CHAPTER 3

MAINTENANCE OF SYSTEMS

3-1. Introduction

Maintenance is defined as those activities and actions that directly retain the proper operation of an item or restore that operation when it is interrupted by failure or some other anomaly. (Within the context of RCM, proper operation of an item means that the item can perform its intended function). These activities and actions include fault detection, fault isolation, removal and replacement of failed items, repair of failed items, lubrication, servicing (includes replenishment of consumables such as fuel), and calibrations. Other activities and resources are needed to support maintenance. These include spares, procedures, labor, training, transportation, facilities, and test equipment. These activities and resources are usually referred to as logistics. Although some organizations may define maintenance to include logistics, it will be used in this document in the more limited sense and will not include logistics.

3-2. Categories of maintenance

Maintenance is usually categorized by either when the work is performed or where the work is performed.

a. *Categorizing by when maintenance is performed.* In this case, maintenance is divided into two major categories: preventive and corrective. Figure 3-1 illustrates how these two categories are further broken down into specific tasks. These categories of maintenance, corrective and preventive, are further subdivided in some references into reactive, preventive, predictive, and proactive maintenance.

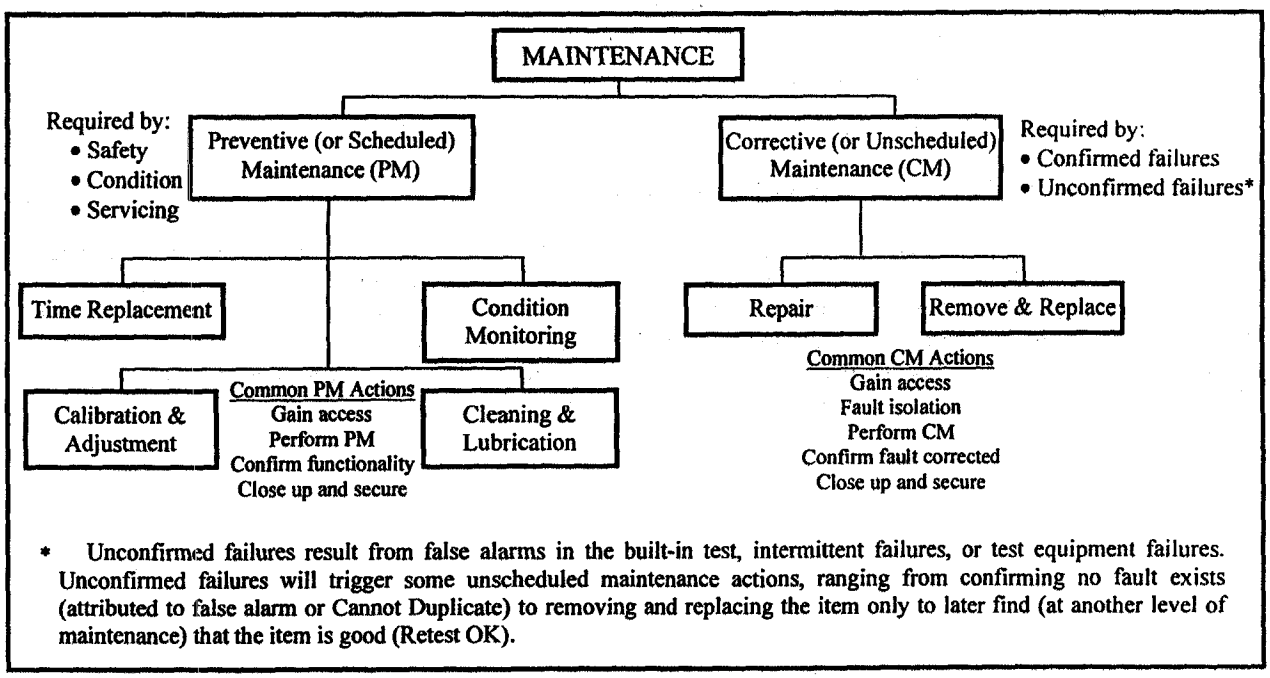

Figure 3-1. Major categories of maintenance by when performed.

