Ministry of Defence

JSP 886
DEFENCE LOGISTICS SUPPORT CHAIN MANUAL

VOLUME 7
SUPPORTABILITY ENGINEERING

PART 8.03B
MAINTENANCE DESIGN

VERSION RECORD		
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1.5	07 Mar 14	Various changes throughout the document (text in blue and sidelined).

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CHAPTER 1: INTRODUCTION TO MAINTENANCE DESIGN

INTRODUCTION

1. Maintenance is all actions taken to retain equipment in or to restore it to specified conditions until the end of its use, including inspection, testing, servicing, modification(s), classification as to serviceability, repair, recovery, rebuilding, reclamation, salvage and cannibalization[1]. In order to ensure that appropriate maintenance is established there is a need to undertake the following:

a. **Maintenance Planning.** Identify the means to fully support a product.

b. **Maintenance Design.** Identify what maintenance is required.

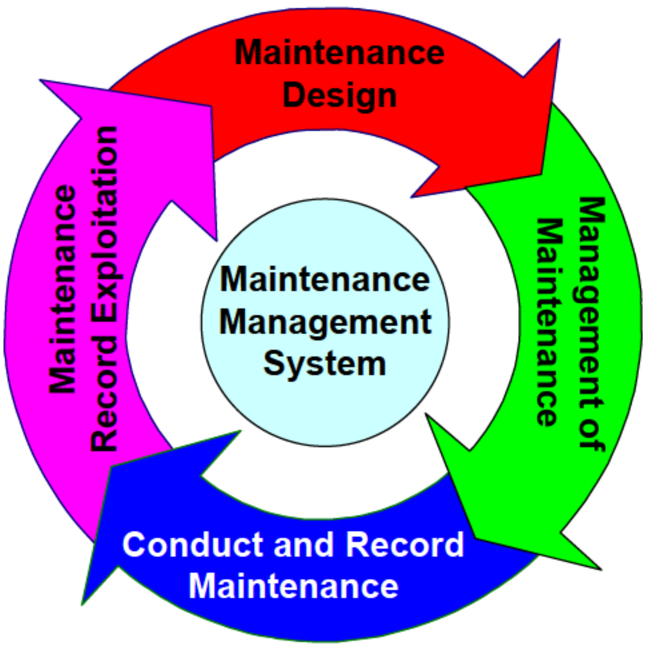
c. **Manage Maintenance.** Decide on when and where actual maintenance will be done.

d. **Conduct and Record Maintenance.** Undertake the maintenance and keep appropriate records.

e. **Exploit Maintenance Records.** Learn from experience to improve current maintenance or to improve maintenance of future products.

2. For most products it is advantageous to use a maintenance management system to record maintenance activities, this is shown schematically in Figure 1, below.

Figure 1: Maintenance Process



[1] Allied Administrative Publication-06 (AAP-06): NATO Glossary of Terms and Definitions.

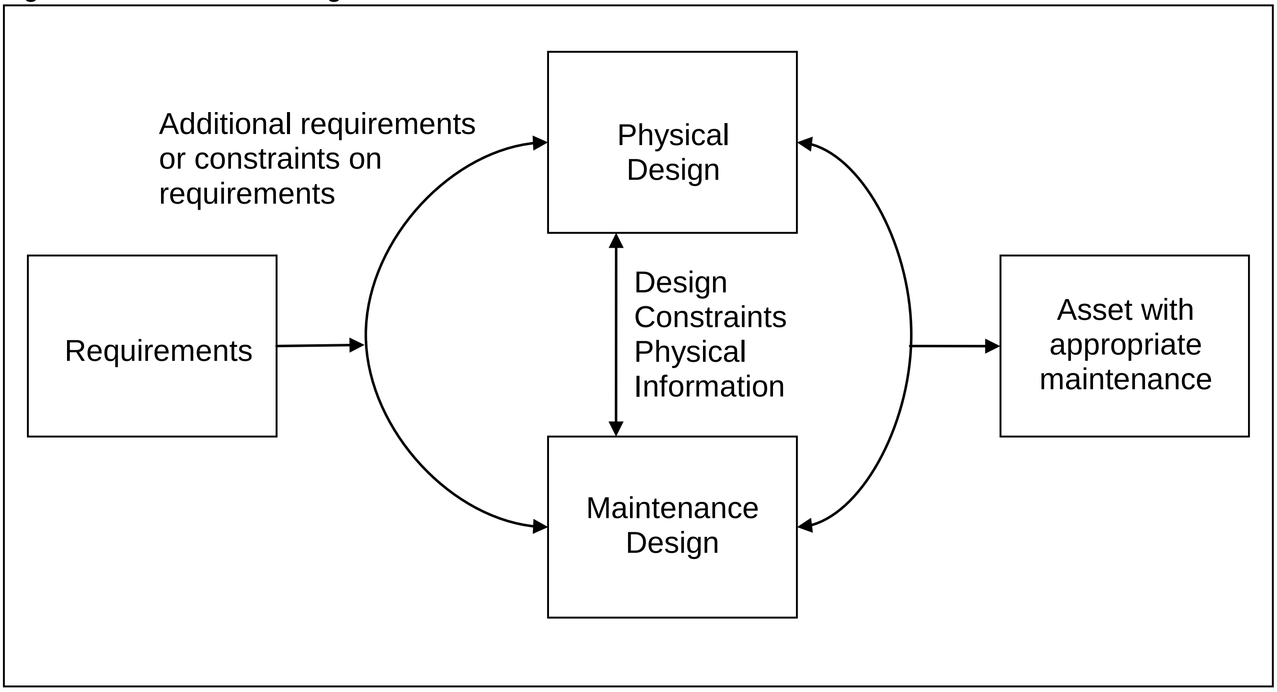
CONTEXT

3. This part provides key points of policy and guidance on how Maintenance shall be designed.

4. Very few items require no maintenance[2]. Where maintenance is required, it needs to be designed while the item is being designed, otherwise the resulting maintenance will be sub-optimal. Maintenance must be considered at the earliest stages of a project's life. The overall process is shown in Figure 2.

