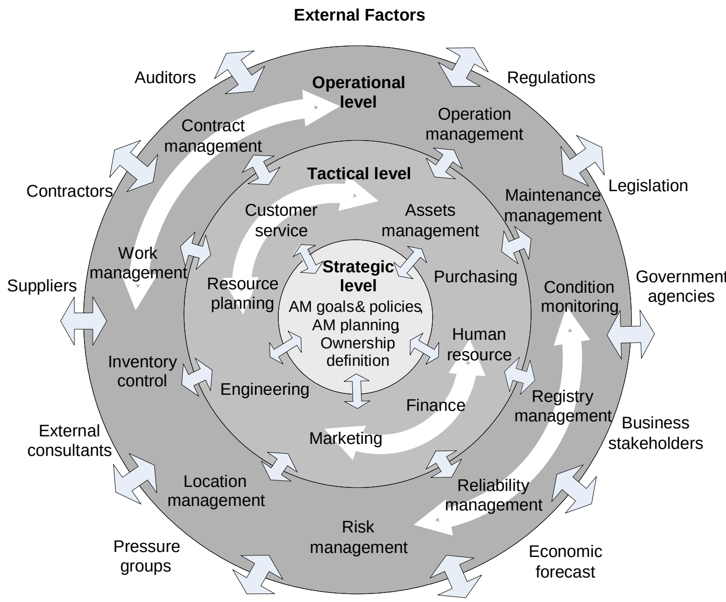


Figure 1: Asset Management Overview (source [1])

2.1 Shift Towards the ‘E’ Factor

Manufacturing and production of products and services is subjected to intense changes in technology and intensely varying market demands ([5], [6]). The resulting effect on industries is one of intense competition that dictates a shift towards renewal of products and services at regular intervals, which consequently is forcing businesses to innovate and update their offerings with added value and features. Shortened product lifecycles and continuous updating of products demands increased and enhanced asset operation capacity, which means assets also have to be upgraded continuously. Therefore, this continuous renewal on one hand impacts corporate and management strategies; and on the other demands equally innovative manufacturing and production paradigms, production philosophies, and processes. According to Taskinen and Smeds [7], technological advances are fast disappearing stock to production business models. Supply and demand mechanisms are changing so fast that, it is becoming critical for manufacturing strategies embrace just in time types of philosophies. Automotive and electronic products like cars, mobiles and computers are some examples of this variation in supply and demand. In these circumstances, it’s the ability of manufacturing businesses to adapt quickly to changing circumstances that provides them with an edge over their competitors.

Koc and Lee [8] summarise these changes in manufacturing paradigm and predicts that the emergent paradigm is ‘e-intelligent’ (Figure 2). The authors argue that the so called e-intelligent paradigm is the one in which there is continuous and seamless flow of information, aimed at real time access to all the stakeholders of a business process to increase the overall business efficiency, responsiveness, and agility. This means a shift that is not just outwardly innovative, as in terms of product innovation, but is also inwardly creative, that is to use the same technologies for process re-engineering and innovation. Lee [9] terms this shift as the “5Ps,” namely predictability, producibility, productivity, pollution prevention, and performance. These characteristics establish the properties of the future e-enabled integrated asset management paradigm. In essence, the emergent e-intelligent paradigm demands an elevated level of expertise and technology that could allow for realisation of distributed processes which contribute towards value creation for the business.

	1980	1990 2000	2010
Product Focus	*3Cs (Chips, Computers, Communications) & Intelligent Mechatronics*	*Products that think & link*	*Products that Learn, Grow, Reconfigure, & Sustain*
Manufacturing Focus	*Factory Automation (Flexibility)*	*Business Automation (Agility)*	*e-factory & e-Automation*
Innovation	*Microelectronics & Computing*	*Embedded Intelligence & Smart Netware*	*E-intelligence Systems*

Figure 2: Evolution in Product Innovation and Manufacturing (source [8])

In such manufacturing and production environments that are riddled with continuous change, stability in manufacturing and quality processes needs to be materialised as soon as possible [10]. In businesses like utilities, where demand for products or a service is continuous for twenty four hours a day, disruptions and interruptions have a devastating effect on revenues as well as customer relationship [11]. Therefore businesses not only need to keep their vital assets that are utilised to produce goods and services in operating condition, but at the same time need to have reliable and efficient support processes in place to ensure asset availability at all times. Nevertheless, the key to this reliability is the ability of asset support infrastructure to sense failure conditions as soon as they emerge. Furthermore, this information needs to be integrated seamlessly with other information systems utilised in the asset lifecycle management for effective follow up to detection of a failure condition.

2.2 Information Flow in Asset Management

In an engineering enterprise there are a variety of operational and administrative systems, which not only control and manage the operations of assets but also provide maintenance and administrative support for the asset life cycle management. In practice, data is captured both electronically and manually, in a variety of formats, shared among an assortment of off the shelf and customized operational and administrative systems, communicated through a range of sources and to an array of business partners and sub contractors [4]. What is more, more often than not these assets operate in unstable environments and consequently generate maintenance demands hitherto unseen. Asset management is an information intensive process that consists of many sub processes to manage the asset life cycle. An asset lifecycle starts at the time of designing the manufacturing system, and typically illustrates activities such as, asset commissioning, operation, maintenance, decommissioning and replacement. Of these activities, maintenance itself is an extremely complex process, and includes planned periodic repairs, scheduled or planned maintenance, equipment breakdowns, deterioration, and other unplanned or emergency maintenance demands [12]. Sandberg [13] argues that contemporary asset management paradigm demands an elevated ability and knowledge to incessantly support asset management processes, with support in terms of quality data acquisition, real-time monitoring, and computer supported categorization and recording of divergences from standard operations. These are essential for effective planning, scheduling, monitoring, quality assurance and acquisition of necessary resources required for carrying out repairs [14].

