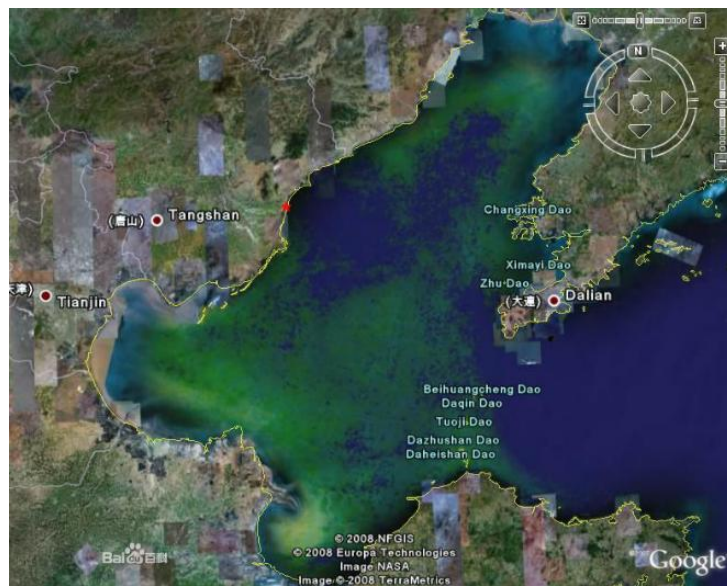


Spare Parts Management in Bohai Bay



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Abstract

Spare parts management plays a critical part in the Oil and gas (O&G) industry. Traditional asset management could not meet the requirement of present equipment. Due to the complexity of inventory plus limitation of offshore platform, it is one complicated issue to accomplish effective and efficient inventory control for offshore operation. Having reasonable inventory is crucial for improving the continuous efficiency for spare parts and decreasing the maintenance budget, especially for the offshore operations.

Inventory analysis requires one criteria to optimize the spare parts stock. Most commonly used models for inventory are spare parts value-usage, criticality, frequency of demand. The combination of management policy and mathematical model is very complicated for the maintenance management. It needs too much mathematical knowledge and is not very efficient in spare parts analysis. Thus one classical model for analyzing the spare part demand is ABC model.

A specific example of platform in the Bohai Bay is used to demonstrate the spare parts management condition more specifically. Through systematic inventory analysis, unchangeable spare parts in the last five years account for high percentage. It is mainly composed of spare parts of turbine, compressor, and crane. After reorganization, spare parts on the platform are optimized and it saves much budget and space for platform.

Key words: *spare parts, inventory analysis, Bohai Bay, criteria for inventory analysis, EOQ model, offshore spare parts management,*

Abstract in Chinese

备件管理在油气开发行业有着非常重要的作用，而传统的资产管理已经不能完全满足现有设备的需要。由于海洋石油开发受到着诸如库存种类繁多以及海上平台空间有限等因素的局限，在开发过程中实现高效的库存控制是一个很复杂的课题，合理的库存对于提高备件的使用效率并降低维保成本是至关重要的。

为了更好地优化备件库存，库存分析通常需要使用一个科学模型。常用的三种库存分析模型分别是价值分析，关键性分析，需求频率分析。对于库存管理人员来讲，由于需要过多的数学背景知识，将库存管理策略和数学模型结合起来存在一定的难度，操作起来也并不是非常有效。因此，综合来讲，常用的备件需求分析模型还是价值分析模型。

为了更具体地阐述海上备件管理，本文采用了渤海湾一个具体的例子来说明。通过系统的库存分析，库存管理人员发现，平台上拥有大量的五年无动态库存，其中大部分是透平，压缩机及吊车三种设备的各种备件。经过重新清理库存，平台的备件得到了极大地优化，一方面节省了大量平台空间，另一方面大大降低了平台库存成本。

关键字：备件，库存分析，渤海湾，库存分析模型，EOQ模型，海上备件管理

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List of Abbreviations and Terms

AM - Asset Management

CBM - Condition Based Maintenance

CMMS - Computerized Maintenance Management System

FMECA - Failure Mode, Effects and Criticality Analysis

HSE - Health, Safety and Environment

ICT - Information and Communications Technology

IMS - Information Management Systems

JIT - Just-In-Time

NCS - Norwegian Continental Shelf

O&G - Oil & Gas

OEM - Original Equipment Manufacturer

OPEX - Operational Expenses

PM - Preventive Maintenance

PMP - Preventive Maintenance Process

RAM - Reliability, Availability and Maintainability (Analysis)

RBI - Risk Based Inspection

RCM - Reliability Centred Maintenance

WBS - Work Breakdown Structure

Some basic definitions (Stefanussen 2012)

Availability: The ability of an item to be in a state to perform a required function under given conditions at a given instant time or over a given time interval, assuming that the required external resources are provided (IEV 191-02-05).

Deliverability: Deliverability is the ratio of deliveries to planned deliveries over a specific period of time, when the effect of compensating elements such as substitution from other producers and downstream buffer storage is included (Norsok Z-016).

Dependability: Dependability is the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance (IEV 191-02-03).

Failure: Failure is the termination of the ability of an item to perform a required function (IEV 191-04-01).

Fault: A fault is the state of an item characterized by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources. A fault is often the result of a failure of the item itself, but may exist without prior failure (IEV 191-05-01).

Maintainability: Maintainability is the probability that a given active maintenance action for an item under given conditions of use can be carried out within a stated time interval, when the maintenance is performed under stated conditions and using stated procedures and resources (IEV 191-13-01).

Maintenance: Maintenance is the combination of all technical and administrative actions, including supervision, action intended to retain an item in, or restore it to, a state in which it can perform a required function (IEV 191-07-07).

Maintenance support performance (supportability): The ability of a maintenance organization, under given conditions, to provide upon demand, the resources required to maintain an item, under given maintenance policy (IEV 191-02-08).

Mean time between failures: The expectation of time between failures (IEV 191-12-08).

Mean time to failure: The expectation of the time to failure (IEV 191-12-07).

Mean time to repair: The expectation of the time to restoration (IEV 191-13-08).

Non-repairable item: An item which is not repaired after a failure (IEV 191-01-03).

Repairable item: An item which is in fact repaired after a failure (IEV 191-01-02).

Reliability: The probability that an item can perform a required function under given conditions for a given time interval (IEV 191-12-01).

Term	Definition
Cash flow	The net gains or loss of cash in a business through its business cycle
Inventory	Materials and spare parts that are held for future use without knowing where and/or when the item will be used
Lead time	Measured from when ROP is reached to the actual physical stock
Materials	All items that are purchased for use in, or for supporting, manufacturing and engineering activities
Max	In some systems, this is used to determine the reorder quantity when the minimum is reached
Min	In some systems, this is both safety stock level and reorder point
Reorder point	The trigger point for reordering stock(ROP)
Reordering quantity	The quantity to be reordered when the ROP is reached(ROQ)
Safety stock	An allowance for both demand and supply variations during the lead time to restock
Stock turn	The number of times in a year that in theory the inventory is completely repurchased. Higher is better
Storeroom	The area for storing the inventory; sometimes referred to as the warehouse or the store
Stores	Sometimes used as a synonym for inventory
Working capital	The cash invested in inventory

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1. Introduction

The aim of this chapter is to introduce the background, problem description and objectives for the master thesis. The scope and limitations of the thesis are described at the end of this chapter.

1.1. Introduction of Bohai Bay



Figure 1.1. General map of Bohai Bay (Source: Google map)

The Bohai sea, consists three bays Liaodong Bay, Bohai Bay and Laizhou Bay, It is an almost enclosed internal sea of China with an area of 77, 000km² (370 07'-400 00' N to 1170 35'-1210 10'E). The coastal line is 2,900km long and the average water depth is 18m, and the maximum depth is 70m in the Bohai Straits(Zhijie and Chunyin 2000).

Three provinces and one Municipality are surrounding the Bohai Sea namely Liaoning, Hebei, Shandong Province and Tianjin City Along the sea coast. The geomorphology of the Bohai Sea is similar with the land, higher in west and lower in east, and all regarded as continental shelf. The Liaodong Bay seabed mainly consists of fine sands. The Bohai Bay mainly consists of silts and fine sands, and Laizhou Bay consists of very fine sands, and the center part consists of sands and fine sands.

1.2. Problem description and objectives

With the fast development of offshore oil & gas (O&G) industry, equipment management of offshore platform face a series of new challenge. While production of

offshore platform is increasing, asset management meets more diversity and complexity. Traditional asset management could not meet the requirement of present equipment. It forces offshore maintenance personnel to apply new technology and development methods. The strong wind and occasional snow in the winter may have a significant effect on the spare parts management by affecting the production characteristics like reliability, availability, maintainability, supportability (RAMS).

Due to the complexity of inventory plus new limitation of offshore platform, it is one complicated issue to accomplish effective and efficient inventory control for offshore platforms. Identifying proper and economical inventory is one key issue for platform maintenance and repair operation. Before maintenance personnel believed that the more inventory, the less risk they would have during operation. However, this concept does not meet changing environment of offshore maintenance management. It would result in extremely high inventory and management cost.

Having reasonable inventory is critical for improving the continuous efficiency for spare parts and decreasing the maintenance budget. In reality, on offshore platform and onshore base, purchasing period does not always comply with the actual demand. Thus, many unnecessary spare parts are piled in the warehouse. On the other hand, some demanding spare parts are in short. The application and use of spare part budget is not done according to some guidelines.

Based on above mentioned problems, the following research questions have been formulated:

- Why is it important to manage spare parts especially for offshore operation?
- Which model is an appropriate model to optimize the spare parts?
- How can spare parts management be done?

The purpose of main objective of this research is to propose an effective method to manage spare parts during operations in the Bohai Bay. Thus a more effective and efficient spare parts management model could be set for actual use in the Bohai Bay.

The main objective will be reached through the following sub-objectives.

- Finding one systematic theory for spare parts management.
- Finding an appropriate model or criteria to optimize the spare parts.
- Finding proper series of offshore spare parts management procedures.

1.3. Delimitations

The limitations of this thesis include:

- Some of the figures in this thesis are from Bohai Bay, thus it is difficult to translate the Chinese figures totally into English.
- When evaluating the procedure, one specific example is utilized in this thesis.
- EOQ model is only discussed in theory aspect, no specific calculations are listed

in the thesis.

- Finding proper series of offshore spare parts management procedures.

1.4. Thesis outline

The thesis consists of 8 chapters. The present chapter, chapter 1, contains an introduction on Bohai Bay and some challenges in the oil and gas industry. Furthermore, this chapter consists of the problem description and objectives and a short explanation of the limitations in the thesis.

Chapter 2 presents the theoretical background related to the subject of the thesis. Here, literature, methods, and models relevant for finding answers to the problem descriptions could be found.

Chapter 3 gives us a thorough explanation of inventory analysis criteria, listing three commonly used criteria for inventory control. Through listing three classification models of inventory analysis, general method for inventory management is found.

Chapter 4 states the offshore spare parts management procedures, taking the specific standard and regulations used in NCS into consideration.

Two specific case study are presented in Chapter 5 and 6, where each chapter are related to each of the questions described in Chapter 1. These chapters present two case studies related to offshore spare parts management. One is in the Bohai Bay and the other is in the Norwegian continental shelf, taking into consideration of some specific discussions in the area.

Chapter 7 presents the summary of the results found under research results and discussion, and presents the concluding remarks. In chapter 8, recommendations for future research are presented and in Chapter 9, references used throughout this thesis are listed.

2. Spare parts and inventory theory

2.1. Spare parts definition

Spare parts are parts that are stored in the inventory to replace or in support of an existing part in a production asset. Spare parts include, but not limited to power transmission equipment (bearings, hydraulic cylinders, and electric motors) infrastructure parts (ducting, expansion joints, and conveyor components). Additionally spares include disposable goods, such as nuts and bolts, lubrication, welding rods, air filters, and safety equipment.