(1) *Reactive maintenance.* This term is equivalent to corrective maintenance and both are also referred to as breakdown, repair, fix-when-fail, or run-to-failure maintenance.

(2) *Proactive maintenance.* Includes actions intended to extend useful life, such as root-cause failure analysis, continual improvement, and age exploration. Proactive and predictive are treated herein as categories of preventive maintenance, with proactive included under Scheduled, predictive under Condition-based (see paragraph 3-1), and age exploration as a separate step in the RCM process.

b. *Categorizing by where maintenance is performed.* Maintenance can also be categorized by where the work is performed. These categories are referred to as levels of maintenance. The categories most often used are shown in figure 3-2.

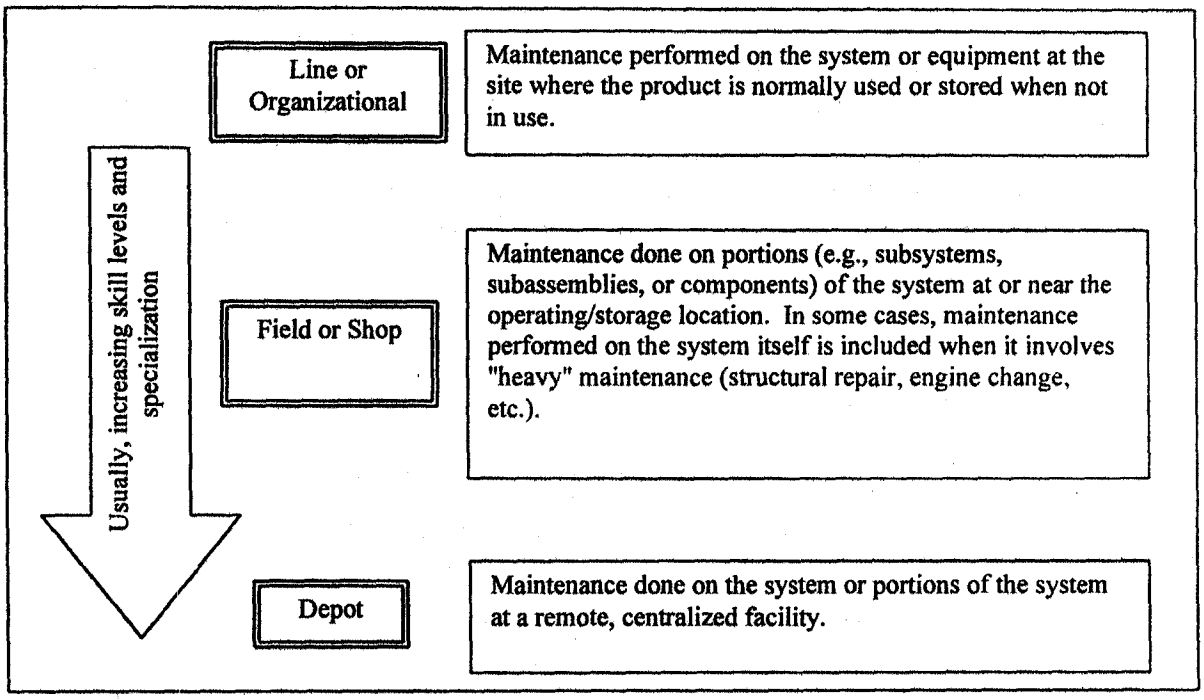

Figure 3-2. Typical approach to categorizing maintenance by where it is performed.

3-3. Categorization by when maintenance if performed

a. *Preventive maintenance.* Preventive maintenance (PM) is usually self-imposed downtime (although it can be done while corrective maintenance is being performed and it may even be possible to perform some PM while the product is operating). PM consists of actions intended to prolong the operational life of the equipment and keep the product safe to operate. This manual defines two types of PM: Scheduled and Condition-based. In both cases, the objectives of PM are to ensure safety, reduce the likelihood of operational failures, and obtain as much useful life as possible from an item. Table 3-1 has examples of each type of PM.