Sokianos et al [15] observe that asset maintenance comprises preventive maintenance, inspection, and repair for operational facilities. Modern maintenance strategies utilize different methodologies, such as corrective maintenance [16], fixed-time maintenance [17], condition-based maintenance [18], improvement maintenance [19] and selective maintenance [20]. Nevertheless, the purpose of asset maintenance is to ensure the availability of operational asset equipment at a minimal cost. While, maintenance activities have been carried out ever since the start of manufacturing, modelling of an all inclusive and efficient maintenance system has yet to come to fruition [21, 22]. This is mainly due to continuously changing and increasing complexity of asset equipment, and the stochastic nature or the unpredictability of the environment in which assets operate, along with the difficulty to quantify the output of the maintenance process itself [23]. Bever [24] points out some of the intricacies of asset maintenance and its interrelationship with other processes and systems (Figure 3). He argues that maintenance strategies that once were run-to-failure now are condition-based. Engineering Asset Management (EAM) systems and computerized maintenance management systems (CMMS) are now being implemented to support maintenance scheduling, workflow management, inventory management, and purchasing; and to integrate these functions with production scheduling, and manufacturing. Of late, engineering enterprises are looking for ways to provide direct connections from their EAM system to Maintenance, Repair, and Overhaul/Operations procurement systems, which allows for paperless purchasing of parts and offer considerable time and cost savings compared with traditional purchasing methods.

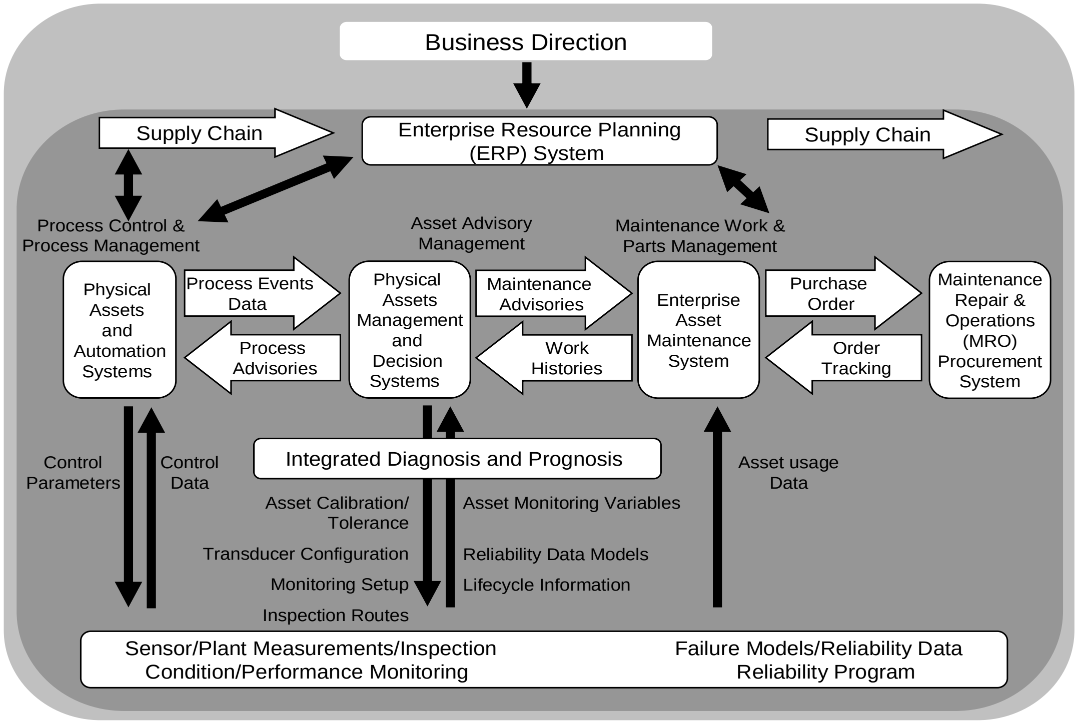


Figure 3: Asset Management Information Flow (Adopted and modified from [24])

Nonetheless, current information systems in operation within engineering enterprises have paid for themselves, as the methodologies employed to design these systems define, acquire and sustain information needs of the past not for the future. Consequently, the data captured is mostly historic and lacks quality, and at the same time is not of much use for real time decision support for asset lifecycle management [4]. End to end interoperability of information, therefore, is extremely important for value added asset lifecycle management. In addition to this, information systems for asset management have to act as instruments for decision support, and provide for the centralised control of decentralized tasks, such as maintenance.