BOM is the short name for bill of material. It is a list of item or ingredient that needed for a product. It is always used to identify a list of spare parts. Computerized maintenance management system (CMMS) is the system to keep an inventory item record to an asset or location record through a bill of material (BOM). It is possible for the workers to just key in the equipment they are using and a list of parts would be displayed. Some systems even allow the storekeeper to build an order of all the parts they have. This order could be pulled out by other people and delivered through web. If a set of equipment is due to retire or removed from service. With the BOM you could quickly identify associated equipment.

Maintenance department always need to well maintain equipment to prolong its life at an optimum cost. It is to some extent a paradox to achieve this function. Machine reliability is difficult to predict without proper condition monitoring equipment and software. Many factors could lead to machine failure such as environmental issues, process problems, poor operator procedure or even an accident. It is imperative to store spare parts. If you store the spare parts on site, it could decrease the time to collect and replace. Many specialized parts need long time to access. For some equipment that has been used for many years, it is difficult to find the replacement part. Sometimes some unforeseen problems like unavailability and long delivery could force us to have large spare parts department.

On the other hand, it is costly and not feasible to have a spare for each piece of equipment. Therefore, you should analyze the criticality of equipment in the BOM and stock spares accordingly.

A good maintenance strategy is based on good maintenance principals. As stated in the book (Srinivasan 1986), the authors point out eight basic operating principals.

- Reduce and minimize production downtime
- Reduce costs of production
- More effectively control spares and inventory
- Control repair and maintenance costs
- Eliminate emergency repair actuations

- Reduce spoilage and enhance quality of plant and machinery performance output
- Achieve fewer large-scale repairs and fewer repetitive repairs
- Increase employee morale and enhance worker safety

While the maintenance department have a great impact on what is included into spares inventory, the engineering part also pose huge influence on the inventory. As is stated in the book (Srinivasan 1986) “Maintenance engineering is a function of providing required engineering and service crafts to ensure the safe and efficient operation of all the assets, including plant and equipment facilities.”

Engineering is responsible for ensuring that proper equipment is used for the process. The engineering group should ensure the equipment is cost effective.

In addition, much attention should be attached to the timely and efficient acquisition of machinery and spare parts. Acquiring spare parts always take lots of time and money. To reduce the spare part purchasing cost, some principals should be taken accordingly.

- The schedule for delivery should be agreed on and written into contract.
- Suppliers should provide stock at agreed rates.
- Slow moving “safety stock” items should be held at one location and drawn from stores as required.

2.2. Spare part needs determination

To determine which spare part are in need and what quantities to store is one key issue for maintenance department. Due to the changing process, it imposes much difficulty to maintenance personnel. In a plant, capital equipment is constantly changing. The replacement spare parts are also changing with time.

What is effective spares management?

Davis and Hemming believe in 2009, "A comprehensive management process applied to the maintenance storeroom ensures that parts are there when needed, redundant items are not being purchased, items are automatically re-ordered as needed, obsolete items are reported upon depletion, cost-effective methods are used for purchasing lot type items, and item usage costs are documented and reported to plant management.”

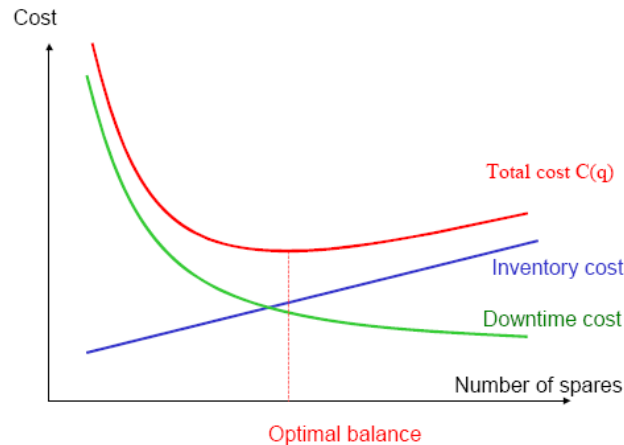


Figure 2.1. *Determining balance between inventory and downtime cost(Kumar 2000)*

Figure 2.1 could tell us the relation between inventory and downtime cost while it is impossible to calculate how to determine the balance specifically. Although it is difficult to calculate the amount or quantity to demonstrate the balance, we could use some factors to depict the tendency. It is logic that factors such as time, rate of usage, delivery time, cost parameters for transport from stock to point of use and total cost could affect the balance.

Most products exhibit failure characteristics during their life time. Failure is defined as “*the termination of the ability of an item to perform a required function*”(IEV 2007). To understand the behavior of failure for a product during its lifetime, the bathtub curve in the Figure below can be used as a good example.

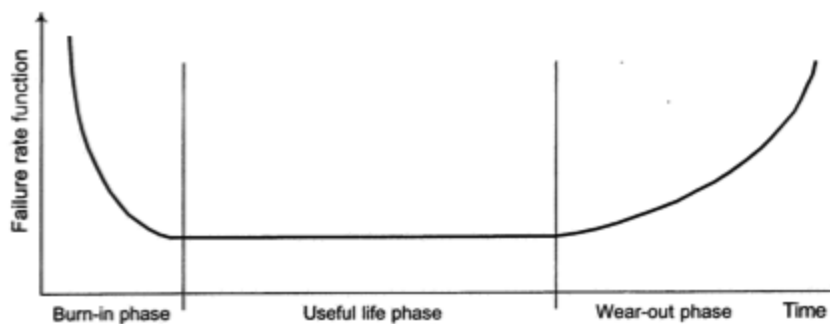


Figure2.2. *The bath-tube curve (OREDA 2002)*

2.3. Spare parts management

Spare parts management can be deemed as an aspect of spare parts logistics (product support logistics). It is a broad field that includes several different topics, such as maintenance, reliability, supply chain management, inventory control and other

strategic aspects. It is essential to have an adequate stockholding of spare parts, especially critical parts. Lack of spare parts could lead to lower availability and increased operational risk.

Spare parts management is an important part in achieving the desired plant availability at an optimum cost. Presently, downtime cost for plant and machinery is extremely expensive. It is observed that in many industries non-availability of spare parts contributes to 50% of the total maintenance cost in the industry.

The company always want to achieve sufficient service level while keep the inventory investment and administrative cost at a minimum (Huiskonen 2001). Each spare part being held and not used needs some money as insurance and maintenance cost. It needs storage space which takes money as well. Sometimes due to poor planning and spare part management, some spare parts would even never be used for many years.

Modern corporation always put high attention on the spare parts management. Procurement cost saving always largely outweighs reverse logistic cost. For example, IBM (Kennedy, Wayne Patterson et al. 2002) is one of the pioneer company that recognize the importance of close-loop supply chain and spare parts management.

Somewhat it is difficult to find a balance between non-availability of spare parts to meet requirement and soaring capital in spare parts inventory. It could be significantly confirmed the vital importance of spare parts management in modern industry.

Spare parts management is to ensure the availability of spares for maintenance and repairs of the plant and machinery at an optimum cost. To secure high quality, many actions are required to have an effective spares management. One systematic spare management has several actions as given below.

- Identification of spare parts
- Forecasting of spare parts requirement
- Inventory analyses
- Formulation of selective control policies for various categories
- Development of inventory control systems
- Stocking policies for rotatable spares or sub-assemblies
- Replacement policies for spares
- Spare parts inspection
- Reconditioning of spare parts
- Establishment of spare parts bank
- Computer applications for spare parts management

2.4. Inventory analysis

The inventory analysis is carried out on the basis of many characteristics such as annual consumption value, criticality, lead time, unit cost and the frequency of use. Optimum replacement policies for selective items which cost of down time and replacement are high should be paid much attention. In addition, some spare parts are transported from foreign countries or need long distance. For these parts, it is essential to extend the life cycle by appropriate methods of reconditioning or repair techniques.

For different industries, it would be helpful to establish one suitable information system for the exchange of spare parts. Application of computers for the processing of spare parts information will also contribute to build one efficient and effective inventory control system.

Some key questions are posed to us like what to stock, what quantity to stock, when to reorder and replenish the inventory. (Behzad Ghodrati and Uday Kumar 2005) To find out the answers to these sophisticated questions, factors such as equipment failure rate, demand rate and number of similar parts need to be determined.

(Behzad Ghodrati and Uday Kumar 2005) System reliability characteristics and factors such as mean time to failure (MTTF) and mean time to repair (MTTR) are required for reliability analysis and spare parts forecasting. Some operating environmental factors such as dust, temperature, humidity, pollution, vibration, operator's skill could affect the reliability greatly.

For manufacturing organizations, inventory could account for up to 50% of the current assets of the business. It means that up to 50% of the asset which could be converted to cash is tied up as inventory. For the wholesale and retail business, this figure could be even bigger. While some companies do not reach this high level, it is common that a large number of corporations have millions even tens of millions dollars tied in this type of inventory.

Normally, maintenance department will face the following question:

a) Keep each spare in stock or not?

Generally, if the benefit of current availability is better than cost of holding inventory, the answer is yes. Comparing the storage cost and the cost related with stock-out could give us the answer.

b) How many to order at once?

After you have determined to buy one spare, it is time to figure out how many to order at one time. To determine an optimal order quantity, there is a well-known model called economic order quantity (EOQ).

c) How many pieces to keep in stock?

With doubt it depends on the annual demand, ordering cost and holding cost of inventory.

d) When to release a new order?

Re-order point, named the moment to release a new order, is one key parameter in inventory control. If one company has too many stock of one spare part, it would give rise to holding cost. On the other hand, if it has too few items on stock, it could result in high penalty cost. The minimum stock will be determined considering the consumption during the lead time. Demand is calculated based on the planned need and previous data.

A general method for inventory analysis and its replenishment for critical equipment is shown in the figure below. It is analyzed based on reliability engineering perspective.