5. Lowering the performance requirements of an item once in service, thereby increasing the reliability, can also reduce maintenance, resulting in an improved system. This type of trade-off can be made at any time, as the item has been designed to perform to its original requirement.

Figure 2: Maintenance Design Process



POLICY

6. Maintenance Design is to be aligned to the design of the item ensuring that the requirements for maintenance are given equal consideration with the design for performance. Maintenance design is to follow a structured process that:

a. Results in optimised maintenance, to include but not be limited to: training, spares availability, access, cost, recording and extracting data.

b. Generates evidence that the maintenance identified is appropriate.

c. Gives confidence during the design or redesign / change process that suitable maintenance is being developed.

[2] Satellites typically have no maintenance due to the costs associated with getting a maintainer to the satellite, other things which may have no maintenance are those things which we use and dispose of, otherwise everything has some sort of maintenance.

d. Generates the supporting information that will allow maintenance to be undertaken.

e. Identifies items critical to safety, reliability and security.

f. Ensures items that affect the safety case are identified in the maintenance plan.

g. Ensures maintenance requirements for similar products are considered and tailored where appropriate.

PRECEDENCE AND AUTHORITY

7. Ownership of Logistics policy in support of the Logistics Process falls to the Assistant Chief of Defence Staff Logistics Operations (ACDS Log Ops) as Chief of Defence Materiel (CDM)'s Process Architect[3]. This role is exercised through the Defence Logistics Steering Group (DLSG) reporting up to the Defence Logistics Board (DLB). It is against this governance framework that responsibility[4] for developing and promulgating current R&M policy is delegated to Hd IMOC SCM. Project Teams (PTs) are required to assess and show compliance with key policies and governance as directed by this JSP and signposted by the SSE.

KEY PRINCIPLES

8. An agreed structured methodology shall be used to identify maintenance activities required to prevent failure or deterioration of an item below acceptable limits. (See JSP 886 Volume 7 Part 8.04: Reliability).

9. These studies shall be undertaken sufficiently early in the programme to allow elimination/minimisation of maintenance by redesign to be considered.

10. Maintenance activities shall be packaged in a way that adequately identifies the resource, manpower, facilities, infrastructure, tools, access and removal routes or requirements etc. The ILS process requires that all maintenance activities shall be detailed and agreed in a Product Deliverable (the Maintenance Plan). This shall detail all physical and manpower resources necessary to maintain the item at the required availability, and outline how these will be delivered in the operating scenarios and environments defined in the use study.

11. A strategy for the management of maintenance, fully integrated within the overall item support solution and compatible with integral and other related items, shall be developed and detailed in the maintenance plan. The maintenance plan shall also outline the plan for the data exploitation, review of maintenance, its adequacy and alignment with specification, including how the review will be integrated with business reviews.

12. An audit trail of decisions and changes with respect to the design of maintenance shall be kept.

13. For each major item the way the material state will be assessed and trigger a maintenance activity shall be determined. This can range from a very simple reactive approach, repairing when failed, through a fixed maintenance schedule, a reactive schedule based on rate of deterioration through full condition based maintenance &

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[3] JSP899: Logistics Process – Roles and Responsibilities.

[4] Responsibility - The person responsible for the content, currency and publication of a JSP (as per letter of delegation). Responsibility established through Letters of Delegation (LoD), issued through the DLPWG chair and exercised through Terms of Reference.

prognostics. Usage and / or condition information required to trigger a maintenance activity shall then be identified for each.

14. The usage of automatic systems to collect this information shall be investigated – the benefits of such systems shall be balanced against the costs of additional complexity and any needs for data bandwidth. These can be: immediate (alarms & warnings), near real time (HUMS / SIE) or off-line (forensic records).

15. For each item the need for maintenance records shall also be identified, consistent with whichever maintenance strategy has been chosen.

16. The structure of the maintenance organisation and how it will operate will be included in the maintenance plan, outlining the responsibility for analysis of maintenance data necessary to support the maintenance approaches chosen. It will also include details on the amount of discretion the maintenance manager and other key personnel may have, and how their responsibilities map with safety delegations.

17. The appropriate maintenance management system(s) shall be populated with the requisite product information and be able to receive and store data related to maintenance in time for the commencement of maintenance activities.

18. Where appropriate a demonstration of how maintenance will be performed and how data will be transferred to the maintenance management system or alternative system for analysis should be undertaken.

19. Once the item enters service the review of the maintenance records for trends and improvements shall be implemented in accordance with the strategy outlined in the maintenance plan.

ASSOCIATED STANDARDS AND GUIDANCE

20. Reference and, if practical, link to the relevant publications involved.

a. JSP 886: Defence Logistics Support Chain Manual:

(1) Volume 7 Part 2: Integrated logistic Support (ILS) Management.

(2) Volume 7 Part 5: Management of Support Information.

(3) Volume 7 Part 8.03A: Maintenance Planning.

(4) Volume 7 Part 8.03C: Management of Maintenance.

(5) Volume 7 Part 8.03D: Conduct and Record Maintenance.

(6) Volume 7 Part 8.03E: Maintenance Record Exploitation.

(7) Volume 7 Part 8.04: Reliability and Maintainability.

b. BR 1313 Maintenance Management in Surface Ships.

c. AESP 0200-A-090-013: Land Equipment Engineering Standards.

d. AESP 0200-A-100-013: Equipment Care Inspection and Mandatory Equipment Inspection.

e. MAP 01: Military Aviation Authority (MAA) Maintenance and Airworthiness Processes (MAP).

f. JAP(D) 100A-0409-1 GOLDespTM Logistic Information System. Procedures Manual.

g. JAP(D) 100A-0409-1A GOLDespTM Logistic Information System. Procedures Manual (E-Certification).

h. JAP(D) 100A-0409-2 GOLDespTM Logistic Information System. Support Policy and General Orders.

i. DEFSTAN 00-600: Integrated Logistic Support Requirements for MOD Projects.