2.3 Genesis of E-Maintenance

Lately there have been many initiatives geared at complete automation of maintenance; joint strike fighter (which is a joint venture of US Marine Corps, US Navy, and US Air Force) is one of them (see figure 4). While in operation, the fighter jet or what the JSF calls an intelligent air vehicle continuously monitors its own condition. This continuous prognostic is aimed at detecting a failure condition in development rather than failure reporting; whereby the aim is to reduce maintenance time and as a consequence increase operational time. The concept of this prognosis is the same as there is for any fatal disease among humans, the earlier the prognosis is made the better the chances are to increase the operational life of an asset and its economical operation. Continuous prognostics are communicated to the base station on the aircraft carrier in real time where assessments are made about the condition of the fighter. This assessment generates recommendations for repairs or parts replacements required to carrying out maintenance. Combat planning and the ground to air ratio of the fighter jet, therefore, rests with the speed of failure condition detection and the speed with which maintenance resources are acquired. This framework not only provides for continuous availability of the asset but also ensures cost effectiveness by aiding in maintaining critical stock levels of essential spares on the ship; planning major overhauls well ahead in time; identification of maintenance resources and routines; and early planning and scheduling of standby assets. These features ensure that the maintenance process is highly responsive and based on informed decisions rather than common judgement.

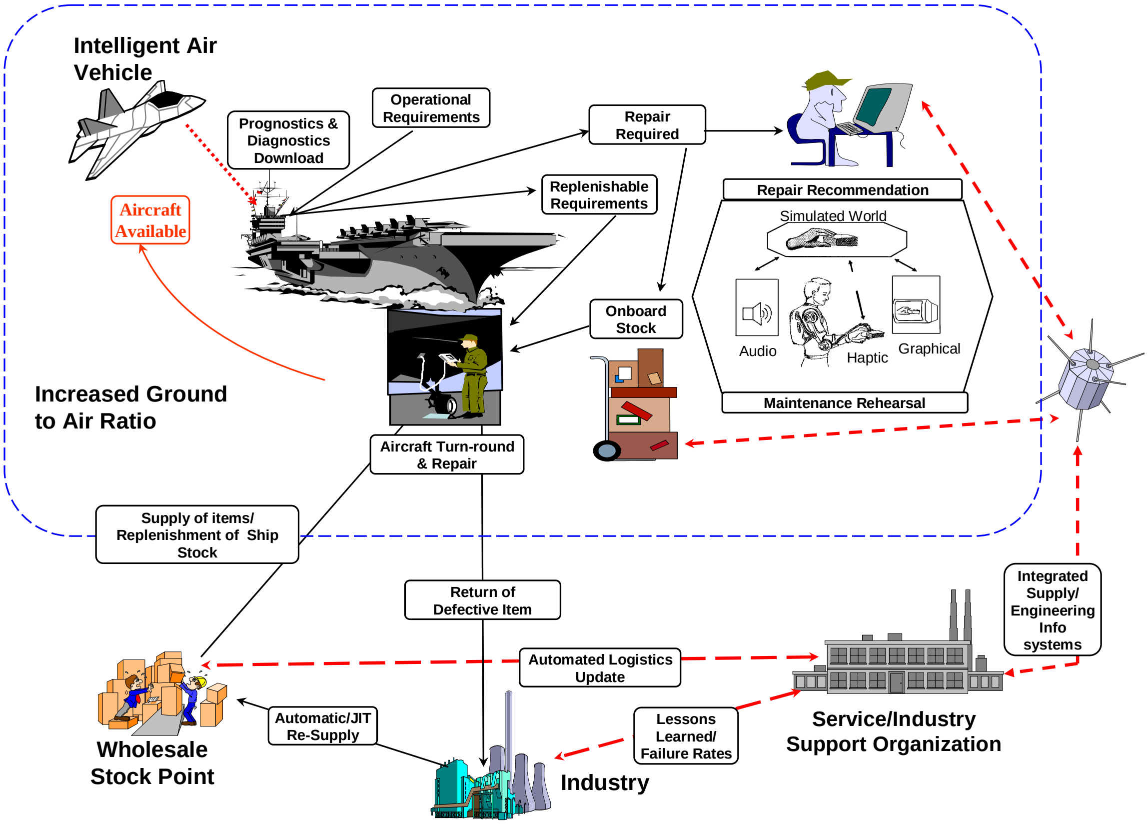


Figure 4 - Autonomic Logistics Structure – Joint Strike Fighter (Source [25])

This framework could be easily applied to e-enabled production and manufacturing paradigm, for example, a typical water pump station in Australia is located away from major infrastructure and has considerable length of pipe line that brings water from the source to the destination. In this situation, assets are deployed over an area of various kilometres; however, the demand for water supply is continuous for twenty four hours a day, seven days a week. Although, the station may have some kind of an early warning or process control and condition monitoring system installed, such as Supervisory Control and Data Acquisition (SCADA), maintenance labour at the water stations and along the pipeline is limited and spares inventory is generally not held at each station. Therefore, it is imperative to continuously monitor asset operation (which in this case constitutes equipment on the water station as well as the pipeline) in order to sense asset failures as soon as possible and preferably in their development stage. An asset reaches failure mode is in one of the following three ways [26]:

a. When an asset become inoperable suddenly, and can no longer perform its required operations;
b. When an asset cannot fulfil some or all of its operations at the same performance standard as originally specified; or
c. When an asset gradually deteriorates to an unsatisfactory level of performance or condition, and its continued operation is unsafe, uneconomical or aesthetically unacceptable.