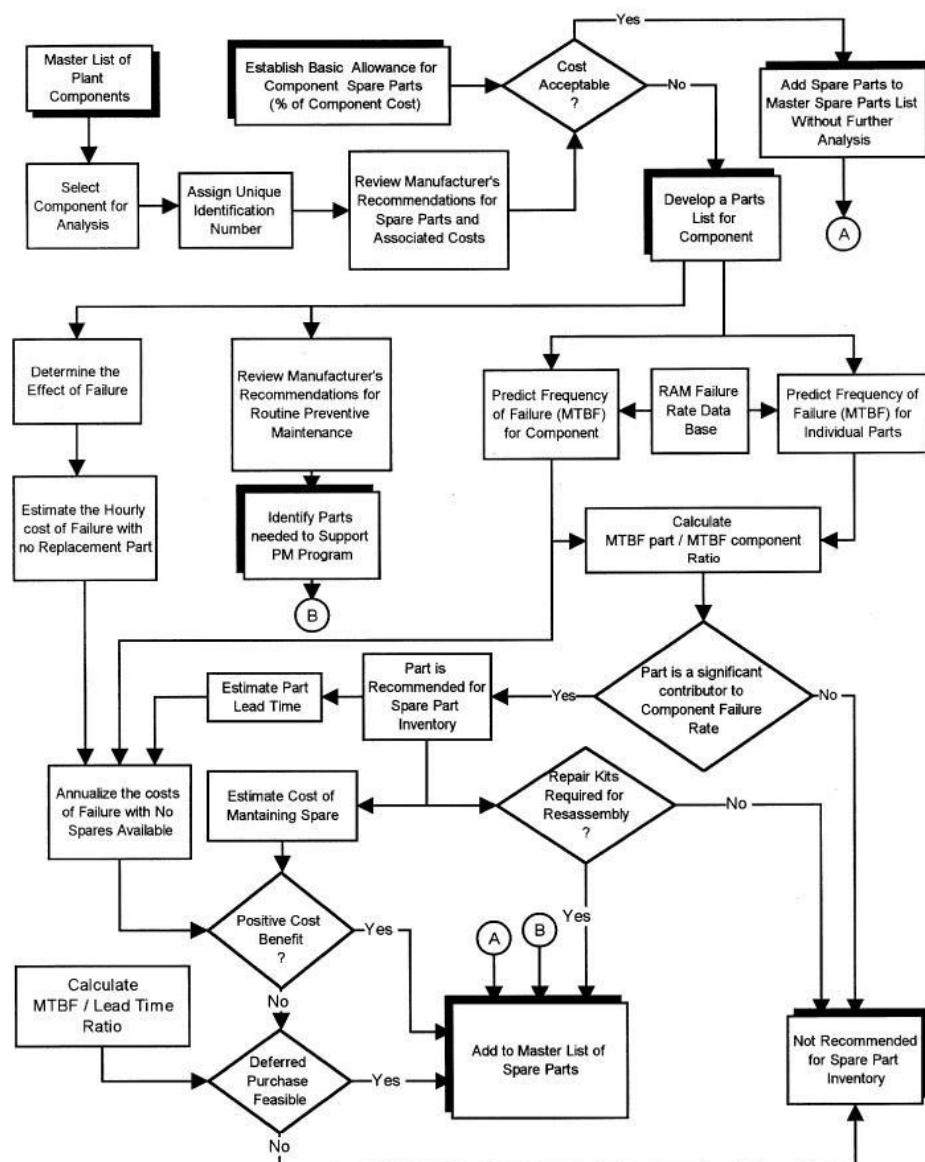


Figure 2.3. Spare parts optimization process (determination of inventory) (Source:(IAEA 2001))

Therefore one proper criteria or standard is needed to calculate or quantify the demand. The maintenance personnel in all industry have various comments and theories about this.

2.5. Criteria for inventory analysis

(A.A. Syntetos 2009) Demand classification constitutes one essential element of every inventory management system since it facilitates decision-making to stock control. (Boylan 2008) In big corporations, spare parts are always classified into several patterns with different costs, service requirements and demand patterns. (Naylor 1996) For the industrial spare parts, it is common to use the criticality of spare parts to classify them.

(Department of Defense 1980) The FMECA (failure mode, effects and criticality analysis) is commonly used in the analysis of criticality. This approach is defined as “A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence”. ABC analysis is by value the most common used proxy for criticality.

Spare parts fall within the definitions of product support (Behzad Ghodrati 2012). The operating environment of a system has a great influence on the performance of the system. If one company is in a lack of timely support, it is possible cause unexpected down-time. It could further lead to losses which is unable to compensate.

SKU (Tim J. van Kampen 2012) is short name for stock keeping unit (SKU). Various approaches are used to classify SKUs. One well-known approach is ABC analysis, which always takes the use of demand value or demand volume. Another well-known approach is the fast, normal and slow moving (FNS) technique, which classify different classes with demand rate (FNS). Appropriate method for classifying SKUs is needed to guide managers. Four main characteristics used for SKU classification are volume, timing, product and customer.

In summary, most commonly used criteria or models are listed as follow.

Spare parts value-usage (A,B,C group)

Criticality (V,E,N group)

Frequency of demand (F,S,N group)

In the next chapter the criteria listed above would be discussed concisely.

3. Inventory criteria model for spare parts

3.1. Inventory control

3.1.1. Objective of effective inventory control

Professor Tore Markeset (Markeset 2012) state that “The objective of effective inventory control are to relate stock and stores quantities to demand, to avoid losses due to spoilage, pilferage and obsolescence, and to obtain the best turnover rate on all items by considering both the cost of acquisition and possession”.

3.1.2. How to store the parts

- Classification of spare parts. The ABC classification system is used to know the significance of different spare parts separately. Hence, spare parts are categorized into several grades to have different stock strategy.
- Bar coding and computerized maintenance inventory control. Inputting various spare parts data into computer, a huge database could be built to enable us to have a better monitoring of real-time monitoring of spare parts. It would great increase the work efficiency and decrease the operation cost.
- Record procedure. Tore Markeset (Markeset 2012) states that “weather computer-controlled or manual procedures are employed, there must be informative inventory records to assure that parts and materials are available for routine maintenance, repairs and overhauls”.

3.1.3. Where to store the parts

- Centralized VS Decentralized. Some common spare parts and dangerous spare parts can be used by all the platforms should be centralized stored, especially some high value spare parts. For example, the flammable spare parts should be centralized stored; Spare parts that need special storage container should be centralized stored.
- Onshore VS offshore. Limited space offshore determines that we cannot store all the spares parts offshore. We need to decide where to store our parts. For instance, critical and frequently consumable parts should be stored offshore. While the huge, heavy, easy-corrosion and other high requirement forstorage spare parts should be stored onshore. The suggestions from the site maintenance group and logistics department should also be considered.
- Monitor and update the spare parts periodically (per week or per half month, etc.).CMMS (computerized maintenance management system) should be utilized to realize better spare parts logistics and inventory control. For example, Min/max should be setup, if the number of spare parts number achieve the minimum level, an automatic purchasing request should be sent to the buyer.

- The spare parts should be reviewed and updated according to the situation of the equipment. For example, with the aging of the equipment, the spare parts prepared should be much more than the early year.

3.1.4. Examples

Based on the upper theories and philosophies, the spare parts management is planted into the SAP software system which is make it efficient in tracing, controlling and management the materials in modern companies. The status of the materials (including what, where and how many) is available online and known by the maintenance group. The max stock level and Min stock level can also ensure the automated purchase order for the materials which can ensure purchase the required materials on time. One sample material list run by the SAP is listed below:

Material	Short Text	Total Stock	UOM	Type	Max Stock Level	Min	Location
1040403	BRG,22220 EK,SKF	10	EA	V1	14	6	platform
1040802	PIPE,4.500" OD,.674" WALL,27.54#/FT,SMLS	2	EA	PD			warehouse
1041063	JOINT,ESS,5 1/2" X 11.8M,270 MICRON,316L		EA	ND			No STK
1041125	Motor Model:CT400-Y2	440	EA	V1	440	220	warehouse
10513497	VALVE,1" CK,1-V0067,C'TREAT	2	EA	V1	2	1	platform
10513507	VALVE,BALL,V0004,C'TREAT	1	EA	V1	2	1	platform
10513508	VALVE,BALL,1-V0008,C'TREAT	1	EA	V1	2	1	platform
11737443	RELAY,INSTR,120 VAC,KRPA-14-AG-120	2	EA	V1	2	1	platform
22343443	BREAKER,CIRC,1P,20A,C65H-DC,MERLIN GERIN	2	EA	V1	2	1	platform

Notes:

- The material number 11737443 is a critical part for electrical control system and the frequency of failure is relatively high, so the location of 11737443 is on platform.
- MRP Type: V1 means stock has been set up for the material. When the quantity reach the Min stock level, the automatic purchase order will be initiated.
- MRP Type: ND means no stock set up for it as the low probability of the parts fail, but the information is ready to use, if it really fails, purchase directly using the information.
- MRP Type: PD means no stock set up for it, but currently warehouse has on-hand stock, when you need materials with MRP type PD.
- The total stock is the quantity of spare parts on-hand. If the total stock is

lower the Min set, the automatic purchase order will be initiated.

- The Max/Min value is based on the criticality, Mean Time To Failure, total quantity of equipment etc.
- The location is considered the criticality of equipment, consumable or not, etc.

3.2. Criteria for inventory models for spare parts

Generally, it is not a wise idea to implement the same inventory management policy on all items in stock. Due to the different demand and present stock, it is compulsory for the maintenance management to analyze the inventory in a scientific method. Each item in stock is analyzed according to certain criteria. The commonly used criteria are listed below(Bošnjaković 2010).

- Spare parts value-usage
- Criticality
- Frequency of demand

3.2.1. Classifying by value-usage

Normally, every spare part has its value, no matter how long it have been used. It takes money when it is brought into the warehouse.

Value-usage is defined as a product of:

Cost of an item * annual inventory demand

If you have a thorough analysis of all spare parts in the warehouse, it could be noted that few spare parts always constitute most of the total cost. The spare parts are ranked into three groups: A, B and C. Group A is the group that takes the majority cost of all spare parts, say 80%. Group A always comprises about 20% of items. It represents the most significant items from the value-usage. In the warehouse, one group always comprises the most of items, say 50%, but consists of the minority of total cost, say 5%. Group B is in the middle with 30% items and 15% of value-usage.

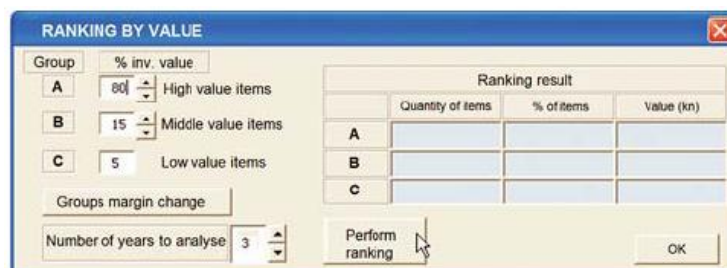


Figure 3.1. Classifying by value-usage (Bošnjaković 2010)

Definitely, the percentage used before is only one example, it is not fixed. The maintenance personnel could set the percentage according to the real condition and

stock. The exact number varies from inventory to inventory. But one principal exists, a few items with a significant proportion of the value-usage and a large number with relatively small value-usage. Group A would be paid much attention and careful monitoring as well. For these items strict control principal would be applies. Constant reviewing of stock level, a relatively small back-up supply, and ordering just in time, is the key principal. However, for the other extreme of the situation, group C should be controlled mildly. The maintenance personnel should have a greater security stock and periodic review.

3.2.2. Classifying by criticality

For spare parts and components, they are generally classified into three categories : Vital(group V), essential(group E) and desirable(group D).

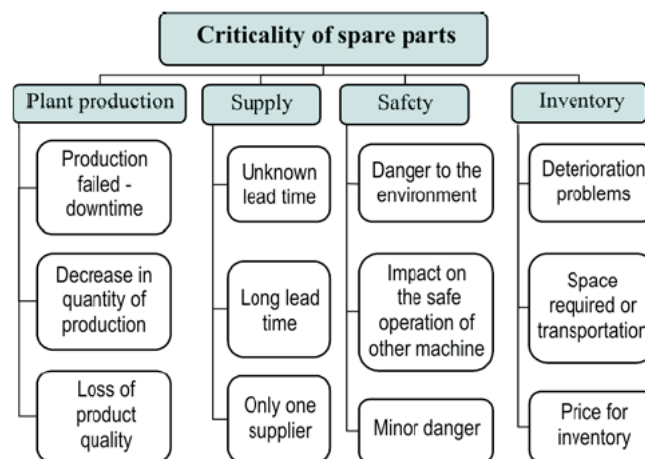


Figure 3.2. Spare parts criticality(Bošnjaković 2010)

It could be noted that four perspectives should be taken into consideration, production, supply, safety and inventory.

a). Criticality related with production

For the maintenance personnel, basic goal of their job is to achieve the availability and reliability of equipment to ensure the production. Not every equipment has the same influence to the system. The production would not be affected if in shortage of some spare parts. But for other spare parts, the shortage would result in the interruption of operation of the overall production. For one spare part, whether it is or not on the stock does not have the same importance. The criticality of spare part is primarily conditioned by criticality of equipment in which the spare part is used. Some spare parts are used only in one machine, while some are used widely in many machines.

b). Criticality related with supply

Every spare part has its time for purchasing. Normally it depends for every spare part.