OWNERSHIP AND POINTS OF CONTACT

21. The policy for Maintenance Design is sponsored by DES IMOC SCM-TLS.

a. Sponsor details:

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b. Document Editor:

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CHAPTER 2: MAINTENANCE MANAGEMENT SYSTEMS

CONTEXT

1. Many approaches to Maintenance management incorporate the use of bespoke software systems for the capture, conduct and recording of maintenance activity. Functionality can include, but is not limited to, the integration of maintenance schedules developed during maintenance design (for example, RCM feed) through to the capture and recording of in-service maintenance activity and the disposal of the equipment/system at the end of its useful life. Aside from providing core functionality for the scheduling of work orders/packages for inspections and routine preventive maintenance, they are often tailored to incorporate additional functionality including: asset management, inventory control and mandatory documentation required for the processing of safety requirements.

POLICY

2. It is MOD policy that all maintenance activity from the undertaking of maintenance design through to maintenance exploitation be integrated into, and managed within, a suitable Maintenance Management System (MMS).

PROCESS

3. The established MMSs used within the MOD are as follows; their functionality varies in respect to domain specific requirements:

a. **Maritime Environment.** BR1313: Maintenance Management in Surface Ships. Chapter 5: Unit Maintenance Management System (UMMS). UMMS is a web based computerised MMS based on the principles of RCM. UMMS administers the management of Ship, Submarine, RFA and shore environments.

b. **Land Environment.** JAMES (Land) is an Enterprise Resource Planning (ERP) System designed to provide all asset managers, engineers, planners and executives with data and information on all equipment in service in the MOD Land environment. It is a tool for all UK Armed Services, DE&S, Government Agencies and Defence contractors involved in MOD Engineering and Asset Management (E&AM).

c. **Military Air Environment.**

(1) **Rotary Wing.** Three documents (JAP(D) 100A-0409-1 Procedures Manual, JAP(D) 100A-0409-1A Procedures Manual for E-Certification and JAP(D) 100A-0409-2 Support Policy and General Orders) set out the policy and procedures for the GOLDesp Logistics Information System application, which is an electronic method of recording, storing and forecasting logistics and engineering data relevant to the operation and maintenance of an aircraft.

(2) **Fixed Wing.** The Logistics Information and Technology System (LITS) includes within its suite of applications both an Asset Management Application (AMA) and Maintenance Management Application (MMA). LITS Orders and Instructions (DAP 300A-01) Leaflet 13 describes the use and impact of the MMA. The MMA enables users to generate maintenance programmes and calculate the remaining life of assets to permit more effective management of the life of the equipment and the resources used for maintenance.

4. These systems should be used in preference to bespoke systems, it is the PT's responsibility to ensure that all maintenance activity relevant to their particular equipment / systems integrate with these standard MOD systems.

5. Records for maintenance and maintenance plans need to be retained. The following is not a comprehensive list but identifies issues that need to be considered when determining what to retain and for how long:

a. Meeting legislative and regulatory requirements.

b. Managing the risk associated through not having records.

c. Continuity of service.

d. Supporting the management of maintenance.

e. Efficient and accountable running of maintenance.

f. Determining what is to be recorded and retained.

g. The maintenance, transfer and disposal of electronic records.

CHAPTER 3: CONDITION MONITORING AND CONDITION BASED MAINTENANCE

INTRODUCTION

1. This chapter gives the MOD policy on Condition Monitoring (CM) and Condition Based Maintenance (CBM). In addition the benefits of the approach are presented.

2. The top level procedure describing the application of CM and CBM is presented. This procedure applies to both new and in service equipment.

STATEMENT OF POLICY

3. Policy requires that MOD PTs must consider an appropriate level of CM and apply a suitable CBM approach to through life support of their platforms.

4. The Procedural Framework section of this chapter defines processes to determine if CBM is appropriate and how to apply the technique.

5. PTs are to use CM and develop a CBM plan that is monitored and endorsed by the CM Review Panel process described in Procedural Framework section below.

6. The plan is a through life requirement and shall be contained in the Through Life Management Plan (TLMP). Compliance will be monitored through the Support Solutions Envelope (SSE) assurance process.

DEFINITIONS

7. Figure 3 below, lists the main definitions (as given in the Controlled Values Repository) used within the CM and CBM discipline.

Figure 3: Main Definitions used in Condition Monitoring and Condition Based Maintenance.

Term	Definition
Condition Based Maintenance (CBM)	Maintenance initiated as a result of knowledge of the condition of an item of EQUIPMENT gained from routine or continuous monitoring.
Condition Monitoring (CM)	The collection and analysis of data from equipment to ensure that it retains the integrity of the design and can continue to be operated safely.
Maintainability	The ability of an equipment under conditions of use to be retained in or restored to a state in which it can perform a required function when maintenance is performed under given conditions and using stated procedures and resources.
Prognostic Health Management (PHM)	The process of using one or more parameters to predict the condition of a component at a defined point in its future operation.
Reliability	The ability of an item to perform a required function under given conditions for a given time interval.
Reliability Centred Maintenance (RCM)	A highly developed methodology through which an optimised maintenance schedule can be formulated incorporating the maintenance practices of Preventative (time based), Corrective (reactive) and Predictive (condition monitoring, prognostic) maintenance as appropriate to the subject system.

LINK BETWEEN RELIABILITY CENTRED MAINTENANCE AND CONDITION BASED MAINTENANCE

8. It is important to recognise there is a link between Reliability Centred Maintenance (RCM) and Condition Based Maintenance (CBM). This section discusses RCM and CBM and explains the link between the two disciplines.

9. RCM is a highly developed methodology through which an optimised maintenance schedule can be formulated and involves the following principles:

a. Focussing on preserving the function of the equipment.

b. Identification of the specific failure modes which may cause loss of equipment function, by performing Failure Modes Effects and Criticality Analysis exercises.

c. Prioritisation of the importance of each of the identified failure modes.

d. Determining an optimum maintenance schedule, that can incorporate Preventative (time based), Corrective (reactive) and Predictive (condition monitoring, prognostic) maintenance, as appropriate for the equipment.

10. RCM is described in DEFSTANs 00-40 and 00-49, and described in 00-45 and is therefore not covered further in this chapter.

