

PRESERVING THE RELIABILITY OF SPARES AND EQUIPMENT IN STORAGE

Institution of
**MECHANICAL
ENGINEERS**



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FOREWORD

This document has been prepared by the Institution of Mechanical Engineer's Reliability Working Group, part of the Safety and Reliability Group; a special interest group established by the Institution to advance engineering practices. Offered herein is specific guidance to persons seeking advice on the management of spares and equipment in storage, whereby the lack of such a management system has the ability to generate business harm.

Further information on the Reliability Working Group, along with team members who have contributed to the creation of this document, can be found at:



www.imeche.org/get-involved/special-interest-groups/safety-and-reliability-group/how-we-are-governed/reliability-in-engineering-for-reliability

Other guidance documents are available on this webpage.

IMECHE POSITION STATEMENT ON SAFETY AND RELIABILITY

Government has encouraged the Engineering Institutions and academia to promote the achievement of Safety and Reliability. A statement has been prepared to present the Institution of Mechanical Engineers' current views on Safety and Reliability issues.

For the purposes of the statement, the following have been agreed:

Safety is the visible and demonstrable absence of unacceptable risk of undesirable events affecting the health and safety of the workforce and the public at large.

Reliability is the ability of an item to perform a required function under stated conditions, including environment and usage, for a stated time.

Generally, these and other aspects, such as maintainability and availability, referred to as 'Safety and Reliability', are considered to be core aspects of risk management in engineering.

In addition to this, practitioners of Safety and Reliability activities are expected to follow a code of conduct, such as that defined by the IMechE, namely:

“““

In order to facilitate the advancement of the science of mechanical engineering by preserving the respect in which the community holds persons who are engaged in the profession of mechanical engineering, every member shall, for as long as he continues to be a member, comply with By-laws 29 to 31 and the Code of Conduct Regulations. All members are ambassadors of the Institution and must therefore conduct themselves in a manner that upholds and enhances the reputations of the Institution, the profession of mechanical engineering and the Institution's members. All members shall conduct their professional work and relationships with integrity and objectivity and with due regard for the welfare of the people, the organisations and the environment with which they interact. All members shall take reasonable steps to maintain appropriate professional competences.”

1. INTRODUCTION

The intent of this document is to give guidance on how to develop robust controls for the management of spares and spare equipment. A methodology is proposed that can be used to identify the correct asset management principles for an item, from a spare component to a complete operational platform, which requires medium to long-term storage.

The Institution of Mechanical Engineers' Safety and Reliability Group have prepared this guidance in response to requests from various industry sectors, where it is apparent that a lack of a management system for spares has led to organisational stress. A number of specific issues have been raised at seminars, cases that could undoubtedly be added to by many more practicing engineering professionals. The group consists of professional engineers from a broad industry background, including rail, nuclear energy and regulation, Ministry of Defence, aerospace engineering, petrochemical and oil and gas.

The target audience for this document are:

- Engineering and maintenance practitioners
- Transportation, stores and warehouse personnel
- Business /operations /production managers

Spare components and equipment are a cornerstone of any organisation which, when correctly managed, can deliver real competitive advantage by improving operational uptime and controlling working capital. The technical management of such equipment can enhance operational robustness for any organisation.

Management controls are fairly simple, i.e. storage, monitoring shelf-life, packaging, transportation, handling and maintenance. A robust spares management system reduces the potential for hidden failures such as:

- Spare equipment in an unknowingly failed state
- Degradation of components during maintenance activities
- Degradation of components during normal storage
- Degradation of equipment/components due to incorrect maintenance whilst in storage
- Degradation of equipment/components due to incorrect storage conditions
- Spare parts that have not been repaired to standard but returned to stores
- Spare equipment that requires some level of preparatory or maintenance work prior to use
- Equipment damaged in transit, but damage not detected upon delivery
- Equipment ordered as spare, delivered in an unusable condition but not revealed upon delivery (incorrect item, substandard quality etc.)

2. SCOPE

This document is intended to cover the preservation controls required for any item that can be called a “spare” to ensure that such item is fit for purpose when required for use.

The process described would work well to define the controls for installed spares and standby equipment, however this is not the primary intent of the document.