The lead time for purchasing could be more than 4 months, less than 2 weeks or in the middle. The lead time classification could be arbitrary.

c). Criticality related with safety

It is significant to evaluate the safety factor of each spare part. Lack of spare part could cause ecological disaster, danger to human-being, or impact on the safe operation of other machines. While for some spare parts, the failure of it does not have great influence to other machines, environment or human-being.

d). Criticality related with inventory

Some spare parts eventually lose their quality or usability, and may be critical for storage from this point of view. If the spare parts have large dimensions and weight , it may cause some practical difficulty for the maintenance personnel. In this respect if the spare part is very critical, its desirability is less than the one with normal dimension and weight. Thus this parameter actually acts against the three parameter discussed above.

3.2.3. Classifying by frequency of demand

Frequency demand is a critical parameter in the process of inventory analysis. As the frequency of demand varies, different analysis model have to be used accordingly. For this aspect it is important to separate spare parts into several groups according to respective frequency of demand.

Definitely, every corporation could have their own separation criteria. Normally used criteria for separating the spare parts is to classify into three groups. The first group named F group includes the spare parts that are frequently used. The second group named S group includes the spare parts that are less used. The third group named N group includes the spare parts that are very rarely used.

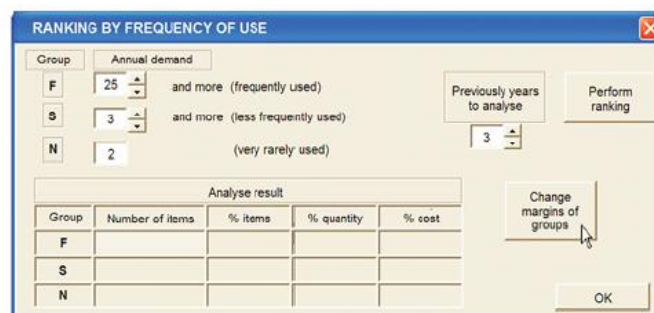


Figure 3.3. *Classifying by frequency of demand*(Bošnjaković 2010)

Every spare part could have three parameters. The parameters could have three values. It means that the total number of possible combinations is 27.

(A,V,F)	(A,E,F)	(A,D,F)
(A,V,S)	(A,E,S)	(A,D,S)
(A,V,N)	(A,E,N)	(A,D,N)
(B,V,F)	(B,E,F)	(B,D,F)
(B,V,S)	(B,E,S)	(B,D,S)
(B,V,N)	(B,E,N)	(B,D,N)
(C,V,F)	(C,E,F)	(C,D,F)
(C,V,S)	(C,E,S)	(C,D,S)
(C,V,N)	(C,E,N)	(C,D,N)

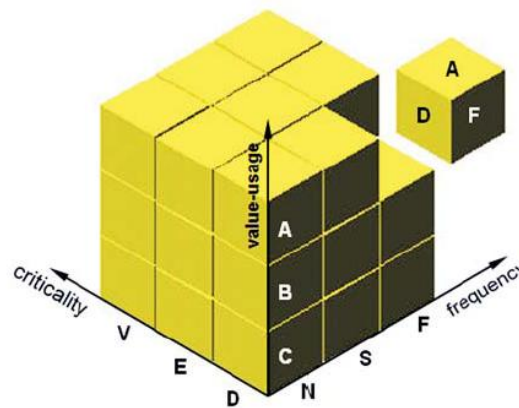


Figure 3.4. Possible combinations of parameters(Bošnjaković 2010)

The specific criteria could take average demand during lead time into consideration. Normally, three basic policies are used for managing the spare parts and components as follows.

- No spares in stock.
- Only one piece in stock.
- More pieces in stock.

There are two fundamental types of maintenance, preventive maintenance and unplanned repair. For preventive maintenance, the demand for spare parts is predictable. It could be possible to just order the spare parts and they could arrive in time for use. For unplanned repair, it could lead to production loss due to stockouts. Therefore some kind of stock policy is mandatory.

Thus, it always has several steps to analyze the possible combinations of parameters.

1. Define the proper management policy.
2. Choose an appropriate method for predicting the demand.
3. Predict the demand for each spare part in a specific period.
4. Predict the total demand for all the spare parts in one year and total required cost.

To clarify the analysis of spare parts, sometimes the three dimensional model is simplified into three two dimensional model accordingly. For many spare parts, the policy of more pieces in stock is common used. At this time EOQ model or dynamic model of storage would be utilized. Later EOQ model would be demonstrated specifically.

It is important for the maintenance personnel to periodically analyze the demand in the previous period and to establish whether it is a nearly constant demand. If the analysis proves it is nearly a constant demand for one spare part, economic order quantity (EOQ) is recommended to express the demand.

3.3. EOQ model

To use the EOQ model some assumptions are made(Kumar 2000):

- A constant demand rate.
- The ordering cost (S) is incurred, whenever an order of size ‘Q’ is placed.
- Neglecting the lead-time.
- No backorders.
- ‘H’ is the carrying cost of the inventory.
- ‘S’ is the unit purchasing cost.
- ‘D’ is the annual demand rate.

From the underlying assumptions the basic EOQ formula can be written as

$$EOQ = \sqrt{\frac{2DS}{H}}$$

To find the optimal total inventory cost we can use the formula

$$TC = \frac{EOQ}{2} \cdot H + \frac{D}{EOQ} \cdot S$$

The EOQ could give us the best quantity of items to order at the minimum cost. When the inventory stock drops to a certain amount of item(s), a new order needs to be placed. It is referred to as the reorder point (ROP). The ROP is “*the sum of average demand during lead time and the safety stock*” (Ghodrati 2003), and the safety stock is the minimum inventory held, to prevent shortage if the demand is not met through the lead time.

Reorder point could be calculated on the basis of the level of service to minimize the total cost. Periodic review or continuous review is always demanded in the process of EOQ model.

The management of spare parts always plays a critical role in the management of equipment and cost.

This thesis proposes the use of multicriteria inventory model to optimize the cost for spare parts. Frequently used criteria are value-usage, criticality and frequency of demand. The combination of management policy and mathematical model is very complicated for the maintenance management. It needs too much mathematical knowledge and is not very efficient in spare parts analysis. Thus one classical model for analyzing the spare part demand is ABC model. This inventory analysis model is simple, clear and efficient for implementation in daily practice.

3.4. Coding

To realize the optimization of inventory control, coding is one key issue.

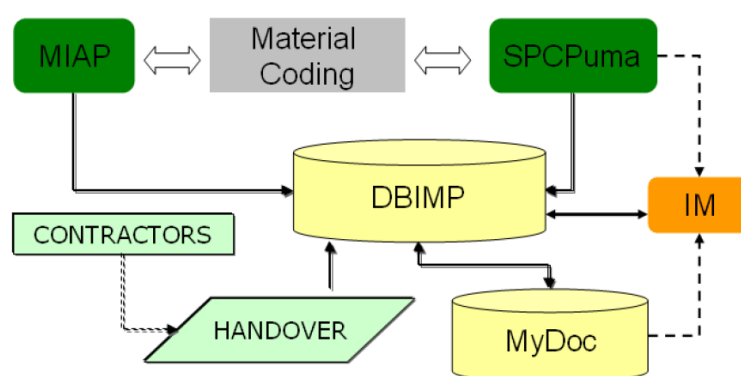


Figure 3.5. *Eni E&P methodologies and tools(Fistarol, Ratti et al. 2011)*

Eni E&P has begun a process of standardization concerning coding and management of plant material. It has developed internally a series of information system and management software during the project life.

MIAP“Material di Ingegneria e Area Pozzo”: an information system for coding and management Later Eni implemented.

SPCPUMA“Software Piping Class”: execution and optimization of engineering management of piping material during project life.

IM (Inspection Manager): an information system for management of inspections on material.

MyDoc (Document Repository): detail information for piping and equipment.

Easy Loader: a tool for collection and input of data.

Eni utilized five methods of tagging or coding the material of plant.

- a. Provides the rules for identification of all itemized material(equipment,

- instruments)
- b. Coding of bulk material
- c. Defines the main characteristics of engineering and well area equipment
- d. A method for coding manufacturer models
- e. Coding manufacturer spare parts

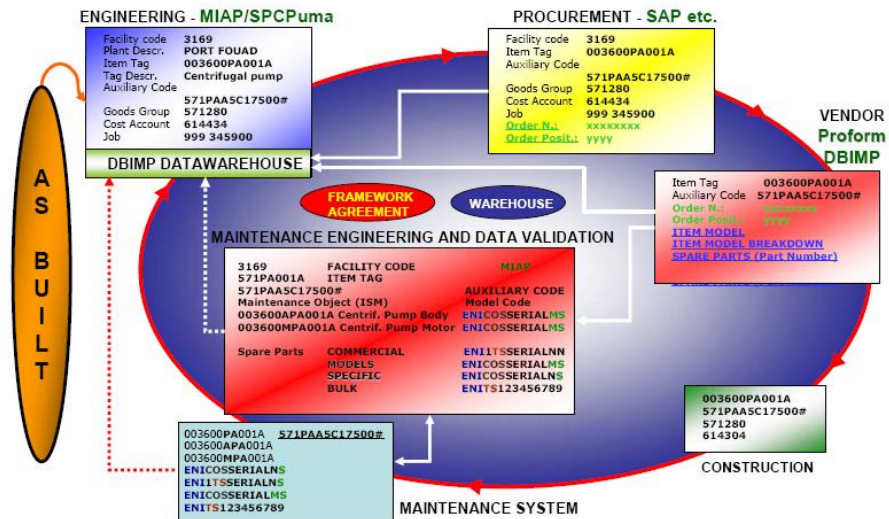


Figure 3.6. Eni E&P vision of material life cycle (Fistarol, Ratti et al. 2011)

With various software listed above, Eni E&P has realized a material life cycle monitoring. It has several prefaces, such as engineering, procurement, vendor, construction, maintenance system etc.

4. Offshore spare parts management

4.1. Spare parts evaluation and optimization

The spare parts evaluation process is a significant part of spare parts management. From a broader view, spare parts management is the link between maintenance planning and maintenance execution. It also connects the suppliers, manufacturers and contractors. In the process of maintenance planning, the risk of equipment failure is taken into consideration. It is one effective way to provide sufficient stock and safety stock for future requirement. Some factors such as lead time, unit price, delivery condition, purchasing costs, etc should be taken into consideration as well to ensure timely supply. All these steps could be vividly described in figure below.