11. In the case of the failure modes identified during the RCM process there will be many where CM will be applicable. In these cases the following key activities apply:

a. Determining an evaluation technique for each failure mode (eg a model).

b. Assessing what data is required, what parameters must be measured and at what frequency should data be obtained.

c. Use of Prognostic Health Management (PHM) techniques to predict the condition of the equipment at a defined point in its future operation.

12. CM in its various forms (from human inspection through to continuous monitoring) is used to underpin the selection and application of CBM thus providing a flexible maintenance strategy that maximises component life and equipment availability.

13. Under CBM programmes equipment maintenance is only carried out to avoid failure when an item degrades below a set level of monitored performance. As such CBM requires its own policy and control which is described in this chapter.

CONDITION MONITORING

14. CM is an element of Integrated Logistic Support (ILS), detail of ILS is contained within DEFSTAN 00-600 and JSP 886 Volume 7 Part 2. CM is used to measure and assess the condition of a piece of equipment during life, which enables the prediction of maintenance points which could prevent equipment failure or down time.

15. CM of equipment is well established in some areas of Defence and commercial sectors. The US Department of Defense has recognised the benefits of CM and CBM and has, since 2003, mandated the implementation of CBM.

16. CM can be considered to have three aspects:

a. **Equipment Husbandry or Equipment Care.** This covers the condition monitoring of the Equipment by the user and the maintainer. It has two elements:

(1) **Project Specific Guidance.** Covers the scheduled tasks such as routine inspections and checks also what actions to be taken upon finding unscheduled

events such as: the Equipment does not work or where there are obvious symptoms - noise or smells:

(a) The periodicity and content of the scheduled checks should be contained in the technical documentation of the Equipment and it is the Project Teams (PTs) responsibility to ensure that the technical documentation and training reflect the requirement for users and maintainers to carry out scheduled checks and to notify unscheduled occurrences for specific Equipment.

(b) This aspect of CM is not considered further in this document.

(2) **Pan-Environment Guidance.** There is also a need for a pan-environment generic Equipment Care policy to be stated. Guidance and policy documents for the specific commands / environments are:

(a) **Sea.** BR1313: Maintenance Management in Surface Ships.

(b) **Land.** AESP 0200-A-100-013: Equipment Care Inspection and Mandatory Equipment Inspection, (with Equipment specific advice given in the User Handbook - AESP Category 201).

(c) **Air.** Continuing Airworthiness Engineering (CAE) – 4000 Series Regulatory Articles – Manual of Maintenance and Airworthiness Processes, (with certain specific advice given in AP 100B-01).

b. **External Analysis.** This is a discrete event driven technique which uses sampling to predict maintenance events in near real time.

(1) Using techniques such as Spectrographic Oil Analysis Programme (SOAP), or specialised techniques such as Non Destructive Testing (NDT) to collect information on a piece of Equipment.

(2) This data is then analysed, on or off site, to give an indication on the condition of a component of the Equipment. The results of this analysis are then used to determine if any maintenance action is required.

(3) This method typically avoids components being used to failure which saves on repair costs and enables the maintenance to be carried out at a convenient time. It also prevents the failure of safety critical components during equipment use. Normally this technique is limited to a small number of maintenance and safety critical components.

c. **Internal Analysis.** This is a continuous monitoring technique which uses onboard systems and sensors to predict maintenance events in real time although much of the in depth analysis will be in near real time.

(1) Internal analysis systems include systems such as Built-In Test Equipment (BITE), Self Test Applications, Data Loggers and Health and Usage Monitoring Systems (HUMS).

(2) These systems outputs can be provided to the user or maintainer; either directly or through an analytical interface. The data collected by these

techniques is often of dual use, providing maintenance and operating information on the equipment.

(3) Examples of the techniques used include wear debris monitoring regimes, vibration analysis for rotating machinery and fatigue monitoring of airframe structures. The data may be measured using on line sensors, derived from off line monitoring processes, empirical observations or some combination of these. Parameters used include vibration and temperature. Advice can be generated in the form of an alarm or alert.

(4) In some cases hand held monitoring kit is used, whilst in other applications the monitoring process is highly automated as in BITE or HUMS which have been embedded in the equipment.

(5) A further issue for Defence is to ensure that information on equipment health is available to all stakeholders in order to support decision making in the support of the platform and its availability, (for example in repair administration, ordering of spares and electronic documentation in an ILS environment).

17. There are a large number of engineering techniques and disciplines that are available for use in CM. The choice as to what techniques and disciplines used is dependant on the equipment type and the degree of data required for maintenance purposes.

PROGNOSTIC HEALTH MANAGEMENT

18. Prognostic Health Management (PHM) is the process of using one or more of the measured equipment parameters taken as part of the CM system such as; vibration, wear debris analysis etc, in order to predict the equipments condition at a defined point in its future operation.

19. In addition, validation of the technique for the failure mode concerned is required by post removal strip examination.

20. Thus having a good PHM system is essential to achieve a successful CBM regime.

CONDITION BASED MAINTENANCE

21. For military systems such as ships, tanks and planes, CBM is a superior maintenance strategy to the two main alternatives:

a. Run to failure.

b. Scheduled maintenance.

22. A run to failure approach can lead to equipment breakdown in unpredictable situations. Scheduled maintenance is usually conservative and can lead to equipment overhaul regardless of condition and result in higher maintenance costs.

23. The scoping study in the Procedural Framework can be used to determine if CBM is the best approach for a particular equipment type.

24. CM, and the use of PHM techniques, are essential prerequisites to implementing a CBM approach.

25. This approach uses both condition and health information about the equipment to predict lead-time and required maintenance prior to failure, resulting in 'just in time' maintenance. To fully support CBM a spares supply system that facilitates this approach also needs to be in place.

26. The main benefits of CBM are reduced cost of maintenance, improved availability of assets and more effective performance of front line equipment. Further benefits are improved safety and identification of design improvements to be passed back to the equipment Design Authority.

BENEFITS OF CONDITION MONITORING AND CONDITION BASED MAINTENANCE

27. The major benefit of CBM is that maintenance significant items can be changed in a benign environment at a point prior to any catastrophic failure which could occur at an operationally inconvenient time thus creating more expensive damage.