This document is not intended to cover the more complex and in depth topics of:

- Which spares should be kept, i.e. this document assumes that a decision has already been made to keep the spares under consideration
- Spares optimisation
- Readily available spares, i.e. generally available at short notice, held on shelves by vendor etc.
- Retirement/refurbishment practices upon depletion of shelf/useful life, and remaining useful life of components

3. DEFINITIONS

The following definitions shall be considered true in the context of this document

OPERATIONS

Describes the fulfilment of the organisation’s main objective, whether that be manufacturing a product or providing a service

PRESERVATION

An effective method of maintaining components and equipment so that, when installed, they meet the required performance standard and/or design intent

PACKAGING

Materials (coverings, structures and otherwise) used to maintain the condition of equipment during transportation and storage

STORAGE

The keeping of components and equipment in a suitable environment, and the management of all associated requirements, such as documentation, that ensures they are fit for duty when required

SPARE

A component or piece of equipment, from individual component up to a complete assembly, not in operation but required for future use by an organisation

SHELF SPARE

Any new or refurbished spare that is kept in storage

INSTALLED SPARE

A complete spare that is installed within a process, which can be brought online in the event of equipment failure, with the purpose of minimising disruption to operations, with a physical intervention

STANDBY EQUIPMENT

Equipment installed within a process that can be brought online without a physical intervention

TRANSPORTATION/LOGISTICS

The movement of spares between source, storage and final point of use and anything in-between

CMMS

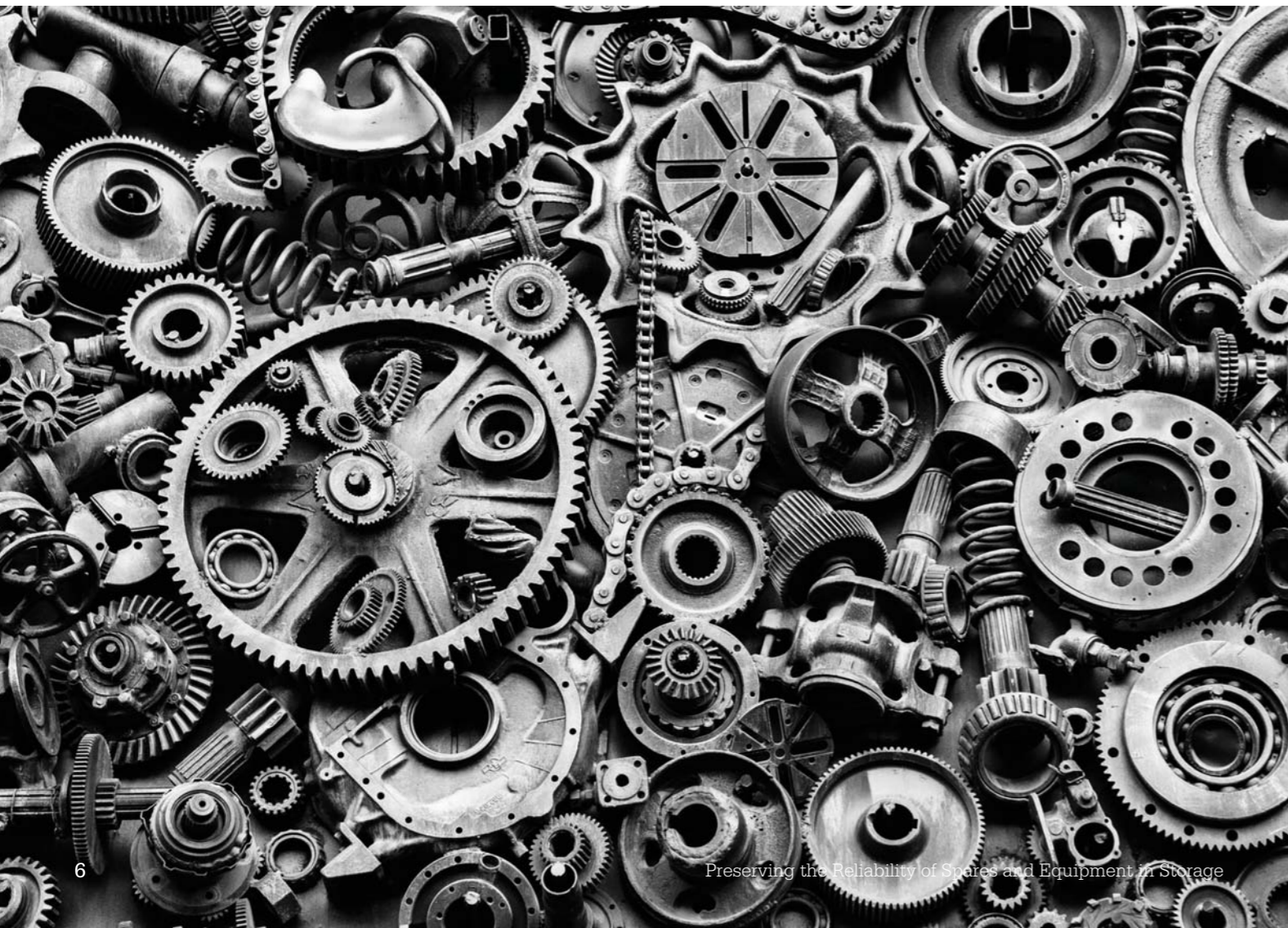
Computerised Maintenance Management System, a system for controlling maintenance within a company