Failure modes are divided into two categories [27],

a. Hidden failures, where the asset operator doesn't become aware of the loss of asset functionality, under normal circumstances. For example, chemical additives in oil affecting its viscosity, which consequently affects the output of the machine.
b. Evident failures, where the asset operator becomes aware of the fault due to an evident break down.

Failure detection is a difficult task and in certain cases it is extremely difficult to locate a failure, primarily due to the complexity of configuration of the asset or a fault occurring due to more than one set of reasons. Ideally CM techniques provide for prediction of potential failures by scanning asset operating environment and condition and reporting of critical variables such as temperature, pressure, current, vibrations etc. Nevertheless, for ensuring reliable asset management early fault detection is not all, it needs to be backed up by effective maintenance strategies which guarantee that the asset continues to fulfil its intended functions in its present operating context.

3 Challenges of Asset Reliability Assurance

There are four reliability related concepts being applied in the industry. Their genesis is owed to airline and oil and gas industries, nevertheless, these concepts are increasingly adopted by other industries. These are reliability centred maintenance (RCM) [28], total productive maintenance (TPM) [29], reliability engineering (RE) [30], and control engineering (CE) [31]. All of these employ different methodologies to ensure reliability, Table 1 provides and overview of the intent and methods employed in these paradigms.

	RCM	**TPM**	**Reliability Engineering**	**Control Engineering**
Scope	Machine functionality	Machine efficiency	Machine durability	Machine controllability
Maintenance objective according to paradigm	Keeping the machine functionality at the required level	Maximising the machine capacity by equipment efficiency	Enhancing the machine life-time and reliability	Maintaining the production process state
Failure or failed state	Inability to fulfil user-required functional capability	Loss or reduction of a capability with regard to optimal performance	Loss of a function	Statistically abnormal process state
Life-cycle phase being applied	At the machine design and operation phase	At the machine operation phase	At the machine design phase	At the machine operation phase
Context	Single machines, users, and plant	Single machines, users, and plant	Multiple machines, users, and plants	Single production process
Applicable methods	Proactive maintenance by preventing failures before they first occur	Personnel participation in continuous improvement for preventing sudden and chronic failures	Design-out failures with enhanced component design and materials	Control of process states and compensation of disturbances by mathematical algorithms.

Table 1: Reliability Paradigms (Source [32])

Although the choice of a methodology largely depends upon the nature of the assets used by the business, RCM is a methodology that focuses on reliability of an asset by recognising that as the asset designs and operations differ so do their maintenance demands. This uniqueness entails that assets have different probabilities of undergoing failures. RCM is aimed at optimising operations such that maintenance plans are devised according to the needs and priorities of assets, and the availability of maintenance resources and manpower to carry out maintenance. RCM considers an asset as a system in an operational or environmental context and regards failure state as a state that is unacceptable to the user, therefore it focuses on preserving the primary function of asset in the operational environment. The most significant value of RCM is human safety, therefore there is maximum emphasis on analysing asset condition information so as to predict what might happen to the asset in different scenarios. RCM tries to answer the following questions [27]:

a. What are the functions and associated performance standards of the machine in its present operating context,
b. In what way does it fail to fulfil its functions,
c. What causes each functional failure,
d. What happens when each failure occurs,
e. In what way does each failure matter in respect of the environment, human safety, losses, and expenses,
f. What can be done to predict or prevent each failure,
g. What should be done if a suitable proactive task cannot be found?

Based on the answers to these questions, RCM applies failure modes effect and criticality analysis (FMECA), for each failed state. This allows for identification of causing events and the consequent events and helps in predicting the possible effects of failures. These failure effects are specified in terms of factors such as production operations downtime, repair costs, human safety, environment, maintenance expertise, and spare logistics.