Table 3-1. Examples of tasks under two categories of preventive maintenance

Category	Tasks	Examples	Notes
Scheduled [1]	Remove and replace (R&R)	R&R batteries in smoke alarm twice annually	Maintenance is performed without regard to actual condition of item. Interval based on useful life and other factors. Includes all lubrication and servicing.
		R&R gun barrel after 5,000 rounds have been fired	
		Change oil every 3,000 miles	
		Lubricate bearings every 25,000 shaft revolutions	
	Overhaul or recondition	Overhaul transmission every 100,000 miles	Item is overhauled or reconditioned without regard to actual condition. Interval based on useful life and other factors.
		Refinish blades every 2,000 operating hours	
	Recalibrate	Recalibrate depth setting on drill press daily.	Compensate for changes in calibration due to vibration and other conditions of use.
		Recalibrate gage against standard at beginning of each shift	
Condition[2]	Inspect item or area	Visually inspect belts and pulleys for excessive wear prior to starting machine	Inspections can be performed using human senses (e.g., visually check belts for wear), using non-destructive inspection (NDI) techniques (e.g., inspect for corrosion using dye penetrant), or special measuring equipment (check tread depth using gage). Can also include functional check to determine proper operation.
		Inspect for corrosion every 2 weeks	
		Inspect for delamination or disbond weekly	
		Inspect tires for cuts and proper tread depth before and after each flight	
		Inspect for hidden failure of redundant item	
	Monitor condition	Continuously monitor vibration profile and R&R bearing when limits reached	Objective is to take action before useful life has been reached or a functional failure has occurred. Parameter limits and profiles based on analysis, test, and field experience. Monitoring can but does not need to be continuous.
		Check sample of oil every 50 operating hours for presence of wear metals and overhaul engine when limits reached	

1. Based on time.
2. Based on observed or measured condition.

(1) *Scheduled maintenance.* When a specified interval between maintenance is required, the maintenance is referred to as scheduled preventive maintenance. The interval may be in terms of hours, cycles, rounds fired, or other measure meaningful to the manner in which the item is operated. Note that with scheduled PM, no attempt is made to ascertain the condition of the item. Scheduled maintenance may also consist of recalibrations or adjustments made at regular intervals. Some texts categorize inspections as scheduled PM. Certainly, inspections are based on some periodic interval or event (e.g., inspection of an aircraft prior to and after each flight). However, since the purpose of an inspection is to ascertain the condition of the item, we have chosen to include it under the next category of PM, Condition-based.

(2) *Condition-based maintenance.* Preventive maintenance performed to ascertain the condition of an item, detect or forecast an impending failure, or performed as a result of such actions is referred to as Condition-based PM.

(a) A hidden failure of an item is one that has already occurred, has not affected performance of the end system, but will if another item fails. Ideally, through some form of warnings or monitoring device, no failure will be "hidden." In reality, it is impractical and not always feasible to detect every failure of every item in a system and alert the operator or maintainer that the failure has occurred. Inspections are therefore needed to detect such failures. See chapter 4 for a more complete discussion of hidden failures. Maintenance that is required to correct a hidden failure condition is, of course, corrective maintenance.

(b) Some texts use terms such as predictive maintenance and on-condition. The definition of condition-based PM used herein includes these concepts. In summary, the objectives of condition-based PM are to first evaluate the condition of an item, then, based on the condition, either determine if a hidden failure has occurred or a failure is imminent, and then take appropriate action.

b. Corrective maintenance and run-to-failure. As already alluded to, corrective maintenance (CM) is required to restore a failed item to proper operation.

(1) *Restoration.* Restoration is accomplished by removing the failed item and replacing it with a new item, or by fixing the item by removing and replacing internal components or by some other repair action.

(2) *When CM is required.* CM can result from system failures or from condition-based PM.