FIT FOR USE

Spares or equipment are able to perform the function for which they are intended for their design life

DEMAND SEVERITY

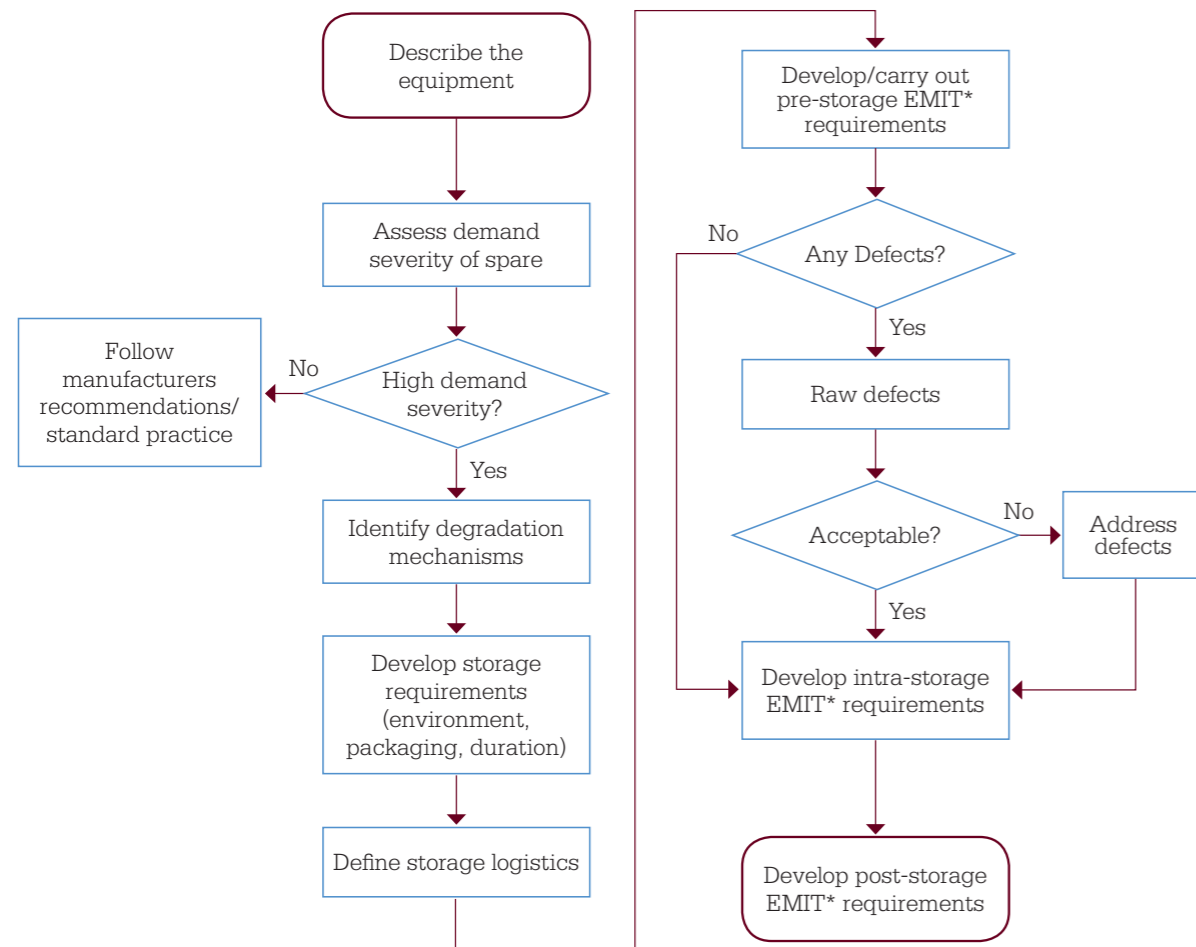
A rating used to describe the expected impact upon a business should spares or equipment not be available, or not be usable, within a time span



4. METHODOLOGY

Practitioners following this methodology are encouraged to use a worksheet. The following sections describe the context for potential steps in a worksheet, with the ultimate intention being the creation of a robust and appropriate storage strategy for each item.