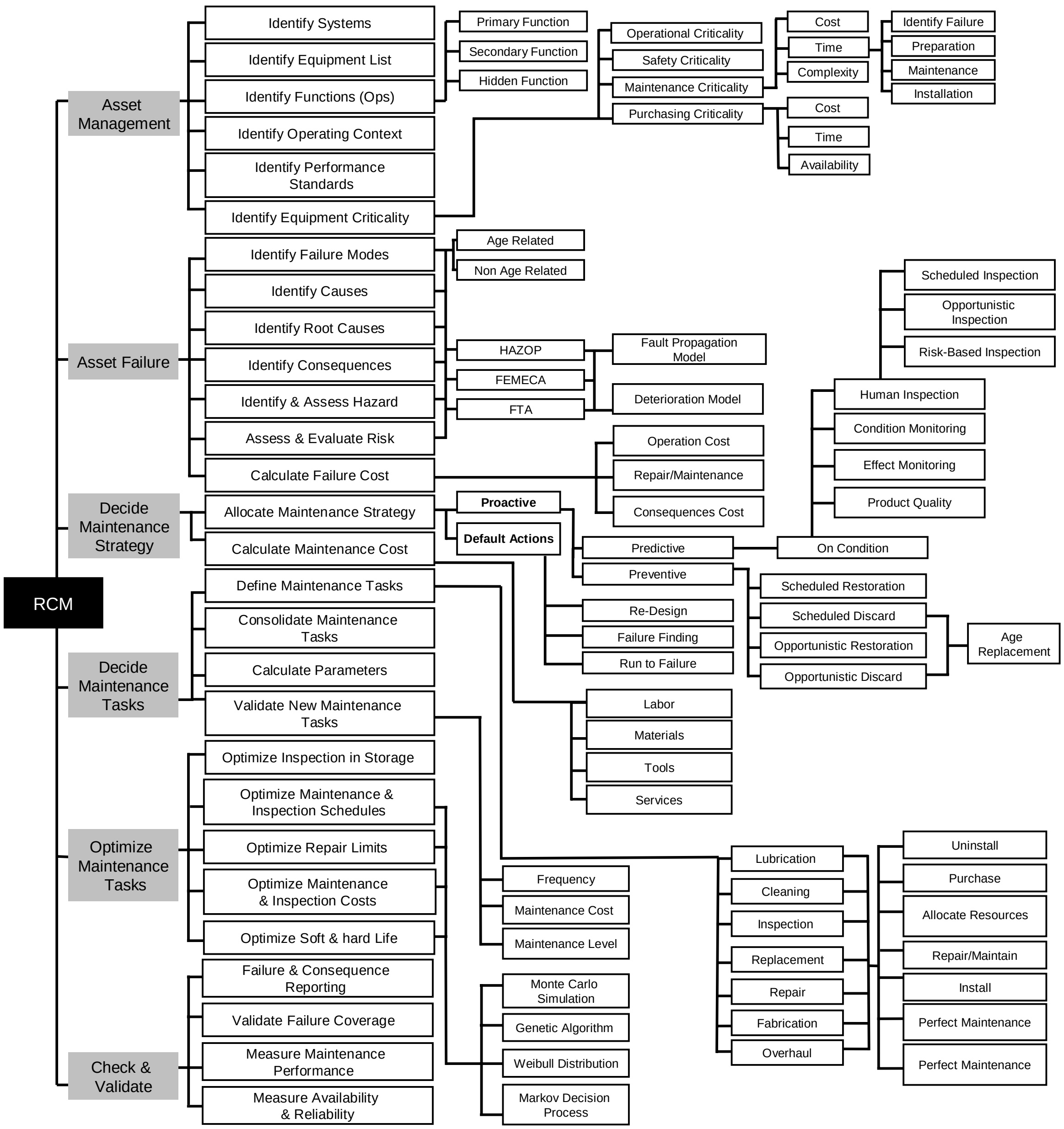


Figure 5: RCM Functional Decomposition (Source [33])

RCM, as evident from figure 5, provides a systematic approach to develop a focused and cost effective preventive maintenance regime and control program for an asset as well as for the asset management processes. RCM particularly addresses the erroneous belief of the save now, pay later approach to asset management by scheduling possible trade-offs. For example investments into pre-warning systems and failure modes analysis might be traded off against eventual, lower maintenance costs if improved reliability could be achieved. It might also be traded off against the value of increased plant availability leading to increased production output. The concept of RCM calls for close collaboration between asset design, operation, and maintenance functions, such that information relating to reliability of an asset is communicated throughout the value chain of asset management. There are a variety of operational and administrative systems used for the whole lifecycle management of an asset, which not only control and manage the operation of asset equipment but also provide maintenance and administrative support throughout the asset life cycle. In practice, data is captured both electronically and manually, in a variety of formats, shared among an assortment of off the shelf and customized operational and administrative systems, communicated through a range of sources and to an array of process stakeholders. It is therefore important to have mechanisms in place that provide seamless flow of standardized information to process stakeholders, which is vital for asset life cycle support processes that ensure asset reliability. In this regard, it is important to sense the failure conditions in their development stages, such that appropriate actions could be taken immediately. This not only saves effort and money to the asset managing organisation, but also ensures continuous availability of the asset. However, to sense a failure condition in its infancy requires complete information on the operational behaviour and operating environment of an asset, such that the information thus captured could be used to trigger appropriate and timely follow up actions.

4 Asset Reliability through Integrated Condition Assessment

The fundamental issues in ensuring asset reliability are capturing information on the operational and environmental variables of an asset operation through a single channel, and using the same to predict asset behaviour and failure conditions. From the discussions in pervious sections, there is a need for a system that could be integrated with the overall asset management information systems framework (figure 3); provides processing capabilities embedded with the asset to allow for seamless flow of information aimed through reduced human computer interaction (HCI) (figure 4); and generates quality information to ensure reliability cantered maintenance of an asset (Figure 5). This system thus has the following requirements,

a. Complete, current, and accurate information on each asset, including its current configuration, location, workload, health status and history, and the physical environment that it operates in.
b. A certain level of intelligence embedded with the asset, such that it itself reports any malfunctioning in its operating environment or in its own behaviour.
c. An integrated approach to economic and performance tradeoffs and lifecycle decisions, through
    (i) Organization of information relating to asset condition and performance for condition assessment and trend analysis;
    (ii) Analytic models that predict future changes in asset condition, as well as the variations in support mechanisms to forecast and plan for resources.
    (iii) Cost benefit decision support for asset repair, maintenance, renewal, and decommissioning.
d. Integration of condition information with legacy systems and applications for support processes such as spares supply chain management, maintenance request generation and logging.