28. This approach optimises equipment availability as CM and CBM assist the maintainer to maximise the equipments availability both in the in-barracks and operational settings, by having improved planning of maintenance work.

29. CM and CBM must be assessed on the benefits and costs involved. Figure 4 illustrates some of the benefits and costs associated with implementing the techniques.

Figure 4: Benefits and Costs of Condition Monitoring and Condition Based Maintenance

Benefits	Costs
Improved equipment availability in mission window.	Design of Condition Monitoring system.
Equipment health information available to support strategic and tactical decisions.	Procurement of Condition Monitoring systems.
Reduced logistic footprint.	Installation and trialling.
Improved operational safety.	Operational including data analysis and storage.
Reduced maintenance costs.	Personnel training.
Identification of design improvements.	Related organisation changes, eg 1st and 2nd line.
Reduced need to change components on 'safe life' expiry.	
Reduced need for preventive maintenance, particularly invasive inspections.	
Improved spares availability due to improved warning times and more accurate fault diagnosis (note that this is only one aspect of spares availability).	
Equipment showing signs of failure can be screened from deployment or remedied before deployment.	
Secondary damage and its effects can be reduced.	
Less maintenance induced difficulties.	
Improved safety..	
Improved effectiveness of all units including front line equipment.	

30. Analysis of the industrial use of CM has shown that the maintenance strategies of 'Run to Failure' and 'Scheduled Maintenance' are increasingly unacceptable in manufacturing operations.

31. The alternative of using CM with predictive capabilities provides early detection of machinery problems based on collection of machine data. This leads to lower machine maintenance costs and higher machine availability.

32. The results are generic and not restricted to any industry. Typical industrial benefits are:

a. 50%-80% reduction in repair and maintenance costs.

b. Spares inventories reduced by more than 30%.

c. 30% increase in revenue with overall profitability increased by 20%-60%.

33. In the Defence arena, the availability of assets is improved by the ability to plan maintenance work outside the mission windows. The battlefield maintenance commander is assisted by having information about the health of his battle-winning assets.

34. In addition a reduced need for maintenance activities in theatre will facilitate leaning of deployed logistic resources such as technicians, tooling, test equipment, facilities and storage space.

35. The costs associated with CM and CBM have to be recognised.

36. The planning work associated with identifying failure modes and associated assessment techniques (if these exist) and the procurement of equipment, including sensors, data storage and analysis software carry a cost.

37. A further cost is the trialling and testing of the system, including training of staff and reorganising existing support activities.

38. CM and CBM are to be borne in mind when a Contractor Logistic Support (CLS) or Availability solution is being considered. The onus will be on the contractor to develop the condition monitoring policy and plan; the PT may only have limited input to this process. The PT is to ensure that the raw data gathered by the contractor is made available to the MOD and that the data gathering regime is not onerous to the MOD and particularly not to the Front Line Commands (FLCs).

PROCEDURAL FRAMEWORK

39. The responsibility for managing the implementation of the technique rests with the individual platform PTs, with MOD regulatory organisations helping the PT to ensure that best practice is followed. The following procedural framework has been developed from best practice documents including international standards, for example ISO 16587.

40. There are three distinct stages to the Procedure, these are:

a. **Stage 1 - Scoping Study.** This determines the failure modes to be monitored. RCM techniques can be used in this process. In addition this stage identifies the CM kit requirements. A cost benefit analysis is performed to check that a positive benefit is realisable

b. **Stage 2 - Detailed Design and Implementation.** Central to this is performing trials of the CM and CBM system on at least one candidate platform, analysing and assessing data and undertaking some staff training

c. **Stage 3 - In-Service Use.** This is the introduction and use of the CM and CBM System across the whole fleet. Involving the regular collection and analysing of data such as looking for trends and where limits have been exceeded. If developing failure modes are detected the use of Subject Matter Experts to assess the severity and likely remaining safe life is recommended.

41. After Stages 1 and 2 in the Procedure the PT must present a detailed description of its approach to a technical Review Panel.

42. Additionally at periodic intervals (every 3 years unless agreed otherwise), during Stage 3, the PT must present an ongoing review of the operation of its CM and CBM system to the review panel.

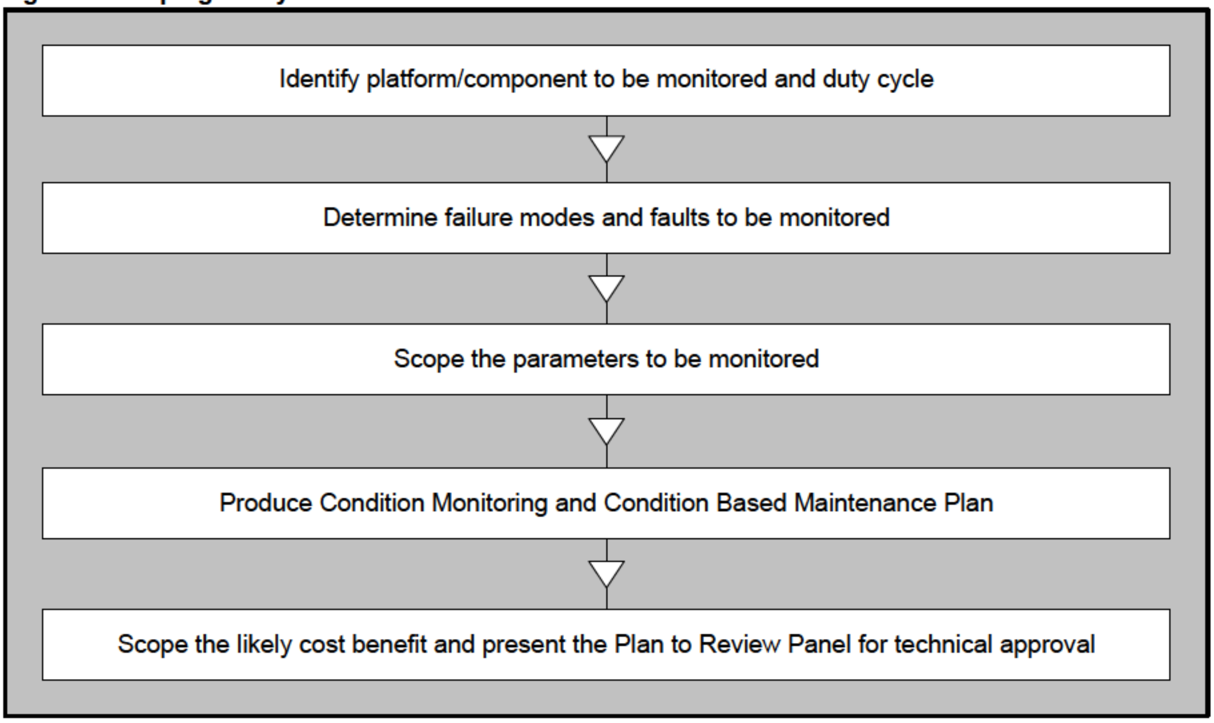
43. The review panel will form part of the SSE assurance process and should nominally include the PT, MOD subject matter experts and representatives of the agency responsible for performing the CM, for example, the Design Authority (DA) within an Integrated Operational Support (IOS) arrangement. The PT's methodology and approach will then be critically appraised to assess the technical validity of the approach including any safety implications.