The flow chart in figure 4 shows an overview of the process flow for defining storage requirements for equipment:



*EMIT - Examination, Maintenance, Inspection and Testing

Figure 4 Storage requirement determination process flow

4.1 Describe the equipment

Begin by describing the equipment to be stored. This will help determine the level of equipment that is being stored, which may range from a complete functioning assembly through to component piece parts. An example from the petroleum and oil and gas industries would be level 6 through to level 9 in the asset hierarchy as described in "ISO 14224 - Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment", see figure 4.1.

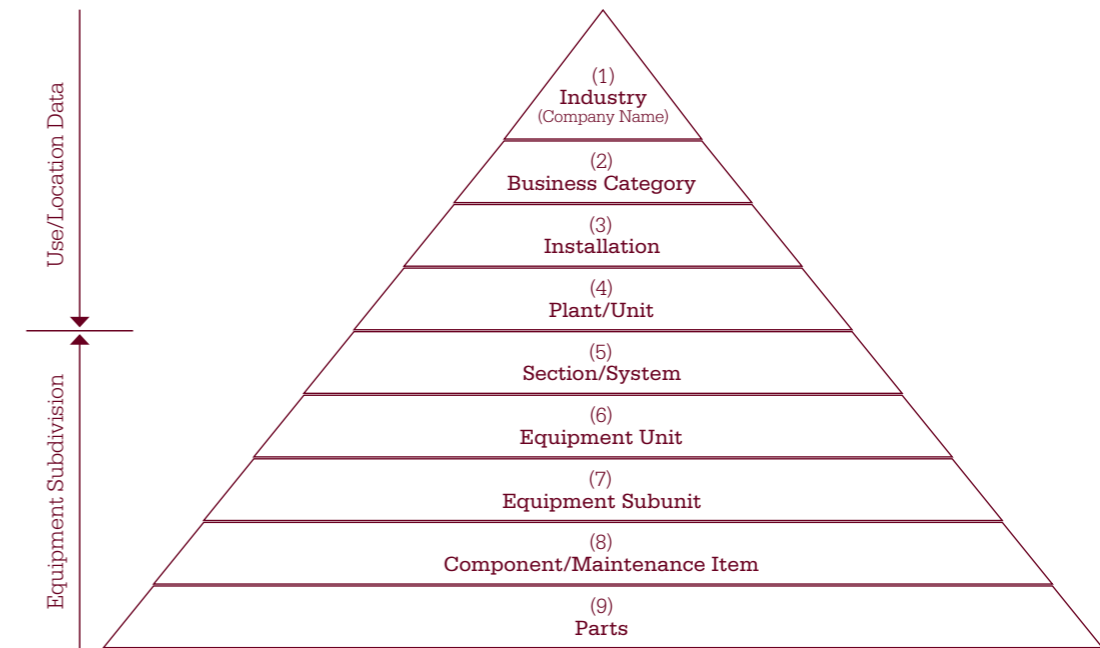


Figure 4.1 – ISO 14224 Plant Taxonomy Hierarchy

It is also important to know the reason for storage to allow appropriate considerations to be made. Consider two ends of the spectrum, an infrequently used vehicle and a bearing.

The reason for storing the vehicle may be "to be close to the required point of use".

The reason for storing a bearing may be "to be used in the event that maintenance, proactive or reactive, is required".

Some reasons for storage:

Maintenance capability

Risk minimisation (long lead item, sometimes termed insurance spares)

Loss minimisation – modular maintenance as opposed to strip and re-build

Over-abundance

Obsolescence management

Fleet management

Production turndown

Availability of equipment

4.2 Spare demand severity

Establish how critical the spare is to the organisation. An effective method for defining criticality is by using a Risk Assessment Matrix, see figure 4.2. The exact details for the Risk Assessment Matrix will be dependent upon the organisation, so this figure should only be taken to be an example.