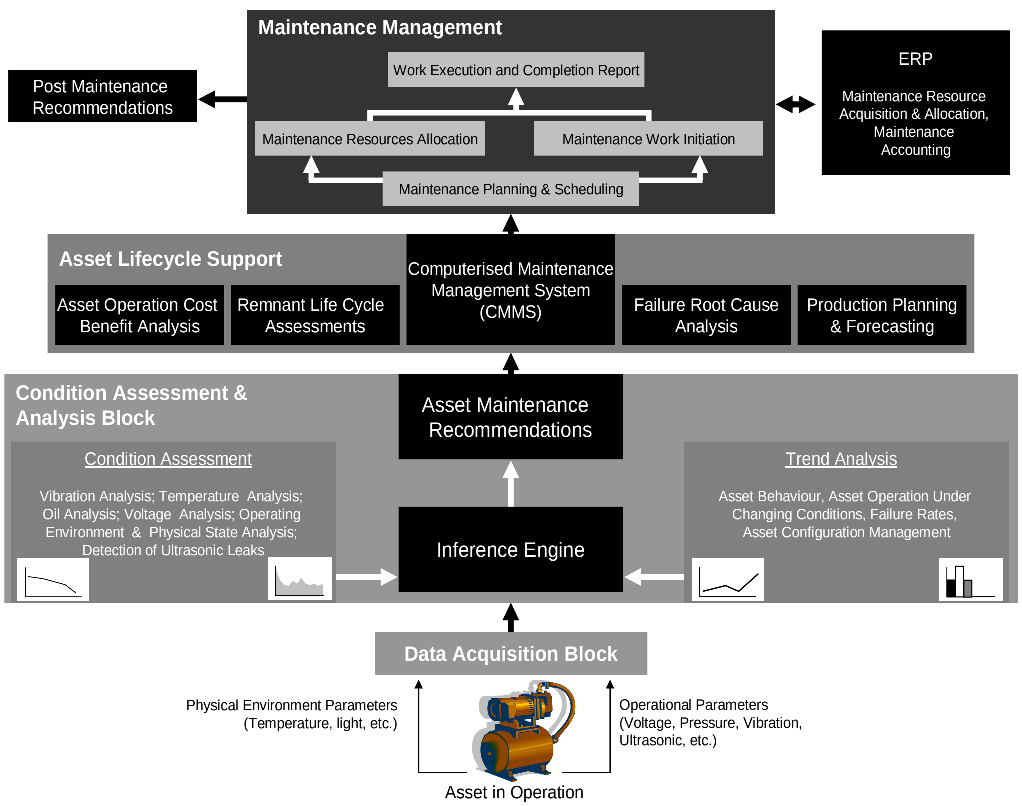


Figure 6: Integrated Prognostics Architecture

Figure 6 presents an integrated prognostics architecture developed on the requirements set forth. In this architecture, real time data on operating environment and operating condition is captured through sensors without human interaction, and is analysed to profile the operational behaviour of the asset or the configuration of an asset that the sensors are attached to. This analyses provides for notifications on the existing state of assets, which enables failure condition reporting in failure development stage; generation of maintenance demands of the asset; and workload apportionment of assets such that no asset is overworked. The inference engine acts like a watch dog and compares the probabilities and possibilities before generating recommendations concerning asset life cycle support and other associated processes. The real time availability of such information ensures cost effective planning, reduced labour cost, better fault detection, and identification of dangerous or hazardous areas without incurring risks to maintenance crew. However, the wireless capability also realises economical remote monitoring, as information can be transferred over great distances using this architecture. The condition assessment block provides for comparisons and behaviours of asset operation, which may be used for life cycle support planning of assets of similar type, make or model, along with providing information for maintenance scheduling, and asset shut down. Recommendations from inference engine provide basis for decision support, including asset life cycle management, cost benefit analysis of asset operation such as tradeoffs between asset maintenance and renewal, production planning and scheduling etc. If total automation is sought, information input to maintenance management system can provide for the automation of the maintenance work execution by generating automated work requests, spare acquisition requests, and assigning tasks to maintenance crew by integrating condition assessments with maintenance workflow. The following section describes the proof of concept by using RFID technology.

5 Integrated Wireless E- Prognostics

5.1 Why RFID Technology?

RFID technology consists of three components, an RFID tag, a reader, and a Tag/Reader management systems or a middleware [34]. RFID tags are made up of a small microcontroller and antenna available in many different packages. They provide a contact free form of identification through the use of radio frequencies. Each tag has an electronic product code (EPC) or an identification number embedded into the tag microcontroller that is used to uniquely identify each tag, which can also be termed as the RFID's version of a bar code. When an RFID tag is placed close enough to the reader it is powered up through a magnetic field emitted by the reader thus powering the microcontroller of the tag, such that it transmits the EPC to the reader. RFID tags do not require line of sight between tags and readers for them to be detected and therefore make it possible for tags attached to items to be identified from a single point.