44. A continuous record of the PT's submissions to the review panel, the CM and CBM regime proposed and adopted, and the periodic three yearly reviews are to be maintained in the Through Life Management Plan (TLMP). The Processes required for each stage are described below.

STAGE 1 – SCOPING STUDY

45. The Scoping Study processes are shown in Figure 5 below, and a detailed description of the work required is given after the Figure. Each headed paragraph relates to the processes shown in the figure.

Figure 5: Scoping Study Process



Identify Platform / Component to be Monitored and Duty Cycle

46. Equipment types which are most suitable to CM and CBM are those where breakdown or failure will adversely affect operational capability in the mission window, presents a serious safety hazard or gives rise to high costs.

47. A comprehensive study of the operating environment, the duty cycle of the equipment and its reliability is also essential. This can be done using RCM techniques.

48. A simple cost benefit and risk analysis should be used to eliminate the majority of items from being considered for CBM. For example items that are not significant cost drivers in terms of provisioning and / or repair costs or do not have a significant maintenance man hours content and whose breakdown does not present a serious safety hazard should not be considered for CBM.

Determine Failure Modes and Faults to be Monitored

49. The capability of any System to diagnose impending failure requires the advance knowledge of possible failure modes and how they manifest themselves. Failure modes can be identified using a variety of methods.

50. The simplest approach is to list the failure modes with their effects on the equipment.

51. The most detailed approach is a Failure Modes Effects and Criticality Analysis (FMECA) which can be broken into 4 simple steps:

a. Identify failure modes and determine their causes.

b. Analyse the data which then determines the effect of these failure modes and classifies their severity.

c. Estimate the probability of failure occurrences.

d. Use the severity rating and probability of occurrence to calculate the criticality.

Scope the Parameters to be Monitored

52. The list of failure modes derived in the previous step must be reviewed to determine which components to monitor and the parameters to measure.

53. The choice of which parameters to monitor is assisted by any in service knowledge of the equipment being monitored and whether a model or assessment technique for the failure mode exists. Parameters considered should include but not be limited to:

a. Limits.

b. Frequency of monitoring.

c. Requirements for models.

d. Material data.

54. Knowledge of how the equipment reacts to failure modes is essential in deciding the type of measurement regime to implement and the level and frequency of measurement and any limits or alerts to impose.

For example: An identified failure mode such as gear teeth cracking which potentially can propagate quickly resulting in catastrophic consequences, such as the loss of a helicopter, should be monitored continuously using a suitable system such as HUMS.

Produce Condition Monitoring and Condition Based Maintenance Plan

55. Identifying a suitable CM and CBM system, (for example, hardware, software, assessment techniques) depends on a number of factors such as; the equipment being monitored and whether continuous monitoring or selective monitoring is required.

56. Consideration should also be given as to the requirements for sensors (such as vibration transducers or chip detectors), data recording (whether continuous or periodically), data analysis (either online or offline), assessment techniques, data management and data storage.

For Example: On line analysis is carried out by a HUMS system which can process raw time history vibration data and calculate parameters such as the sixth moment of the signal average. Whereas data collected and passed to a data analyst to process and extract parameters of interest is classed as off line analysis.

57. Assessment is the activity which determines the significance of the analysed data. In the case of failure modes the assessment can aid in the diagnosis and rectification of potential failures. A wide variety of prognostic health management techniques are relevant and examples of these are:

a. Numerical algorithms which can be on or offline.

b. Expert systems or neural networks trained on historical data.

c. Laboratory analysis, such as wear debris analysis.

d. Subject matter experts, for example, performing fatigue assessments.

58. The result of this assessment activity is to provide information showing the health and likely future availability of the equipment being monitored.

59. A crucial aspect of this monitoring is the data storage and management. It is essential to have an archive of data available in order to assist in trend analysis.

60. A further consideration is the preservation of data for the subsequent use in any accident investigations. In addition it is important to ensure that information on the health of a system is readily available to battlefield commanders before and during the mission window.

Scope the likely Cost Benefit and present the Plan to Review Panel for Technical Approval

61. A study must be undertaken to see whether a positive cost benefit will be achieved by implementing the CM and CBM strategy. The following items should be considered in a cost benefit analysis:

a. Installation costs of CM equipment. Including the cost of items such as transducers and HUMS, additionally deployed kit such as ground stations and computers as well as any costs associated with the adaptation of equipment.

b. Operational costs including data analysis and interpretation.

c. Maintenance costs of software and hardware. Cost of the unavailability of a system due to breakdown.

d. Fault rectification and repair costs e.g. of run to failure and fault detection scenarios taking into account the probability of detecting the fault using CM.

e. Factors to account for the tactical advantage of the availability of the equipment in the mission window.

f. Personnel safety factors, for example, of performing emergency repair in theatre.