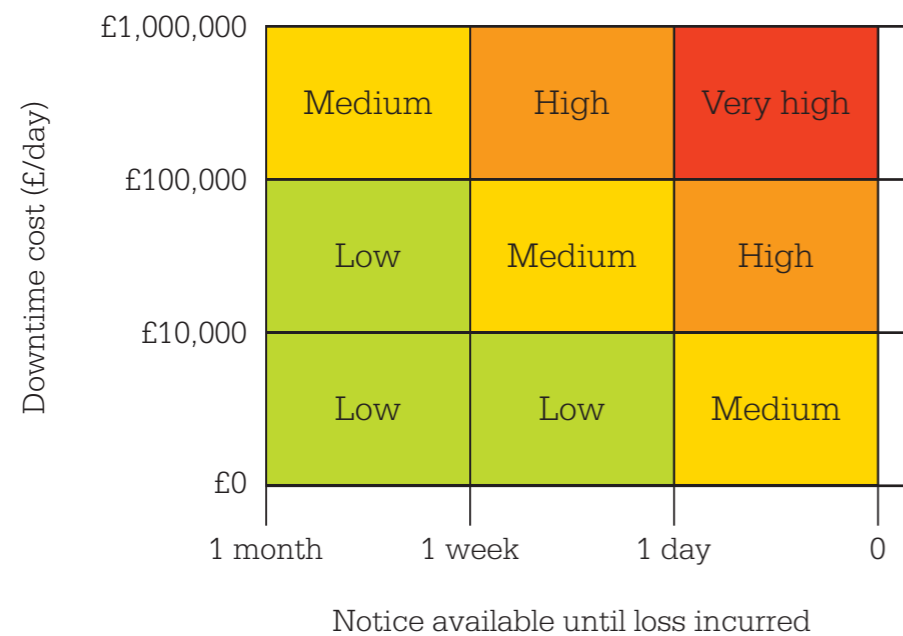


Figure 4.2 – Example Risk Assessment Matrix

To define criticality, first determine the consequences should the spare not be available when needed. This may be in the form of impact upon production, the inability to provide a service for a number of days or the reputational damage that comes with service unavailability. This correlates to the duration on the x-axis in figure 4.2.

Next, consider the usage horizon, i.e. how urgently will the spare be required. This is clearly very fast when items are stored to cover equipment breakdown, but may be slower when the need is to respond to predictable production upturns or deployment into the field.

The intersection of the two determined values is the “demand severity”. The higher the demand severity level, then the more attention will need to be given to the controls around the storage of the spare. Assessment using a Risk Assessment Matrix can use quantified or qualified values, i.e. the simplest could have low/med/high on the vertical axis and short/med/long on the horizontal. If a standard Risk Assessment Matrix exists within an organisation then it may be beneficial to use this, otherwise a specific one may need to be developed. It is common to place other dimensions, such as Safety, Environmental, Quality or Reputational factors, depending upon the organisational pressures, with the worst situation becoming the ruling case.

Any spare that has been assessed to have a high demand severity level should be subject to a rigorous review methodology to determine the controls. The following steps are proposed as a methodical system to help establish the controls required to ensure spares are fit for use when required, therefore completing the worksheet. Those with a lower demand severity level may be managed by standard practices and procedures; the further completion of the worksheet is at the discretion of the practitioner.

4.3 Identify degradation mechanisms

Is there any history available for the specific item with regards to usability when required? I.e. is there a history that vehicles do not start? Are bearings frequently found to be corroded when required for use? What storage strategies for the item, or similar items, have or have not been successful in the past? In what environmental condition was this? Such information may be available from the manufacturer, whether it is new equipment or there may be a mature fleet of similar items in the field.

Equipment history should be recorded in a suitable system, i.e. the CMMS, an equipment database or any other such records system the company might run.

The period for which items are expected to be kept before usage, (not including any current testing or maintenance activities) will allow an appropriate strategy to be developed. In the case of fast moving maintenance spares, this may only be a matter of weeks or months. For insurance spares, this could be many years. Consider consumption and lead times in this parameter.

It may be prudent to consider the maximum foreseeable storage period if the exact period is unknown. For example, usual storage period is around five years but an eight year storage is foreseeable. The considerations made might be different given this longer period.

Any restricted shelf life of the spare must be understood. This may be provided by the vendor or known from experience. It also needs to be understood if this is a hard stop, or if there is a rapid degradation after this period. It may also be worthwhile considering standard degradation between the start of storage and use – i.e. is “shelf life” storage life plus use. Consider how much useful life might be remaining if used after a long storage period.

If the shelf life is important, then the date of storage and subsequent life of the component should be logged and monitored as part of the intra-storage maintenance requirements. It must be considered that one of the spares management requirements may be the retirement and replacement of the spare. At this stage, the principles of first-in first-out should be applied in order to help minimise loss due to life expiry.