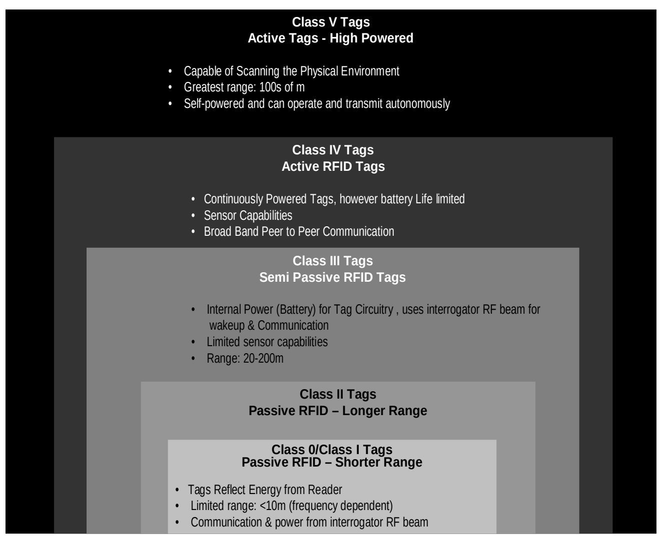


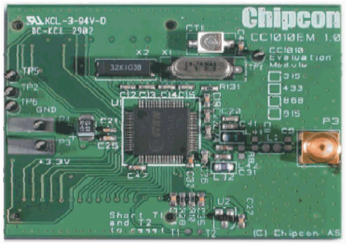
Figure 7

RFID tags can be active, passive, or semi-passive tags, and are classified into five classes according to their capabilities and functionalities (Figure 7). However, there are commonly referred to as either passive or active. Passive tags are interrogated by the reader for information contained in them, whereas active tags themselves transmit the data streams to the reader, hence the name passive and active. Passive tags are powered via the reader thus they do not require batteries to operate, whereas active tags have an onboard power. Passive tags can be detected from a distance ranging from a few centimetres to a few metres, whereas active tags, on the other hand, have an on-board battery, and therefore, have a far longer read/ write range and memory size. Class 1 and 2 tags are the most common and can be easily found in operation today. These tags are mostly used for item tracking and inventory management purposes. Class 3 tags are semi passive, which means that they are on board power available, but that power needs to be activated by the magnetic filed that the sensing beam of the RFID reader creates. They have relatively smaller read range, which means that the reader has to be placed in close proximity to the tagged item. Class 4 and 5 tags have on board continuous power available (usually a life span of 10 years) as they are fitted with a battery, in most cases have a microcontroller available on board, support on board memory, and also have sensing capabilities. Table 2 summarises typical characteristics of active and passive tags. Active tags have external interface available that allows for interfacing additional sensors and devices. On the other hand, major advantage of the passive tags is their small size; consequently they can be used for many applications where size and weight are limiting factors. Extra features on a tag, however, do increase the size and cost of each individual unit. RFID technology is becoming quite popular in logistics applications, however a number of research initiatives have explored the potential of RFID technology for other applications as well. Among these are applications such as tracking a box, web luggage, smart shelves for pharmaceutical products, smart toolbox, and smart box etc [35, 36, 37, 38]. An analysis of available technologies led us to choose RFID technology for its unique identification features, and the provision of an onboard microcontroller and memory.

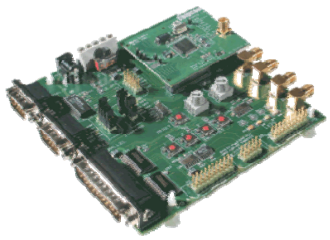
5.2 Using RFID for E-Prognostics

A water station was chosen as field experiment site. The station has four water pumps, and two of these pumps were used in this experiment. The water pump environment was chosen because of relative stability it offers over other asset operating environments. Since the objective of the project was to demonstrate the acquisition of sensory information through a single channel, only three generic brand, off the shelf sensors were chosen for this field test. These were temperature, pressure and flow sensors. The test was carried out for a week, during which snap shots of data were taken at regular intervals.

Each pump asset was installed with Class-V RFID tags, Chipcon's CC1010 (Figure 8), such that collectively they formed a sensor network with the provision of a gateway tag that provides for communication of data captured by the network through a single channel, as highlighted in figure 9. An RS-232 to CMOS level converter chip, was included to enable a tag to act as gateway. The gateway tag serves as the liaison between the database server and sensor mote network and delivers data captured to condition monitoring database as illustrated in figure 10. Since CC1010 is equipped with a temperature sensor, therefore the on board sensor was used. However, the existing analogue vibration and pressure sensors of the pump were interfaced with the tag through the available serial port. CC1010EB supports three ADC (analogue-to-digital converter) channels, a Universal Asynchronous Receiver Transmitter (UART), and 26 I/O pins. CC 1010 has an onboard 8051 8-bit microcontroller with 32Kb of flash for code and non-volatile data, 2K of RAM. An important feature of CC1010 is that it can be read and written from distances in excess of 100 meters. At the same time, the tag supports a serial peripheral interface, and a hardware Data Encryption Standard chip for secure communication.



Chipcon CC1010EM



Chipcon CC1010EB

Figure 8 Source [39]