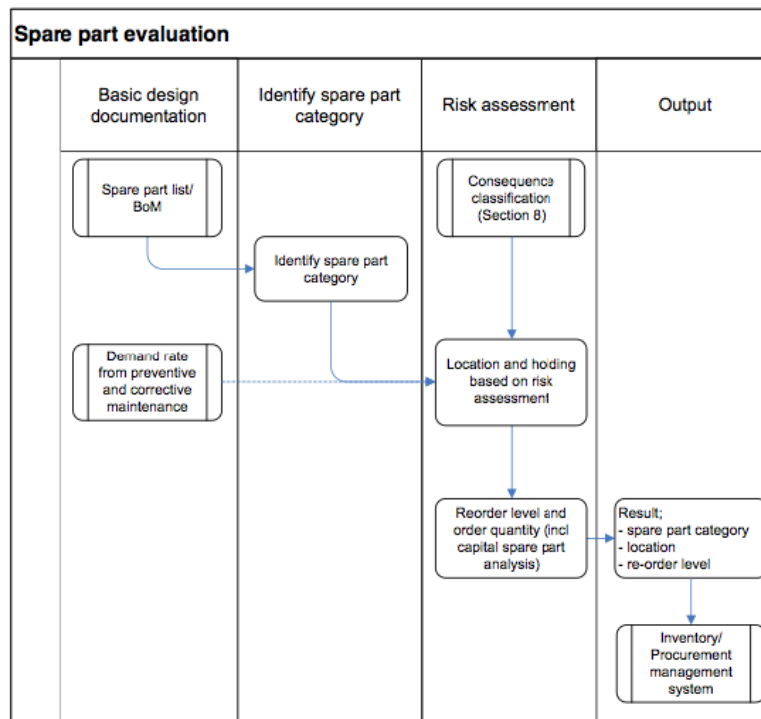


Figure 4.1. *Spare parts evaluation process adapted from (Norsok 2011)*

If a spare part is to be kept as one part of inventory, it is time to figure out the quantity of spare parts needed to stock. When the inventory level drops, replenishment needs to be done to avoid the risk of failure of the machine. The replenishment should be determined on the basis of expected usage rate of the part and economic risk of unavailability of the spare part. With several factors such as the part failure rate, the usage rate per component and the number of similar components in the system, the annual usage rate could be calculated. It would influence the total usage rate and the replenishment. The figure 4.2 could give us a visual relationship between these factors.

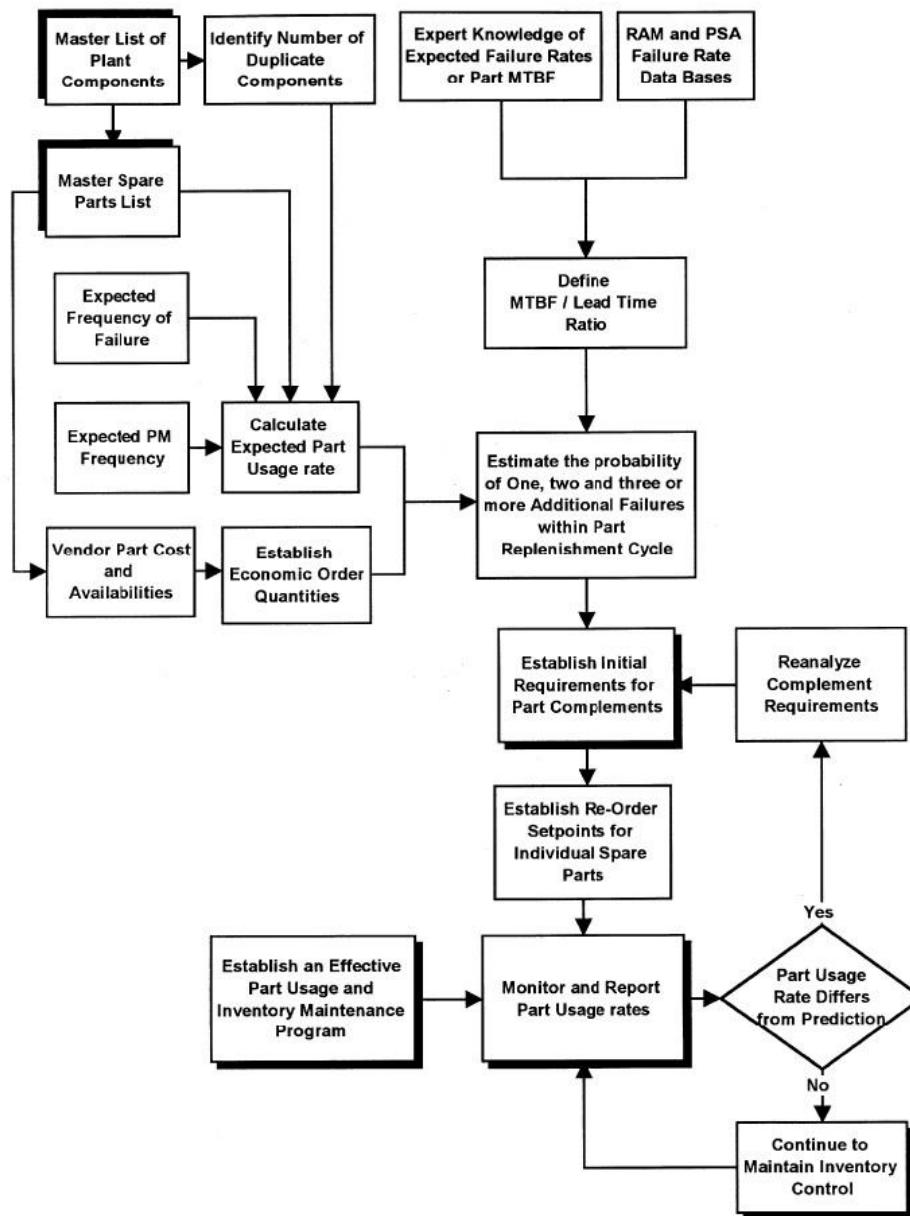


Figure 4.3. Spare parts optimization
(determination of complement) (Source:(IAEA 2001))

Dependability is defined as “the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance” (IEV 191-02-03).

To decrease the risk for health, safety and environment is the focus of dependability management. It is carried out through improving the quality during the life cycle phases. Production performance is related with some key factors such as customer, market, regulatory, demands and requirements etc. The dependability would affect the availability directly and affect the production performance indirectly. The relationship between dependability concept and other factors is illustrated in the Figure 4.4.

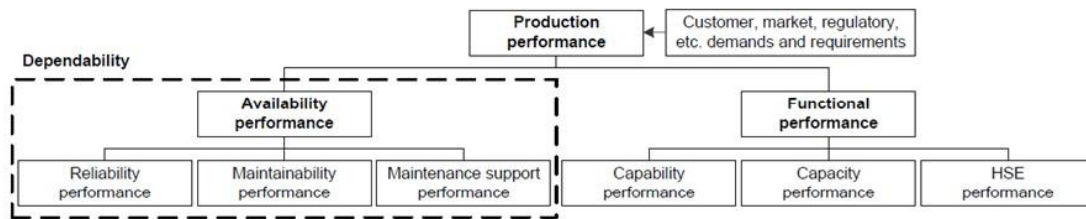


Figure 4.4. *Dependability concept and relationship with production performance (Markeset 2010)*

4.2. Offshore spare parts management

Many risks are involved in the offshore drilling operation. It includes environmental, economical and other risks to human-beings and concrete asset during operation. To minimize the risks and avoid underlying damage to human and asset, some methods are utilized to keep the risk as low as possible. The government and authority always carries out various rules, regulations to achieve this process, for example, the Norwegian Petroleum Safety Authority which are famous as PSA(Samland 2011).

PSA has published a set of regulations to guide petroleum production. Chapter 9 emphasizes need for maintenance and spare parts. Section 46 classification states that:

“Facilities’ systems and equipment shall be classified as regards as the health, safety and environmental consequences of potential functional failures. For functional failures that can lead to serious consequences, the responsible party shall identify the various fault modes with associated failure causes and failure mechanisms, and predict the probability of failure for the individual fault mode. The classification shall be used as a basis in choosing maintenance activities and maintenance frequencies, in prioritizing between different maintenance activities and in evaluating the needs for spare parts. ”

For spare parts at operating drill rigs there are regulations concerning safety of the personnel, infrastructure, and environment. Related regulations and rules are always made to guide the operation. For example, the NORSOK D-010N for drilling and well interventions describes that critical spare parts or back-up equipment with a long expected delivery time should be identified. These critical parts should be placed either at the platform where it is to be used or at a land based warehouse.

(Ghodrati 2005) For the analysis, some important inputs to consider during optimizing the spare part inventory are listed as follows according to DNV’s standard (DNV 2009).

- Consequence classification of parts
- Parts demand rate
- Unit price of the part
- Lead time
- Service level

4.3. Paradox for offshore spare parts management

Some maintenance personnel believed that the more stock in the warehouse, the more safe it is. Actually, it is not a good decision to have too many spare parts in the warehouse.

Overstock would occupy a large amount of money. With the increase of stock, it would require more space and money to stock it. The Rate of Equity (ROE) and revenue per capital would decrease more or less. On the other hand, overstock would prolong the storage period and cause aging even damage to sophisticated spare parts. The original values of spare part would be decreased.

Compared with land transportation, offshore platforms will have huge challenge for logistics. Due the severe influence from weather condition, such as snow or harsh wind, timely and adequate supply of spare parts would be difficult to accomplish.

On the other hand, if stock is not enough for offshore platform. It may not meet the demand of spare parts for daily consumption offshore. Thus frequent purchasing of spare parts would increase purchasing cost and decrease the availability of equipment.

In a word, it is a paradox between production demand and optimum inventory control. Reasonable stock proportion, stock volume and purchasing period is key issue for offshore production management.

5. One specific optimization process in Bohai Bay

Having reasonable inventory is critical for improving the continuous efficiency for spare parts and decreasing the maintenance budget. In reality, on offshore platform and onshore base, purchasing period does not always comply with the actual demand. Thus, many unnecessary spare parts are piled in the warehouse. On the other hand, some demanding spare parts are in short. The application and use of spare part budget is not done according to some guidelines.

Insufficiency of critical parts and overstock for not critical parts is common during the inventory management. To demonstrate spare part consumption period, one timeline is whether specific spare parts are used or not in the last five years.

In this chapter one specific example of platform in the Bohai Bay is used to demonstrate the spare parts management condition more specifically. In this chapter Platform A is used on behalf of the specific example.

5.1. Inventory analysis for Platform A

For Platform A, a general inventory analysis is done as illustrated in Figure 5.1

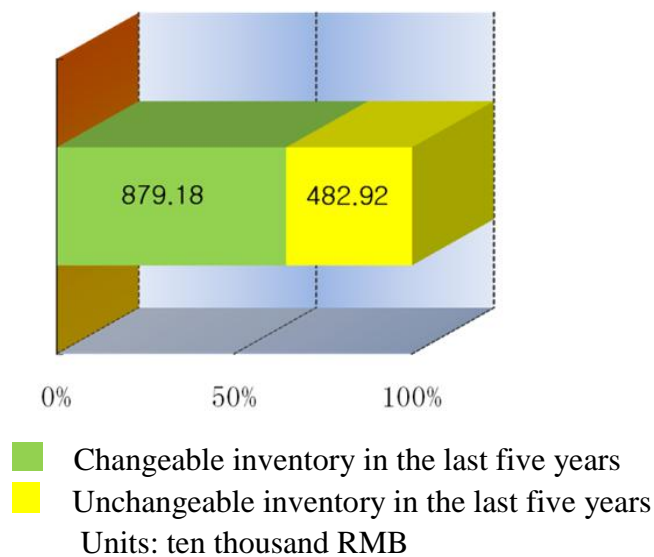


Figure 5.1. General inventory analysis for Platform A

As shown in Figure 5.1, total inventory for the platform is 8,791,800 RMB. The unchangeable spare parts in last five years account for 35.5 percent. In another word, equipment valued about 4,829,200 RMB is in the status of depreciation.

Further, if we have a analysis of these unchangeable spare parts in the last five years, it is noted that:

- 1、 Turbine spare parts account for 59 percent, summed value is 2,830,566 RMB
- 2、 Compressor spare parts account for 17 percent, summed value is 813,902 RMB
- 3、 Crane spare parts account for 19 percent, summed value is 923,817 RMB
- 4、 Other spare parts account for 5 percent.

It should be noted that these four percentage is the composition of the spare parts that are unchangeable in the last five years, not the composition of all the spare parts.

Figure 5.2 could fully describe the composition of each part furthermore.