There are a whole host of deterioration mechanisms that may be applicable and the timeframes in which these will become apparent will vary. Examples include:

- Corrosion
- Oxidation
- Chemical deterioration of fluids such as lubricants, polymers and plastics
- Separation of liquids (i.e. lubricants, abrasives, adhesives)
- Perishing/Embrittlement of plastics
- U.V. deterioration
- Sag or warping (i.e. machine rotating assemblies or valve spindles)
- Vibration induced false brinelling of bearings
- Over-heating
- Freezing/cold damage
- Contamination by dust/dirt/moisture
- Induced or impressed low electrical currents
- Magnetization/Demagnetization

4.4 Develop storage requirements

Packaging needs to be suitably robust to ensure that spares are not damaged during transport to the point of use, or open to environmental degradation during storage. Any labelling needs to be securely attached to the spare. Bar coding/RFID tags may be used to positively identify equipment and provide links to reference documentation and the CMMS.

It is prudent to consult with manufacturers for recommendations (e.g. testing and exercising) and limitations (e.g. shelf life) for storage conditions and compare this with results, historical or calculated by assessment. Where a discrepancy arises this should be considered and, if deemed necessary the manufacturer included in the consultation. Consideration should also be given to warranty restrictions and provisions if this is a concern. Caution should be taken as the OEM may not have anticipated the users operating context, the ultimate decision for how spares need to be kept lies with the owner.

Care must be taken with assemblies as their components may have incompatible individual storage requirements thus requiring the partial disassembly of the spare and separate storage.

Limited life spares need to be identified and managed correctly to both maintain stock levels and avoid using them when useful / safe life has expired – think about sell by/use by dates in perishable retail. Consideration should be given to how packaging / labelling clearly indicates any 'use before' dates if applicable.

Protective coatings such as lacquers / varnishes may sometimes be applied to prevent surface rusting. Consideration should be made of the effects of the coating once the spare enters service and plans made to remove it if necessary.

It is common for spare equipment for fluid handling duties to have plastic covers fitted, or tape applied to open ends, especially flanges. Care needs to be taken to remove these prior to installation. A recommended good practice is for these temporary covers to be 'Hi-Vis' so it is obvious that they are fitted, and they are fitted after painting.

Care must be taken where orientation is important, any orientation requirements should be clearly marked on packaging. This is especially important for items that may hold fluids and lubricants. Other spares may be damaged if not correctly oriented while transported and stored, such as damage to white metal bearings on vertical centrifugal pumps.

It may be worthwhile investing in robust containers should spares kits / assemblies be subject to "rough" transportation at any point in their lifecycle, such as off-road terrain like a construction site. Such packaging can also help where orientation is critical. "Flight cases" and purpose made stillages/ crates are a good example of such an investment. This type of packaging is reusable, satisfying long-term economic and environmental goals.

The purchasing department needs to be an integral part of developing such controls, and consideration should be made of the international nature of modern day supply. The packaging and labelling standards will undoubtedly be different when

sourcing spares from different countries. Packaging and labelling expectations should be clearly defined in purchasing agreements and, as a minimum, on the purchase order.

Consider the layers of protection between the spare and the degradation mechanism to help identify the appropriate level of environmental control. Consider a bearing that is kept within a Volatile Component Inhibitor (VCI) bag, which is in turn kept within a sealed crate, in turn stored in a warehouse. This provides three layers of protection from corrosion. If the spare is needed in the field, the shipping in the crate still provides two environmental layers of control. Considering the full lifecycle of the spare will allow the optimum level of environmental control to be developed.

Some examples of environmental control are:

- Standard warehousing
- Humidity controlled warehousing
- Outside storage containers
- Field storage tents/temporary structures (standard or humidity controlled)
- Workshops
- Sealed storage crates
- Card boxes and wooden crates
- Hermetically sealed crates
- Crates/containers pressurised with an inert gas
- VCI bags
- Sealed bag/packaging with desiccant
- Vacuum packaging
- Grease/oil cloth
- Protective sprays
- Hot dipped coatings
- Shrink wrap

Good housekeeping (closing doors and windows, cleaning up spills, general tidiness etc.) will also play an important factor in the preservation of the items. The store should be "ran like a store", i.e. if you were personally purchasing something for home use, would you buy it if you found it in a building like your works stores? Pay attention to building maintenance, in particular integrity of the structure and weatherproofing, maintenance of heating, cooling, extraction and climate control systems, quality of lighting and underfoot conditions.

These controls undoubtedly add expense, so the storage system selected should be appropriate for the identified deterioration mechanism and assessed demand severity level. The stores may be split into critical and non-critical spares areas and building maintenance routines and housekeeping requirements developed according to area.