(a) When system operation is impaired by the failure of one or more items, the operator is usually and immediately alerted to the problem. This alert may come from obvious visual or sensory signals (i.e., the operator can see, hear, or feel that a problem has occurred) or from monitoring equipment (indicators, built-in diagnostics, annunciator lights, etc.). When the alert comes from the latter, it is possible that a system failure has in fact not occurred. That is, the detecting equipment itself has failed or a transient condition has occurred resulting in an indication of system failure that is false or cannot be duplicated. Whether or not an actual system failure has occurred, any indication that one has will necessitate CM. The CM may result in a Cannot Duplicate (CND) or Retest OK (RTOK), in-place repair, or replacement. CNDs and RTOKs are serious problems in very complex systems for two reasons. First, they consume maintenance time and can cause unnecessary loss of system availability. Second, without in-depth test and analysis, one cannot be certain whether the detecting equipment failed, the system did fail, or transients caused the failure (and is not evident except under those transient conditions).

(b) When inspection or condition monitoring detects a hidden or failure, then some form of corrective maintenance is required.

(c) If the only concern were to obtain the greatest possible amount of life from an item, it would be allowed to run-to-failure. Under a run-to-failure approach, only CM would be required. No PM would be performed. However, the economic and safety consequences of some failures make a run-to-failure approach untenable. Consequently, most practical maintenance programs consist of a combination of PM and CM. Determining what combination is "right" for an item is one of the objectives of the RCM process.

3-4. Maintenance concepts

a. *Levels of maintenance.* In considering how maintenance can be categorized, the idea of levels of maintenance was introduced. The term "levels of maintenance" has traditionally been used by the military services, although its use is not unknown in commercial industry. Within the services, the norm was once three levels of maintenance (line or organizational, field or shop, and depot). Under a 3-level concept, items are either repaired while installed on the end product or are removed and replaced. Various terms are used to refer to an item that is removed and replaced and include Line Replaceable Unit (LRU) and Weapon Replaceable Assembly (WRA). For convenience, LRU will be used in this document to refer to items that are normally removed from and replaced on the end product.

(1) *The benefits of a 2-level maintenance concept.* In an effort to reduce costs and increase availability, the services have been working for several years to implement a 2-level maintenance concept. Under this concept, repairs made on the system are kept to a minimum and, whenever possible, consist of remove and replace (R&R) actions. The idea is that by making R&R the preferred maintenance on the product, the downtime of the system can be kept to a minimum. Failed items are then sent back to the second level of maintenance, usually a depot or original equipment manufacturer (OEM).

(2) *Making a 2-level concept work.* A 2-level maintenance concept will only be affordable and practical if three criteria are met. First, each LRU's reliability must be "sufficiently high" given the item's cost. If not, availability will suffer, due to an excessive number of high-cost spares failing, and the supply "pipeline" will be

expensive. Second, the integrated diagnostic capability (Built-in Test, Automatic Test Equipment, manual methods, etc.) must be very accurate and reliable. Otherwise, the supply pipeline to the second level of maintenance will be filled with good LRUs mistakenly being sent for repair – CNDs and RTOKs are a serious problem under any maintenance concept but spell disaster for a 2-level maintenance concept. Finally, a responsive and cost-effective means of transporting LRUs between the field and the depot must be available.

b. *Centralized versus de-centralized.* When maintenance at a given level is performed at several locations located relatively close to the end user, a decentralized maintenance concept is being implemented. For example, suppose a 3-level maintenance concept is being used. When an LRU fails at an operating location, it is removed and replaced with a good LRU. The operating location sends the failed LRU to a co-located field repair activity (FRA) where it is repaired. Such repair can consist of either in-place repair or R&R of constituent components often called Shop Replaceable Units (SRUs). Under a centralized concept, each operating location would not have a co-located FRA. Instead, one or more centralized FRAs would be strategically located throughout the geographic operating area (i.e., country, continent, hemisphere, etc.). Each operating location would ship its failed LRUs to the nearest centralized FRA. Such a concept is most effective when the LRUs are highly reliable. If the reliability is high, then few failures will occur at any given operating location making it difficult to keep the technicians proficient in repairing the LRUs. Also, with few failures, the technicians and any support equipment (e.g., automatic test equipment) will be under utilized. Under such conditions, it is difficult to justify a co-located FRA.