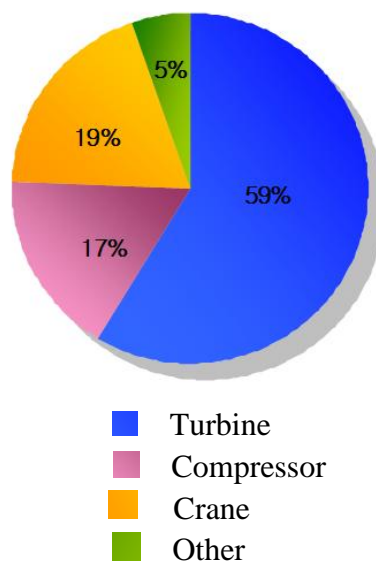


Figure 5.2. *Composition of unchangeable inventory for Platform A*

The inventory of three kinds of critical equipment constitutes a majority of unchangeable inventory. Definitely it is the key part that much attention should be attached.

In consideration of above problems, offshore maintenance personnel analyze each unchangeable asset.

5.1.1. Turbine's spare parts

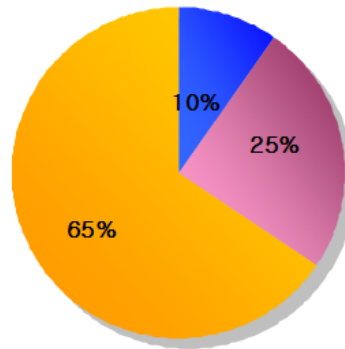





Figure 5.3. *Composition for turbine's spare parts*

To describe the figure more clearly, one graph below is made to demonstrate it.

Item	Cost/ RMB	Percent
 Consumable(Annual Consumption>1)	423151.06	9.81%
 Not always used (Annual consumption<1)	1058645.17	24.55%
 Unchangeable in last five years	2830566.88	65.64%
Total spare parts	4312363.11	100%

Consumption of Turbine's spare parts

5.1.2. Compressor's spare parts

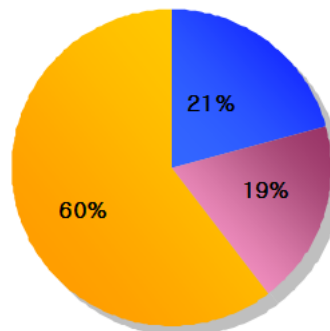





Figure 5.4. *Composition for compressor's spare parts*

To describe the figure more clearly, one graph below is made to demonstrate the composition.

Item	Cost/ RMB	Percent
 Consumable(Annual Consumption>1)	281095.48	20.82%
 Not always used (Annual consumption<1)	254902.4	18.88%
 Unchangeable in last five years	813902.93	60.29%
Total spare parts	1349900.81	100%

Consumption of compressor's spare parts

5.1.3. Crane's spare parts

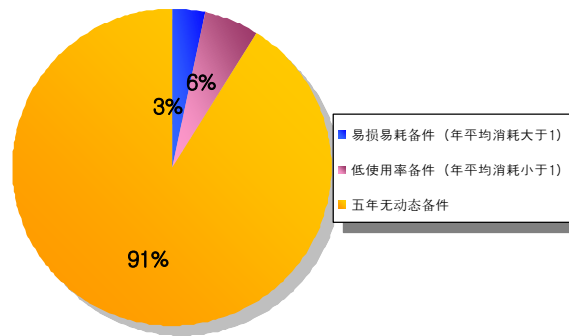


Figure 5.5. Composition for crane's spare parts

Item	Cost/ RMB	Percent
Consumable(Annual Consumption>1)	32495.98	3.20%
Not always used (Annual consumption<1)	58285.86	5.74%
Unchangeable in last five years	923817.79	91.05%
Total spare parts	1014599.63	100%

Consumption of crane's spare parts

5.1.4. Three critical equipment and the relationship between them

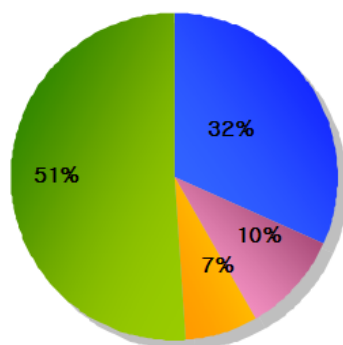
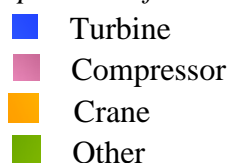


Figure 5.6 *Composition of entire inventory*



As illustrated in Figure 5.6, three kind of critical equipment that is turbine, compressor, and crane together account for 49 percent of total inventory.

It should be noted that Figure 5.6 is different from Figure 5.2. While Figure 5.2 gives us a composition of unchangeable inventory, Figure 5.6 presents us a structure of total inventory.

After the analysis of present inventory, several comments and descriptions are given as follow:

- Unchangeable inventory
- Safety stock need to be adjusted.
- Inappropriate inventory composition, some spare parts are stored too much while some are too less.
- No good purchasing period and huge fluctuation.

5.2. Exploration of inventory management

Through the above analysis, some underlying problems are figured out. How to solve these problems in an effective way is one critical issue for maintenance personnel. A common model for inventory is illustrated in Figure 5.7.

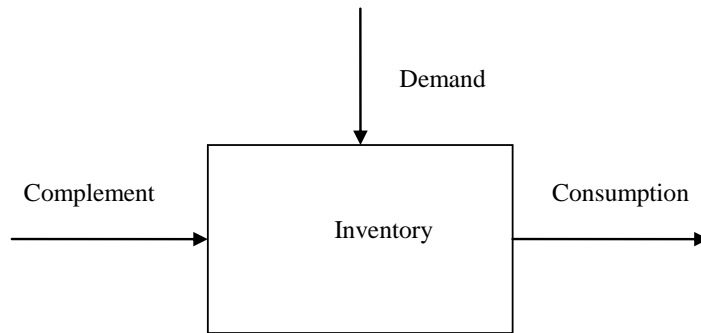


Figure 5.7 *A common model for inventory*

It is common sense that three basic element for inventory control are demand of platform, control target function of platform (determined by complement and consumption), composition of inventory. To accomplish effective and efficient inventory control, the three basic element should be attached much attention.

After comparison of various models, finally multiple random model is adopted as basis for analysis. The basic strategy of this model is (R, s, S). R is the period for next inventory purchasing. Once the stock level is less than s, ordering is implemented until of level of S. This mode is build on the basis of EOQ (economic ordering quantity) model.

Building of inventory model is separated into two phases. Through the analysis and reorganization of inventory, (R, S) model is initially build as a basis for further step. After initial optimization of inventory, according to the present conditions of inventory, (R, s, s) model is built further to regulate subsequent inventory management and spare parts ordering.

To face the stockout of emergency, maintenance manager always set aside some safety stock. A premium balance should be made for safety stock. The safety stock is the S in the model of (R, S). Generally, complement period of offshore spare parts is one year, which is inventory control period we always use. After identification of value of R, how to identify safety stock S in a scientific way is the key issue. After calculation of average consumption level during fixed time, safety factor is brought in to specifically describe it.

Inventory index is also utilized to compare the optimization results as below.

Annual safety stock: $S = \beta * (\text{accumulative spare consumption in five years} / 5)$

Present inventory index: $k = \text{present spare parts stock} / \text{annual consumption of spare parts}$

Ideal inventory index: $K = \text{present spare parts stock} / \text{annual safety stock } S$

5.3. Optimization of inventory

Based on the model of compressor spare parts data, some methods of optimization of inventory is give as follow:

According to the different consumption period, life cycle, different purchasing and storage strategy should be used accordingly. Thus they have different optimization methods. Complying with the classification of critical inventory, it is separated into two kinds of inventory, that is consumable and not frequently used spare parts.

5.3.1. Inventory management of consumable

For an ideal inventory, optimum inventory index should be 1. When it is in the reality of safe production, some extra modification should be considered. Maintenance and repair is a systematic job. It requires involvement of every personnel on site. Professional engineers should have a thorough analysis of each spare part in stock and then identify the safety factor β and inventory index. After comparison of k and 1 , k and K , visual inventory screen is made as figure below.

物资编码	备件描述	仓位号	五年内消耗备件数量	年均使用数量	理想安全库存	实际存量	帐外存量	当前库存状态指数k	理想库存状态指数K	库存视窗	所属专业	备注
80969117	名称:STL.GASKET;型号:20.56	0204E08A	13	2.6	4	13	3	6.1538	4	黄色	机械	返陆共享12个
80969128	名称:DISK VALVE SEAT;型号:	无	5	1	1	0	0	0	0	红色	机械	需采办1个
80969161	名称:GASKET,RET;型号:10.13	0204E18B	8	1.6	3	5	3	5	2.667	黄色	机械	返陆共享5个
80969164	名称:GASKET,RET;型号:150.5	0204E18A	8	1.6	3	4	0	2.5	1.333	黄色	机械	返陆共享1个
80969258	名称:Piston ring,20-1/8K:C,D,N	0204F01A	8	1.6	6	15	12	16.875	4.5	黄色	机械	返陆共享21个
80969644	二级排气阀片	无	80	16	12	12	0	0.75	1	绿色	机械	
80970078	一级进气阀片	无	120	24	18	22	0	0.9167	1.222	绿色	机械	
80970086	一级排气阀片	无	120	24	18	11	0	0.4583	0.611	绿色	机械	
80970088	二级进气阀片	无	80	16	12	15	0	0.9375	1.25	绿色	机械	
80969132	名称:WEAR BAND;型号:20-1/8	0204E07A	9	1.8	3	4	0	2.222	1.333	黄色	机械	
80969146	PISTON RING;20-1/8 K; C;	0204F01B	12	2.4	6	14	0	5.8333	2.333	黄色	机械	返陆共享8个
80969148	名称:STL GASKET;型号:12.93	0204E13A	7	1.4	3	21	4	17.857	8.333	黄色	机械	返陆共享22个
80969157	名称:PISTON RING;型号:12-1/7	0204E06B	25	5	6	4	0	0.8	0.667	红色	机械	需采办2个
80969171	名称:STL GASKET;型号:6.623	0204B16C	104	20.8	24	44	0	2.1154	1.833	绿色	机械	
80969174	名称:VALVE PLATE;型号:148C	无	8	1.6	12	0	80	50	6.667	黄色	机械	修旧利废消耗24,共享44个
80969179	名称:WAFER SPRING;型号:17	无	80	16	120	0	220	13.75	1.833	黄色	机械	修旧利废消耗100
80969180	名称:CUSHION PLATE;型号:17	无	50	10	18	0	256	25.6	14.22	黄色	机械	修旧利废消耗36,共享202个
80969182	名称:WAFER SPRING;型号:14	无	70	14	120	0	189	13.5	1.575	绿色	机械	
80969183	名称:CUSHION PLATE;型号:14	无	12	2.4	18	0	185	77.083	10.28	黄色	机械	修旧利废消耗36,共享131个
80969184	12PT;5/8-11x2-1/4x3/4 1/FC	0204C14A	6	1.2	2	7	0	5.8333	3.5	黄色	机械	返陆共享5个
80969185	BLOW-OUT DISC;3250 PSIA	0204D14C	11	2.2	4	38	0	17.273	9.5	黄色	机械	低费用物资,保持现状

Figure 5.8. Consumable spare parts data for compressors

k value can be adjusted according to the real-time data. Comparison of present inventory index k and ideal inventory index K is made as below,

- k is close to K : reasonable stock, stock screen is green.
- k is far smaller than K : insufficient spare parts, minimum safety stock alarm, stock screen is red, in need of ordering spare parts.
- k is far bigger than K : spare parts, stock screen is yellow, in need of decreasing spare parts.