Further reading on in-storage failure mechanisms and their countermeasures can be found in the paper "Failures of, and Countermeasures for, Spares and Standby Equipment" by M.D. Norris. A copy can be downloaded from: https://www.academia.edu/32954923/Failures_of_and_Countermeasures_for_Spares_and_Standby_Equipment

4.5 Define the storage logistics

Consideration needs to be made of how items will be transported between supplier, within the stores system and finally to point of use. The transportation in itself may be a critical failure inducing activity. It may be useful to keep a log of the items transport history, if such activities are deemed detrimental to usability.

Temporary Stays/Steadies/Fastenings are sometimes used to prevent components moving or rubbing whilst equipment is in transit. These may be hidden, like transport bolts fitted to some washing machines. It needs to be very clear that these must be removed before use e.g. written instructions on a hi-vis label covering the on/off button.

Vibration damping may be required during transport. Care and attention should also be taken to handling activities, it may be easy to assume that the same facilities are available at the point of unloading but this may be a very remote and hostile location.

The transit time may be a factor that introduces degradation mechanisms, i.e. the longer the item is in transit the more it could be exposed to environmental factors, is subject to low level vibration etc. Conversely, it may be assumed that a short transit has low risk and so little control is exercised in the transportation activity which then leads to damage.

Post transit conditioning may need to be considered. For example fridge freezers, when transported horizontally, need time to settle when put back into the vertical position before being switched on to prevent damage.

4.6 Develop pre-storage maintenance and testing requirements

An appropriate plan must be devised for pre-storage checks including examination, maintenance, inspection and testing requirements after refurb and upon receipt of new items. These checks should include verification of all environmental protection, and identification of the shelf life.

Considerations for pre-storage checks may include:

- Any required sample inspections
- Identification that spare is correct according to spec details
- Damage to packaging
- Lubricant levels
- Desiccant condition indication
- Pressure of inert gas
- Integrity of hermetic seals if applicable
- Reinstatement of packaging integrity following any inspection

These activities may be carried out by more than the stores personnel, i.e. it may be necessary for an engineer to confirm that the spares are to specification, or for a specialist to reinstate packaging integrity.

Some of these checks may be required prior to packaging and supply to the stores location. I.e. it may be necessary to inspect components that are to be hermetically sealed at the vendor's location.

Any defects that are found then require a decision from an appropriate authority as to whether they require addressing immediately, or if they can be addressed either during storage or when the item is required for use. Such requirements shall be built into the appropriate section of the storage plan.

4.7. Develop intra-storage maintenance and testing requirements

Special requirements for looking after spares shall be specified and carried out. These requirements should target the specific degradation mechanisms, and must be balanced against the effects of not doing them. In some cases, the best option may be to do nothing. This is best controlled by work orders in the CMMS or other maintenance planning system. Examples include:

- Periodic rotation of rotors to avoid sag
- Periodic exercising of rotating assemblies to prevent false brinelling, seizure and separation of lubricant
- Environmental controls such as temperature and humidity are within specification
- Desiccant is in a good condition, i.e. use self-revealing desiccant
- Inert gas pressure has not dropped
- Shrink-wrapping, hermetic and vacuum sealed packaging is intact
- Correct orientation has been maintained
- Electronics may need firmware or operating system updates

The shorter the notice period for the use of the spare, the more critical attention to defining and controlling intra-storage maintenance and test requirement becomes. If a defect is detected during any of the checks and/or maintenance, these should be dealt with in the same way as any arising plant defect would be, i.e. through the normal maintenance workflow process.

4.8. Develop post-storage maintenance and testing requirements

If preparation for installation of the spare is needed, a reasonable notice period is required before the spare can be used which may in turn influence the demand severity. For example, a gearbox that requires draining of preserving oil may take many hours to prepare. All packaging and temporary protective coatings will need to be removed and appropriately recycled or disposed of.

Testing and validation may be required. Upgrades or modifications may be required if these were not done during storage. Only knowing the notice period will allow an economic decision to be made between doing this work intra- or post-storage.

The defects identified in step 4.7 should be considered, and an appropriate restoration strategy should be devised, bearing in mind how much other work may be required to bring the equipment into service and the speed at which equipment may be required.

5. GOVERNANCE OF THE SPARES MANAGEMENT SYSTEM

An example for a governance model for a spares management system is shown in figure 5.