3-5. Packaging a maintenance program

The total maintenance requirements for a product will dictate a set of preventive maintenance (PM) tasks and a set of corrective maintenance (CM) tasks. The latter tasks are essentially "maintenance on demand" and by definition cannot be predicted. PM, as discussed previously, will consist of on-condition and scheduled maintenance. Once all PM tasks have been identified, they must be grouped, or packaged. By packaging PM tasks, we can use our maintenance resources more effectively and minimize the number of times that the system will be out of service for PM.

a. *Packaging example.* An example is shown in figure 3-3. We could have conducted the pump inspection at 28 hours, the panel inspection at 22 hours, and lubricated the gearbox at 25 hours. But it is much more efficient to "package" the tasks as shown in the example.

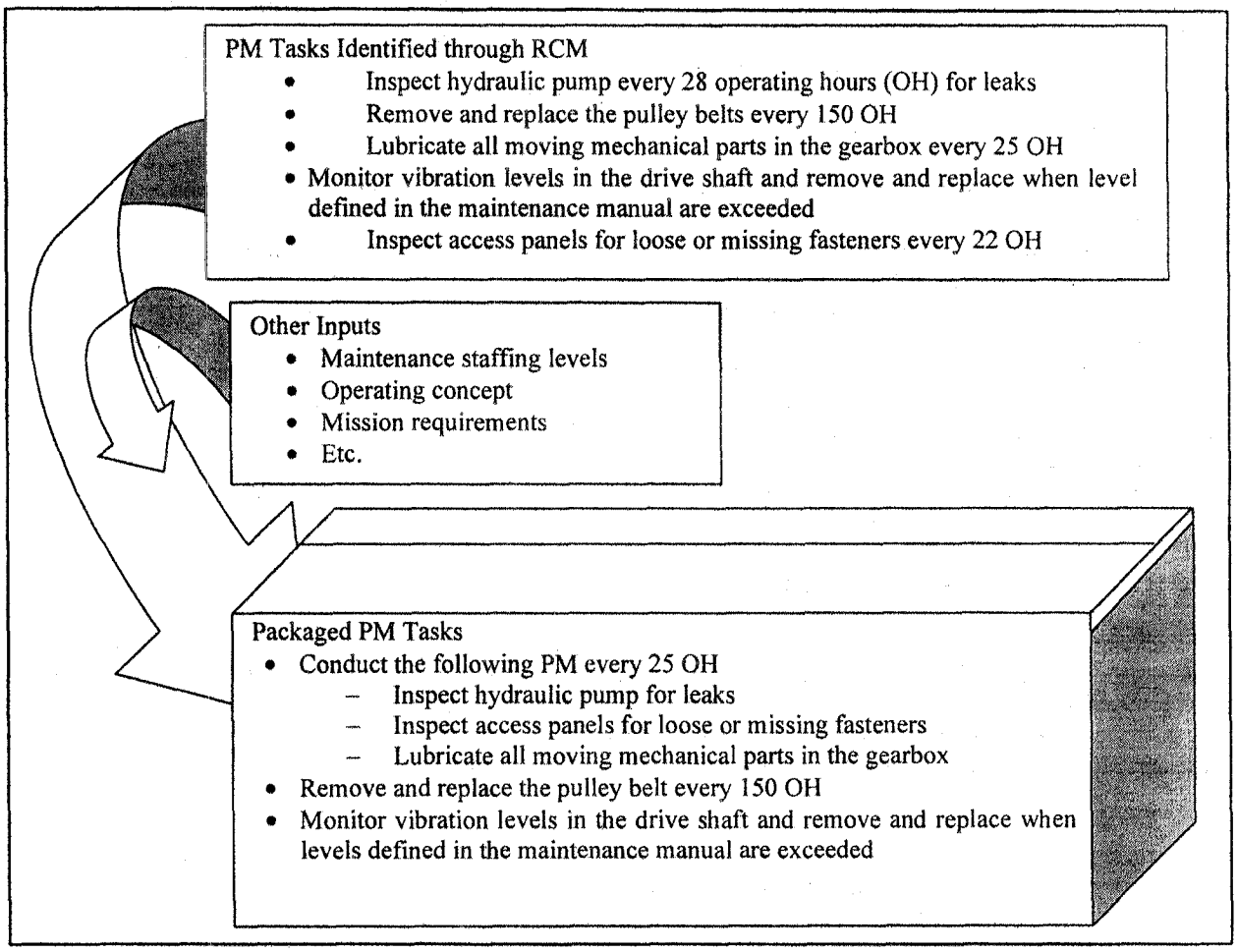

Figure 3-3. An example of packaging PM tasks.

b. *Document the packaging for maintenance personnel.* One method of documenting the packaging of PM tasks is to create inspection cards. For a given point in time (calendar time, number of operating hours, etc.), a set of cards defines the PM tasks to be performed. Figure 3-4 illustrates this approach.