62. A clear cost benefit must be determined by the PT as follows:

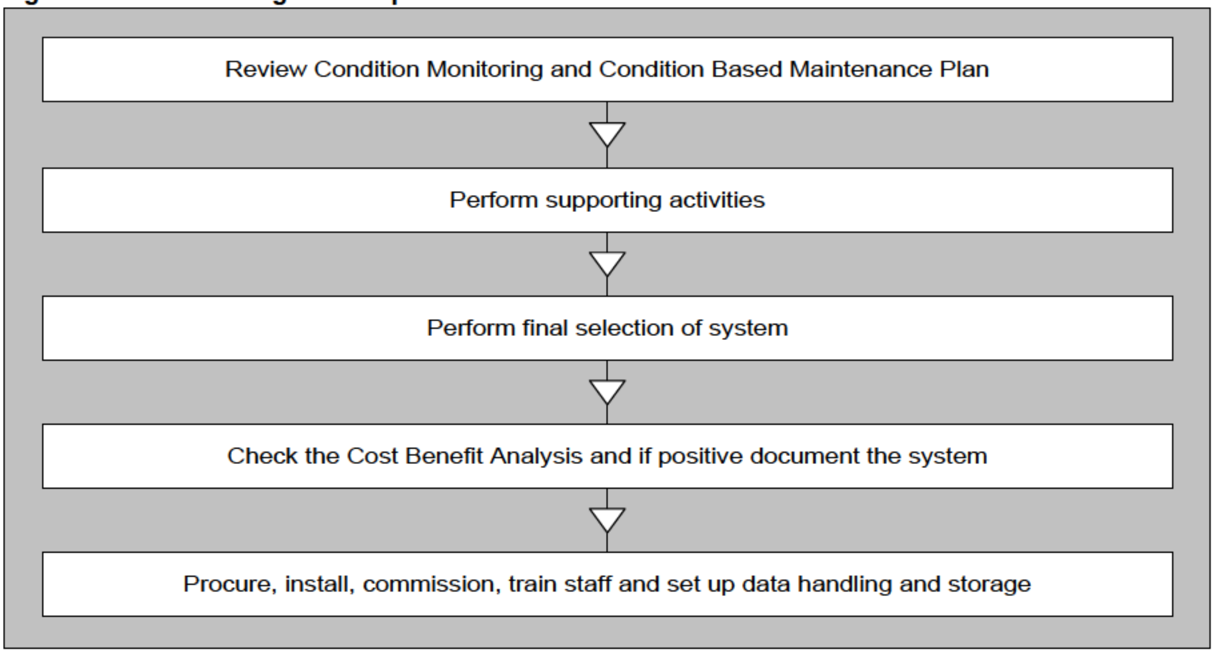
$$\text{COST BENEFIT} = \left[\text{AVOIDABLE COSTS}\right] - \left[\text{CONDITION MONITORING AND CONDITION BASED MAINTENANCE COSTS}\right]$$

63. After performing the full scoping study the PT must document the results and present these to the review panel as part of the SSE assurance process. The panel will assess the technical validity of the proposed CM and CBM system.

STAGE 2 - DETAILED DESIGN AND IMPLEMENTATION

64. The Detailed Design and Implementation stage is shown at Figure 6 below, and a detailed description of the work required is given after the Figure. Each headed paragraph relates to the processes shown in the figure.

Figure 6: Detailed Design and Implementation Process



Review Condition Monitoring and Condition Based Maintenance Plan

65. Having carried out the Scoping Study at Stage 1a CM and CBM Plan should have been produced.

66. The aim of the review is to assess the plan to ensure that the CM and CBM system chosen will help achieve a high level of reliability in the equipment being monitored.

67. In addition the failure modes to be monitored must be finalised, the parameters to be used and limits should be reviewed and refined.

> **For example:** Having decided that vibration will be used to monitor gear and bearing defects the next stage is to decide exactly which parameters will be used and to set limits. In addition the frequency of monitoring can be set.

Perform Supporting Studies

68. It is important to ensure that an assessment route exists for all the failure modes being monitored. The may require, for example, the development of algorithms and models, the collection and measurement of material data.

> **For Example:** The analysis of vibration data to check for bearing defects may require the development of signal processing algorithms performing activities such as signal enhancement and pattern matching.

Perform Final Selection of System

69. Following the review and acceptance of the Plan the relevant systems can be finalised and fully specified. This exercise must take into account all the requirements such as transducers, data recorders, analysis software, data storage etc.

70. Other considerations include the reliability and ruggedness of the kit and its suitability to remain serviceable during deployment to theatre and impacts on current in service procedures for similar systems.

71. Once finalised a full system must be trialled on at least one candidate platform. The purpose of this exercise is to perform a full end to end test including the data analysis, storage and assessment functions to demonstrate that the system can perform as required and any shortfalls highlighted are corrected.

Check the Cost Benefit Analysis and if Positive Document the System

72. A refined analysis should be carried out taking into account the costs and benefits of hardware, software, operation, maintenance and management.

73. This will determine whether or not the system developed is providing a benefit. If this is the case then the CM and CBM system must be documented.

74. This should include a description of the system and its objectives and the following:

a. The failure modes detectable and the rationale for the choice of the system.

b. The case for the fitness for purpose of the system which must include results from the trials work to demonstrate the accuracy and reliability of the system and how it will be used and maintained in service. This will also include details of staff training.

75. The final methodology must be presented to the review panel for technical review. The panel will assess the technical validity of the final system as part of the SSE assurance process.

Procure, Install, Commission, Train Staff and set up Data Handling and Storage

76. After checking that the system performs satisfactorily by the completion of trials on at least one platform and documenting the system a full procurement process can be undertaken to roll out the system over the whole fleet. Key issues to be addressed include:

a. Installation of system to platforms/equipment may require planned works and equipment availability could be compromised if the system is an upgrade or mid-life improvement.

b. Setting up of data storage and retrieval systems may have an impact on other systems such as IT infrastructure, bandwidth etc.