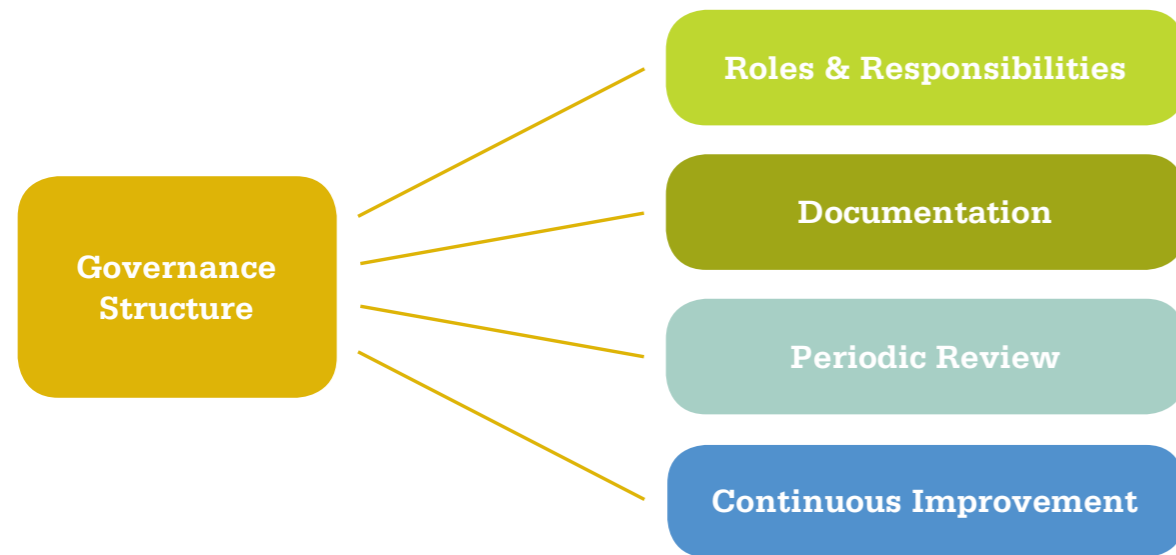


Figure 5.1 – Spares Management Governance Structure

5.1 Identify key responsibilities for equipment preservation

The individual responsibilities will depend very much on individual organisational design, however in principle all of the tasks identified by this process should have a nominated owner or owning group.

Some of this responsibility may be delegated to a supplier, whether it be with regard to providing the correct level of preservation or even storing the equipment themselves. They may be much better placed to do so.

A basic RACI (Responsible, Accountable, Consulted, Informed) matrix related to a spares storage system is shown in figure 5.2. Such a representation of roles and responsibilities is useful in showing the, sometimes complex, interactions required in actually executing a task as opposed to who should just do it.

5.2 Periodic review

The system should be formally audited to ensure that it is meeting the business goals, i.e. that all controls are in place and that they are effective. Ideally, this should form part of an already existing governance and auditing structure. If not, then it is recommended that there is an annual audit of the spares management practices of the organisation against this, or any locally developed, procedure.

5.3 Documentation requirements

Any critical associated records that need to be retained along with the equipment such as quality certification, installation instructions etc. should be managed within a controlled system. If the company has such an electronic system then this is ideal. As a minimum, all paper records required to demonstrate usability should be kept with, or close to, the physical spare.

Key documentation requirements should be listed on the storage control plan, with key documentation referring to any document that, if absent, prevents the spare from being usable. There may have been a change in legislative requirements since the item was last used. Documentation updates for spares should be as important as in-service equipment.

5.4. Continuous improvement

As with any system, there will undoubtedly be inefficiencies that can be eliminated. It is recommended that the management of spares is included in any continuous improvement activities that the organisation may undertake. A good source of information for where the storage requirements are contributing to failures may be a high usage, or a sudden increase in usage rate. The periodic review may give a mechanism for the identification of where the process is not working, however it is the people who are working within the system who will know where the improvement opportunities exist. They should be empowered to make changes to improve the system. There are many methods available and associated texts available on this subject.

Job title	Role					
	Site manager	Goods inwards inspection	In-storage inspection	Defining storage requirements	Defining logistics requirements	Periodic review of system
Supervisor - maintenance		I	I	R	R	C
Supervisor - stores	A	A	A	C	C	R
Technician - maintenance		C	C	C	C	C
Storeman	R	R	R	I	I	C
Mechanical Engineer		C	C	C	C	C
Instrument/Electrical Engineer		C	C	C	C	C
Site manager				A	A	A

R	Responsible (the person who carries out the role)
A	Accountable (the person who bears ultimate responsibility for the role)
C	Consulted (the person who shall or should be consulted regarding carrying out the role)
I	Informed (the person carrying out the role must inform this person of the outcome)

Figure 5.2 – Example RACI Matrix



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