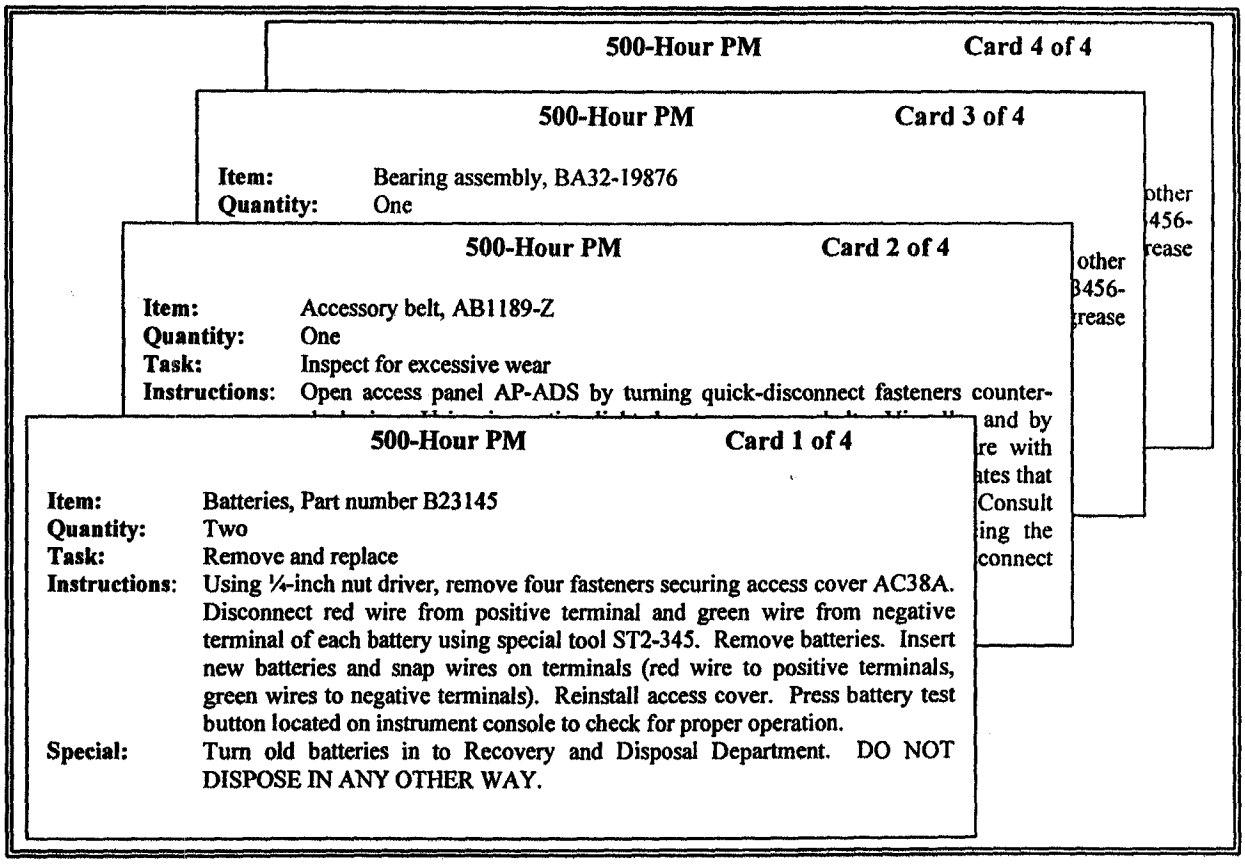

Figure 3-4. Example of how PM cards can be used to document required PM tasks.