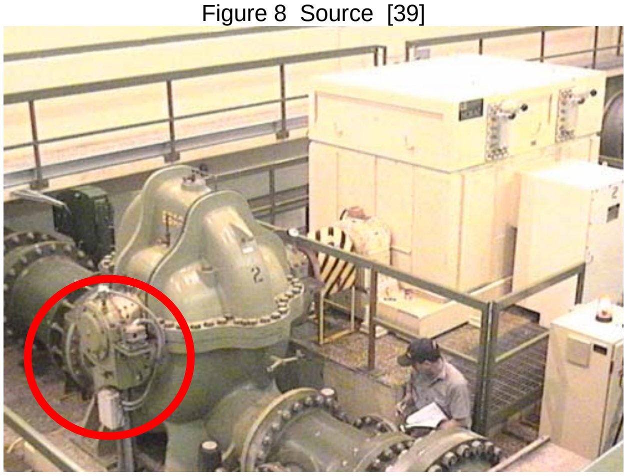


Figure 9: Integrated Wireless Prognostics using RFID

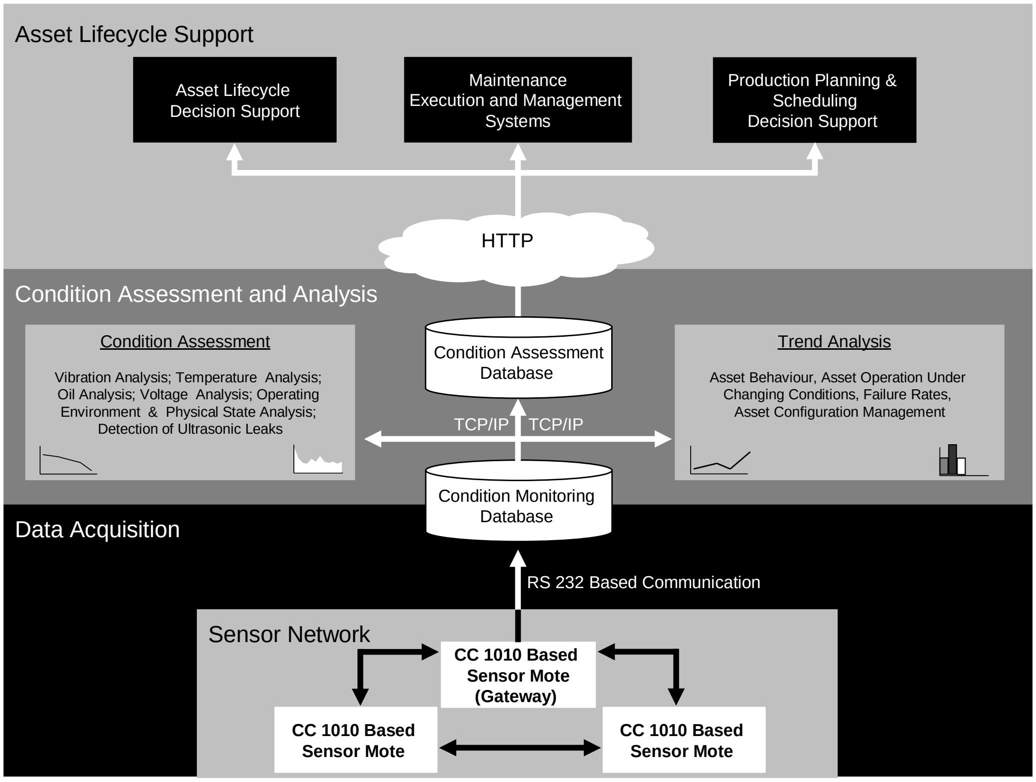


Figure 10: Integrated Wireless Prognostics using RFID

The raw information captured from the sensors was communicated through the gateway to the MySQL based condition monitoring database, where it was converted into relevant units for temperature, pressure, and velocity. The interface allowed for viewing this information as graphs or simple readings over a period of time. Although, we did not analyse this information further as we used only three sensors which were not enough to yield holistic analyses leading to complete health picture of the asset. It nevertheless proved the aim of the project, which was to demonstrate the acquisition of sensor information through a single channel exclusive to an asset. The TCP/IP based connections allowed for a distributed server model, which allowed for remote condition monitoring. Apart from providing advances such as consolidation of condition information and single channel communication, another advantage of this architecture is fast location of failure condition. With the ability of an RFID tag to identify itself; each asset mounted with the tag can also be uniquely identified. Therefore, information captured from each gateway mote provides important indication on exact location of the asset under investigation, for example in case of a failure condition developing it's easy to find out that site number 1, pump no 2's temperature is outside the safe limits. The availability of onboard memory allows for storing asset specific information, for example asset health and maintenance record on the tag such that it stays with the asset throughout its lifecycle. Although, this feature is not of great use for an asset like water pump, however it could be extremely useful for mobile assets, such as main battle tanks.

6 Conclusion

This paper has illustrated an architecture for CM of remote assets, which captures and communicates environmental and operational information through a single channel. Using RFID for prognostics poses significant advantages for engineering enterprises, and may prove to be an important building block towards e-intelligence based maintenance and asset management. This architecture allows for development of a technologically convergent and miniaturized device that could easily be mounted on an asset to provide condition data manipulation. It will reduce monitoring costs significantly and improve asset reliability through efficient prediction of asset failures. However, further research is needed to make the technology more efficient, as the on board power supply of CC1010 has limited life span. Apart from this, other important area needing investigation is the behaviour of this technology with high magnetic fields. This paper has outlined an initial architecture for the application of RFID technology for integrated wireless prognostics of engineering assets. RFID technology promises a new generation of applications in e-intelligent paradigm. Although the initial concept presented in this paper addresses a few issues in asset maintenance, a large number of research opportunities exist in integrating this technology with information systems of large sized engineering enterprises, for which, 'in-sensor' processing capability may be required. Since it is microcontroller based technology, a logical corollary to this application will be an investigation into the ways of integrating the inference engine with the gateway sensor mote on a chip.

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