Through data collection and stock screen, it is visual to understand the status and take actions. Material coordinator and maintenance planning engineer can coordinate with machinery engineer, electric engineer and instrument engineer. Safety stock then would be got by use of data analysis and respective criticality. Corresponding orderings will be made and it would save a huge amount of money. At the same time, it would also save great efforts of evaluation for platform management. It could lead to the decrease of transportation expense of logistics as well.

5.3.2. Not frequently used inventory optimization

Low usage frequency is the direct factor that leads to low inventory control efficiency. Using compressor spare parts as an example, turnover rate η is **annual spare consumption expense/total stock expense** = 237758/1308058 = 18.2%. It can be concluded that huge number of spare parts are not effectively used.

For the not frequently used spare parts, it is not a reasonable method to use dynamic index to monitor the inventory. Assuring the reliability of critical equipment is the premise for sound inventory control. After getting the value of safety stock S , improper stock could be determined and resort to proper optimization methods. Recommendations for low usage frequency spare parts are listed in the below figure. Not used spare parts in the last five years are displayed as the below figure.

物资编码	备件描述	仓位号	五年内消耗数	年均使用数量	历史采购数量	理想安全库存	实际存量	帐外存量	物料状态	所属专业	备注
80969127	名称:SUCTION VALVE SE	无	2	0.4	0	6	0	10	机械	机械	返陆共享4个
80969250	名称:R.T.D. MAIN BRG.W/	0204B15C	2	0.4	4	2	2	0	仪表	仪表	
80969283	PRESS GAUGE/A-0261		2	0.4	0	2	0	0	仪表	仪表	购买2个
80969284	名称:FFLUBR PUMP 3/8 P	0204C02A	2	0.4	0	2	8	0	机械	机械	返陆共享6个
80969298	名称:STL GASKET;厂家部	0204B17A	1	0.2	0	1	1	0	机械	机械	
80969442	件生气压缩机预滑油泵	无	1	0.2	1	1	0	0	机械	机械	需采办1台
80970579	BLOW-OUT ASSY SPECI	无	2	0.4	0	0	0	0	机械	机械	与物资80969185通用, 停止库存
80935492	名称:PRESSURE SWITCH;	无	2	0.4	0	1	0	0	仪表	仪表	购买1个
80969130	名称:WEAR BAND;型号:12	0204E11A	4	0.8	10	4	5	0	机械	机械	
80969136	RND GASKET/2 1/4*1/32/A	无	3	0.6	0	2	0	0	机械	机械	需采办2个
80969142	名称:SUCTION VALVE SE	无	1	0.2	0	5	0	15	机械	机械	返陆共享15个
80969153	名称:GASKET;型号:SQ,5-1	0204E20B	3	0.6	0	2	2	0	机械	机械	
80969156	DNFT MAGAET ASSYA-	0204C12B	1	0.2	6	2	2	0	机械	机械	
80969165	RET GASKET/C-0593\35	0204E19A	4	0.8	6	2	2	0	机械	机械	
80969169	名称:L O FILTER ELEMEN	无	2	0.4	0	1	0	0	机械	机械	需采办1个
80969170	12DT/3/4-10*2-3/4*15/1	0204C14B	2	0.4	0	8	22	0	机械	机械	返陆共享14个
80969176	F F LUBR FILTER/150MIC/	0204C11A	3	0.6	0	3	7	0	机械	机械	返陆共享4个
80969178	MINIATURE G P RELAY/85	0204C07A	1	0.2	0		19	0	仪表	仪表	返陆共享4个
80969181	AMP TRAP FUSE/ATQ3/天	0204C08A	2	0.4	0	4	7	5	电气	电气	超出8个可与其它设备通用
80969192	名称:FUSE/BUSSMAN,3AM	0204D08C	2	0.4	0	4	7	0	电气	电气	超出3个可与其它设备通用
80969193	AMP TRAP FUSE/ATQ30/天	0204C08B	4	0.8	0	6	10	0	电气	电气	超出4个可与其它设备通用
80969201	名称:PRESS TRANSMITTE	0204C17C	3	0.6	4	2	2	0	仪表	仪表	
80969206	TEMP SWLTCH SET/410F	0204D16A	1	0.2	0	2	2	0	仪表	仪表	
80969213	0-RING/A-2688	0204D02A	4	0.8	0	2	4	0	机械	机械	低价值物资, 保持现状
80969217	名称:SUCTION VALVE;型号	无	2	0.4	0	0	0	0	机械	机械	物资已弃用, 停止库存
80969218	名称:DISCHARGE VALVE;型	无	1	0.2	0	0	0	0	机械	机械	物资已弃用, 停止库存

Figure 5.9. Low usage spare parts data for compressor

物资编码	备件描述	仓位号	库存数量	安全库存	负责专业	库存状态及处理措施	备注
80969241	INPUT MODULE\1746-1A16	0204B11A	3	1	仪表	返陆共享2	
80969242	FUSE HOLDER	0204B12A	5	2	电气	超出3个可与其它设备通用	
80969243	ANALOG INPUT MODULE\1746-1	0204B12B	1	1	仪表		
80969244	ANALOG MODULE\1746-NI04I	0204B13A	1	1	仪表		
80969245	RESISTANCE INPUT MODULE\1	0204B13B	2	2	仪表		
80969246	PUSH BUTTON\9001SKR9P1\天	0204B14A	2	2	电气		
80969247	SLEEVE BEARING\B-0772	0204B14B	4	2	机械	返陆共享2	
81029428	SLEEVE BEARING\B-0787\天	0204B14C	2	1	机械	返陆共享1	
80969248	THRUST PLATE BZ JGH: E: K	0204B15A	4	2	机械	返陆共享2	
80969272	GREEN PILOT LIGHT\天然气压	0204C03A	10	4	电气	超出6个可与其它设备通用	
80969209	RED PILOT LIGHT\9001-SKP	0204C04A	18	8	电气	超出10个可与其它设备通用	
80969210	WHITE PILOT LIGHT\9001-S	0204C06A	18	8	电气	超出10个可与其它设备通用	
80969281	PHSH BUTTON\SQUARE INDI	0204C06B	7	3	电气	超出4个可与其它设备通用	
80969282	FUSE\MDA-5	0204C07C	10	4	电气	超出6个可与其它设备通用	
80969274	FUSE\FNQ-4.4-AMP\FNQ4	0204C08D	10	4	电气	超出6个可与其它设备通用	
80970391	CABLE\1761-CBL-AM00	0204C09A	1	1	电气		
80969151	STRAIGHT GREASE FITTING\A	0204C09B	4	2	机械	返陆共享2	
80969152	O-RING\VT\A-0030\天然气压	0204C10A	10	5	机械	返陆共享5	
80969316	O-RING\A-0030	0204C10B	4	2	机械	返陆共享2	
80969135	SPRING RETAINER\A-3148	0204C10C	2	2	机械		
80969162	F F PUMP TRABOV SPRING\A-	0204C10D	6	6	机械		
80969175	BUBR FIL TER KIT\150MIC\A	0204C11B	8	4	机械	返陆共享4	
80969137	BLDW-OUT ASSY SPECIFY DI	0204C11C	2	2	机械		
80969172	PLUG PLASTIC\A-2570	0204C12A	10	4	机械	低价值物资, 保持现状	
80969145	THERMOSTATIC VALVE\AMOT\A	0204C12C	4	2	机械	返陆共享2	
80969286	GASKEY WITON\A-5289	0204C13A	2	2	机械		

Figure 5.10. Unchangeable spare parts data for compressors

5.3.3. Optimization methods for redundant inventory

- Due to spare type change or updating, some spare parts could not be used by the platform any more. Besides, most of them do not have much value for repair. For these spare parts, returning back to land warehouse for the use of other department is a sound solution.
- For some spare parts like fuses, signal lights, pressure switch and thermometer, they always could be used after some necessary changes. They could be shared with other department even platforms to optimize the present inventory.
- Platform managers could make the most use of these low usage frequency spare parts. They could be used for training some trainees and make contribution to human resource management.
- After some necessary function tests, certain spare parts can be regarded as no use spare parts and refer to scrap procedure.

5.4. Repair expense analysis for spare parts

After inventory data analysis of spare parts and annual capital assets expense, it could be calculated how much has been invested on one equipment to assure reliability and dependability. These data could give great support for efficient management of spare parts. In addition, it would also sharpen the level of on-site facility control.

From 2007-2011, the annual operation expense for compressors is as below,

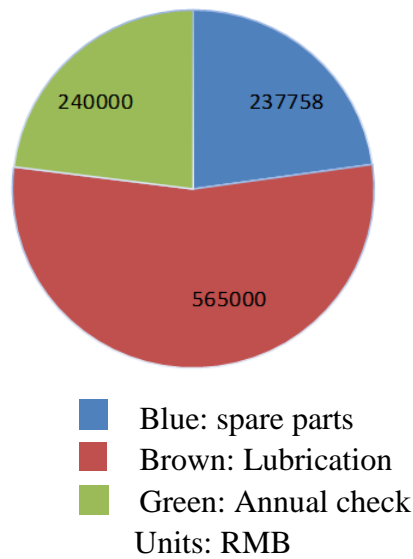


Figure 5.11. Annual operation expense for compressors

The function time of three compressors are shown in the figure below.

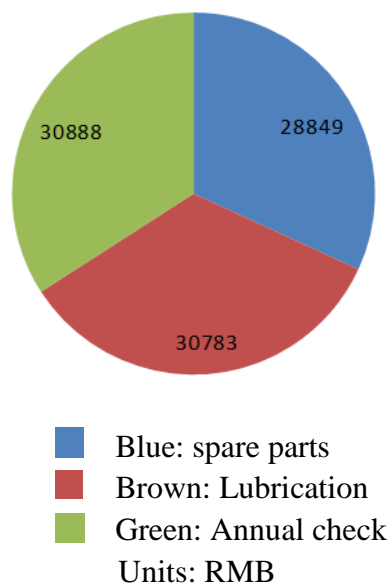


Figure 5.12. Annual operation expense for compressors

Hourly cost for one compressor could be get if total repair expense for five compressors is divided by total functioning time in five years.

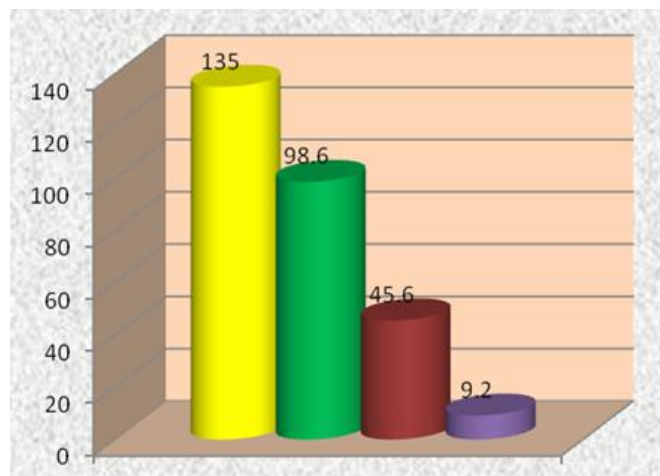
$$Q = 5 * (240000 + 237758 + 565000) / (30783 + 28849 + 30888) = 57.6 \text{ RMB}$$

Q is an average value during some time. It could somehow reflect operation and maintenance level of one compressor. Similarly, it could provide some statistic support for condition monitoring, maintenance planning and relevant cost allocation.

Sometimes the Q value is provided to manufacturing factories or plants. After comparison of compressor data from other factories, economic and mechanic appearance could be concluded. Furthermore, sharing of relevant data and high quality coordination with experts could force us to dig into the difference and improve the on-site inventory management level backwards.

5.5. Inventory analysis result

After above analysis, present status of inventory and underlying problems could be vividly seen. Here we only use specific example of compressors to demonstrate it.