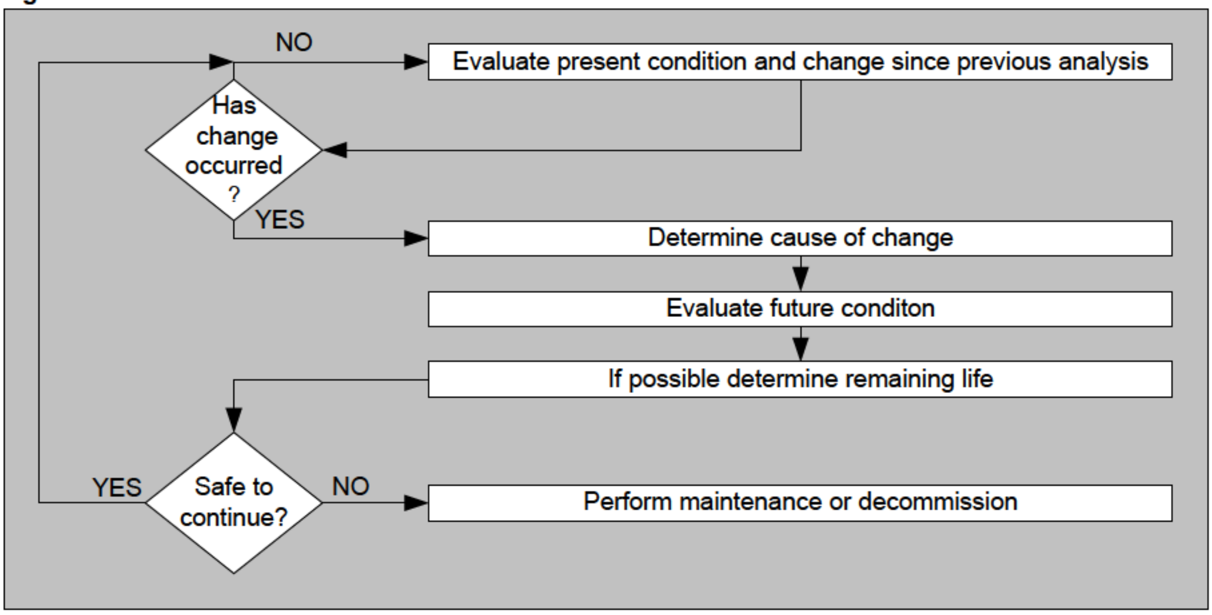
c. The training of staff, including the responsibilities of forward and depth support.

d. Existing scheduled maintenance plans may need to be reviewed in light of the move towards using CM and CBM.

STAGE 3 – IN-SERVICE USE

77. The In-Service Use stage is shown at Figure 7 below, and a detailed description of the work required is given after the Figure. Each headed paragraph relates to the processes shown in the figure.

Figure 7: In-service Use Process



Evaluate Present Condition and Change since Previous Analysis

78. This essential activity involves the measuring and evaluation of the condition of the equipment being monitored. This process can be automated, as in the case of HUMS equipped platforms, where alerts are raised when parameters fall outside of a “normal” range.

> **For example:** One of the parameters used to monitor helicopter transmission systems involves measuring vibration data and performing some signal processing. The parameters can be compared to ‘normal’ data for the system being monitored.

Has a Change Occurred?

79. As discussed above changes in equipment functionality are normally indicated by changes in one or a combination of the parameters used to monitor the equipment. The change may be detected on line, for example, by a HUMS system or off line by maintenance staff.

80. In some advanced CM systems activities such as cluster analysis are used to detect changes in the equipment being monitored. If a change is occurring then the involvement of subject matter expertise is essential.

Determine Cause of Change

81. If a change has been detected in the equipment being monitored the next step is to perform a diagnostic activity to identify the likely failure mode. At this stage the engineer may obtain further information, for example by acquiring extra data from the equipment.

82. The investigation may also be assisted at this stage by the use of databases, expert systems and advice from the Design Authority (DA) of the equipment. Consideration of data from a wide variety of sources is crucial. Examples are:

a. Unscheduled Maintenance history.

b. Strip report.

c. Usage history (For example, Flight Data Recorder).

d. Wear debris analysis.

e. Engine vibration data.

f. Transmission vibration data.

g. Statistical analysis of faults.

h. Component asset management information (e.g. from Logistics Information Technology System (LITS), GoldESP, Joint Asset Management and Engineering Solutions (JAMES)).

83. In addition engineering activities such as advanced signal processing may be used by the engineer investigating the failure mode. This activity must conclude with a clear identification of the failure mode.

Evaluate Future Condition

84. Having identified the failure mode the next requirement is to assess the consequences of allowing the failure mode to develop further. This may involve performing a trend analysis and / or a structural integrity assessment to evaluate the likely safety and suitability for service of the equipment being monitored.

85. Previous experience of the failure mode is invaluable in assisting the engineer at this stage. A check on the rest of the fleet is usually recommended if a failure mode is detected on one platform.

If possible Determine Remaining Life

86. If the failure mode is well understood and possibly quantified by the existence of a model then it may be possible to estimate the remaining safe life, with a suitable safety factor included in the calculation. The involvement of the DA of the equipment may be necessary at this stage.

87. Consideration should be given to recommending changes in the usage of the equipment where this would help to extend the safe life. For example a recommendation that the system is only used in benign flight or controlled temperature regimes may be made.

Safe to Continue?

88. Having noted the existence of a developing failure and performed monitoring and considered the impact on safety and suitability for service a decision has to be made on the next steps to be taken.

89. If the failure mode is considered to be benign or that a long time still remains until the point of failure the decision can be taken to continue with use in service. Monitoring should be continued. Otherwise the decision has to be taken that maintenance action should be performed.

Perform Maintenance / Decommission

90. If required, maintenance action must be performed. In extreme situations the equipment may be decommissioned.

SUMMARY

91. CBM is the forecasting of maintenance actions based on the analysis of the data captured by CM and is of particular relevance for maintenance significant items. These are items whose failure during a mission would be critical and where the repair cost, maintenance load or operational impact is high.

92. The responsibility for managing the implementation of CM and CBM rests with the individual equipment PTs. The Procedural Framework presented in this document should be used as a top level guide with detailed instructions available separately for each service. The result of the activity should be an improvement in the equipment availability.

93. Compliance will be monitored through the SSE assurance process.