- Present inventory
 - Inventory cost after analysis and reorganization
 - Inventory that should be sent back land base
 - Demand for purchasing
- Units: Ten thousand RMB

Figure 5.13. *Inventory reorganization result (compressor as an example)*

6. One specific spare optimization example

Spare optimization is process of optimizing spare. Different companies have their own procedure for spare optimization. SKF is a leading global technology provider regarding bearings and units, seals, mechanics, services and lubrication systems. SKF offers a full range of services to both OEM and aftermarket customers around the world, in every major industry, at each phase of the asset life cycle. They have one world-class spare optimization procedure.

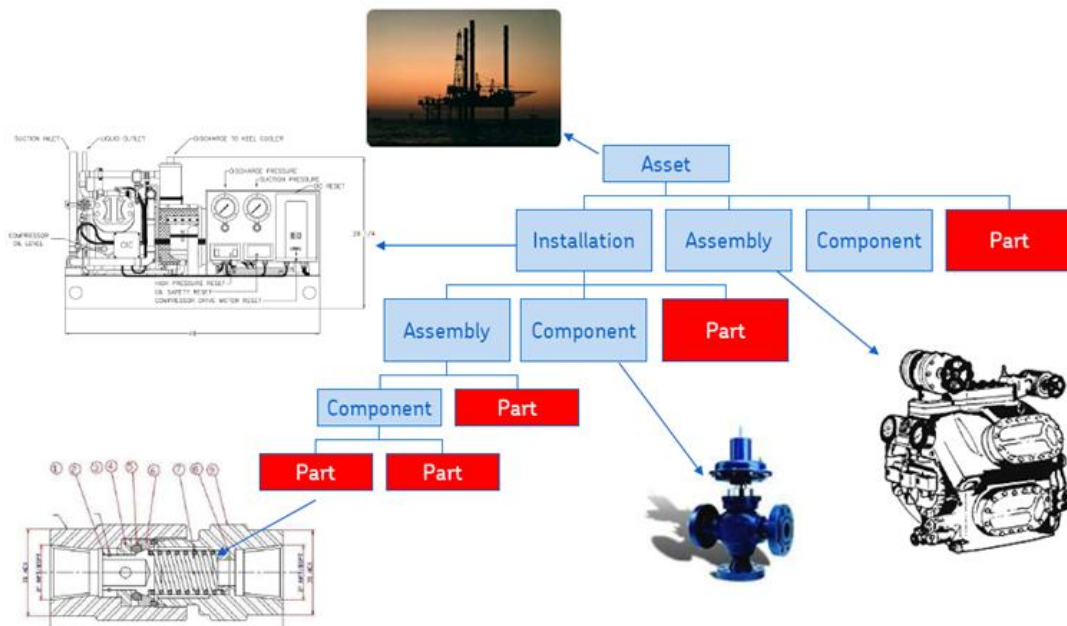


Figure 6.1. Spare part in modern industry (Source: SKF.com)

SKF has a systematic step for spare part management. In SKF, spare part management are separated into four steps, that is spare demand normalization, spare part forecasting, inventory evaluation and inventory optimization.

In the chapters before, the importance of spare parts management is clarified and stated. For the offshore platform, it is especially significant to have an efficient and effective spare parts analysis and take corresponding actions. After the theory discussed before, let us use a systematic example to demonstrate how to optimize the inventory and spare parts.

6.1. Spare analysis

Spares are one of the most important resources for operation and maintenance. Spare management affects availability of production, costs and profits. The spare costs can be grouped in several elements. Generally it includes ordering, purchasing, holding and operation downtime. The spare analysis is based on the principle of minimum of total spare-related cost.

6.1.1. Analysis Process

The analysis includes the following steps:

- Set up assumptions and limitations
- Collect equipment data from SAP
- Collect spares data
- Identify essential spares for drilling operation
- Evaluate the spare costs based on the present spare management strategy.
- Recommend optimal reorder point and order size.

6.1.2. Spare analysis assumptions

The following assumptions have been used for the analysis:

- ◆ All costs in US Dollars
- ◆ All spares are non-repairable
- ◆ All spares are located on rig's warehouse.
- ◆ There is only one piece of each spare installed per equipment
- ◆ Spares criticality is set according to equipment criticality

Relationship between criticality of spares and loss of drilling operation due to out of spares is:

- Criticality 1 No effect on drilling operation
- Criticality 2 50% loss of drilling operation
- Criticality 3 100% of drilling operation

Delivery time dependent of spare criticality and ordering type:

Criticality	Order Type	Delivery Time
3 – High	UAF	2 days
2 – Medium	CAF	2 weeks
1 – Low	OF	6 weeks

6.2. Spare data collection

In the text above the objective of estimating spare costs and recommending optimal reorder point and reorder size is well discussed. To ensure this objective, some data is always required as follow:

- ◆ Spares criticality
- ◆ Spare data: price, delivery time and consumption rate
- ◆ Link between spare and equipment where spares are installed and number of spares installed

6.2.1. Spares Criticality

Due to lack of required spare, Spares criticality affects the downtime cost. At the

same time spare criticality is determined according to the equipment where the spares are installed. Equipment criticality was assessed in earlier studies.

Totally main equipment units are received for Drilling rig ###, which were classified as high (3) criticality.

6.2.2. Spare Data

Spare data was received in Excel spreadsheet format. The datasheet always contains the spares with spare ID, description, vendor, price, delivery time, reorder point and order quantity.

6.2.3. Link Between Spares and Equipment

A BOM (Bill of Materials) list was identified to create a link. It is between spares and equipment. It contains many records with the following data:

- ◆ equipment no
- ◆ equipment description
- ◆ criticality
- ◆ spare no
- ◆ spare description
- ◆ Material group no
- ◆ Unite price
- ◆ Current Stock
- ◆ Present reorder point
- ◆ Present reorder size

6.3. Analysis and discussion

6.3.1. Criticality Classification of Equipment

Spare criticality was determined according to the importance of the equipment units. The spares are installed on these units. When a same spare is installed on more than one equipment unit, the highest criticality is used to make the analysis.

Criticality classification of equipment was performed earlier for maintenance strategy analysis.

Three criticality classes were defined:

- 1 – No effect
- 2 – Loss of 50% of drilling operation
- 3 – Loss of 100% of drilling operation

6.3.2. Identification of Critical Spares

Spare criticality is assigned according to the criticality of the equipment units. Some spares are installed on these equipment units. If a spare is installed on more than one unit, the highest criticality among the units will be assigned to the spare.

In this project, only critical spares are analyzed. The spares with low or medium criticality shall be handled using different approaches. We could list the essential spares in the next step.

6.3.3. Spares Holding Analysis

After having identified critical spares, spare holding analysis was performed. The task of the analysis was to estimate spare related costs and back-order losses under the current spare holding strategy and to recommend optimal reorder point and order size in order to minimize the total spare-related costs.

The spare related costs and losses are:

- Capital binding cost
- Ordering cost
- Holding costs: Storage and preservation
- Back-order cost (deferred production)

To estimate spare related costs, the following parameters were required:

- Criticality
- Unit price
- Delivery time
- Spare consume rate
- Repairable or consumable

The consumption rates were estimated for each spare group using the operation and maintenance practice.

6.3.4. Cost Estimate of the Present Warehouse

The current reorder point and order size were used to estimate spare costs under the present warehouse on the basis of the stock list. The spare costs of the present warehouse practice were estimated and detailed.

6.3.5. Recommendation of Optimal Reorder Point and Order Size

The spare holding optimization is a process to recommend an optimal reorder point and order size that could minimize the total spare-related costs. The personnel uses software to achieve it. The program calculates all the spare related costs and assumptions and repeats reorder points and order sizes. It is carried out until the total spare cost reaches to the minimum.

6.3.6. Comparison of Spare Costs of Present and Recommended Warehouse

The table below shows the annual spare cost for both the present warehouse and the recommended reorder points and order sizes. It can be seen that the recommendation may save over 69 % of the present spare related costs. The main saving is the reduction of loss operation due to back-ordering, which is over 93 %.

6.4. Spare analysis summary

Herein a spare analysis was performed for one drilling rig. This study was to identify critical spares for rig operation and to recommend reorder point and order size for identified spares. Therefore the total spare part cost could be minimized.

After spare analysis, some main equipment units with high criticality could be identified. The relevant spare parts for critical equipment could be identified further. The main conclusion remarks could be stated as follows.

“33 main equipment units with high criticality (3) were identified. 914 spares were linked to the critical equipment for ### drilling operation. They were analysed in the study. ”

“The estimated spare related costs for 914 spares are summarized in the table below (the currency is US\$). It can be seen that the recommendation may save over 69 % of the present spare related costs/losses. The main saving is the reduction of loss operation due to back-ordering, which is around 94 % . ”

7. Summary and concluding remarks

The purpose of main objective of this research is to propose an effective method to manage spare parts during operations in the Bohai Bay. Thus a more effective and efficient spare parts management model could be set for actual use in the Bohai Bay. From the problem description in chapter 1.2 the following sub-objectives were formulated:

- Finding one systematic theory for spare parts management.
- Finding an appropriate model or criteria to optimize the spare parts.
- Finding proper series of offshore spare parts management procedures.

Spare parts management plays a critical part in the Oil and gas (O&G) industry. Traditional asset management could not meet the requirement of present equipment. Due to the complexity of inventory plus limitation of offshore platform, it is one complicated issue to accomplish effective and efficient inventory control for offshore operation. Having reasonable inventory is crucial for improving the continuous efficiency for spare parts and decreasing the maintenance budget, especially for the offshore operations.

It has been widely accepted that spare parts and inventory management is one crucial issue for maintenance management. Due to limited operation space and warehouse capacity plus harsh environment factors, it is imperative to set up a practical spare part management procedure for offshore platforms.

Inventory analysis requires one criteria to optimize the spare parts stock. Most commonly used models for inventory are spare parts value-usage, criticality, frequency of demand. The combination of management policy and mathematical model is very complicated for the maintenance management. It needs too much mathematical knowledge and is not very efficient in spare parts analysis. Thus one classical model for analyzing the spare part demand is ABC model.

A specific example of platform in the Bohai Bay is used to demonstrate the spare parts management condition more specifically. Through systematic inventory analysis, unchangeable spare parts in the last five years account for 35.5 percent. It is mainly composed of spare parts of turbine, compressor, and crane.

After the analysis of present inventory, several descriptions are noted as follow:

- Unchangeable inventory
- Safety stock need to be adjusted.
- Inappropriate inventory composition, some spare parts are stored too much while some are too less.
- No good purchasing period and huge fluctuation.

According to the different consumption period, life cycle, different purchasing and storage strategy should be used accordingly. Thus they have different optimization methods. For the platform in Bohai Bay, it is separated into three kinds of inventory, that is consumable and not frequently used spare parts and redundant inventory. Optimization of the three kinds of inventory is carried out accordingly.

After inventory analysis and reorganization, spare parts on the platform are optimized and it saves much budget and space for platform.

For offshore operation, spare parts management normally consists of several steps: Spare demand normalization, spare part forecasting, inventory evaluation and inventory optimization.

After setting up assumptions and relevant limitations, the data for spare parts and equipment would be collected from SAP system. Next essential spares for offshore operation would be identified through criticality analysis. The links between spares and equipment would be evaluated at the same time. After this, the spare parts costs based on the present spare management strategy would be calculated. At last optimal reorder point and order size would be recommended accordingly.

8. Future research

Based on the findings in this thesis, some suggestions for future research are proposed:

- Development of a simple and practical model for distribution of spare parts
- Logistics related with the equipment, spare parts and consumable
- Logistics related with maintenance and operation personnel
- How to find out the trade-off point during transportation and delivery

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