Vikash Kumar

Recommendations to Improve Spare Parts Forecasting for New Model.

Metropolia University of Applied Sciences

Master's Degree

Industrial Management

Master's Thesis

03 May 2023

Preface

It is a real feeling of achievement for me to complete the thesis alongside my full-time job. When I got my job in Finland, I decided to start my studies again after 13 years of a bachelor’s in mechanical engineering. It gave me a chance to obtain professional knowledge and skills for my career.

I want to express my sincere thanks to my supervisor, Dr. Thomas Rohweder, for his superb guidance and assistance throughout the journey. I want to thank M.A. Sonja Holappa for helping me choose appropriate words and corrections. And the outstanding lecturers from the Industrial Management study program, Dr. Juha Haimala, and Dr. Jarmo Toivanen. In addition, I want to thank all of my classmates for our successful group projects and their invaluable peer support. Especially, Mr. Prabin Sharma for letting me enjoy our class-related car drive from Tampere to Helsinki. Throughout the journey, kept encouraging one another to finish the assignments and thesis on time.

Special thanks to my case company colleagues Mr. Shivpratap Singh, Mr. Mahendra Suthar, and Mr. Juho Jarkkala for their availability and active participation in discussions to keep morale high and suggested the right direction at each turn. They have been supportive and have offered their advice based on their knowledge and experience to assist me in reaching my objective.

I would like to express my love and respect to my mother, Mrs. Sunita Singh, who was supporting and appreciated my efforts during my studies, even though she is not with me here in Finland.

Thanks to my wife Vineeta Singh and my son Vasu Singh, who supported me and always allowed free space for my studies.

Vikash Kumar
Tampere
May 03, 2023

Abstract

Author:	Vikash Kumar
Title:	Recommendations to Improve Spare Parts Forecasting Process for New Model
Number of Pages:	99 pages + 7 Appendices
Date:	03 May 2023
Degree:	Master’s Degree
Degree Programme:	Industrial Management
Supervisors:	Dr. Thomas Rohweder, Principal Lecturer

The objective of the thesis is to provide a final recommendation to improve the spare parts forecasting process for the new model of heavy off-highway equipment. The case company has been facing challenges in the availability of spare parts for the new models in the aftermarket business, especially at service contract sites. The thesis has been focused on the spare parts forecasting process for the service contract sites.

The research approach of this study is design research, and the study includes four stages. The first stage is a current state analysis to gather the strengths and weaknesses of the current state of the spare parts forecasting process for the new model. The second stage is a literature review of the existing knowledge and best practices based on the identified weaknesses and compiled into the conceptual framework. The third stage is a co-creation effort of the initial recommendations for spare parts forecasting, utilizing the outcomes from the previous stage. The fourth and last stage is a validation round of the initial recommendations by the senior management and stakeholders, who provide feedback to finalize the spare parts forecasting recommendations.

All weaknesses in the current state analysis were categorized into four different sections: spare parts classification, spare parts life calculation, annual maintenance plan, and performance measures. The initial recommendations in each section have the potential to improve the whole process of spare parts forecasting and spare parts availability for the new models in the service contract.

The stakeholders from different businesses and divisions were involved in the final evaluation and validation of the initial recommendations. These stakeholders are also responsible for the implementation of the recommended actions in each section. The outcome of the study, the recommended actions in each section, and their implementation will allow for improved spare parts forecasting for the new model. It will improve spare parts availability and increase machine availability at the service contract sites for the new models.

Keywords:	Spare parts forecasting, Maintenance planning, Inidcative operative cost, Spare parts life value

Contents

Appendices

List of Figures

List of Tables

List of Abbreviations

OEM:	Original Equipment Manufacturer
CSA:	Current state analysis
AMC:	Annual maintenance contract
CPH:	Cost per hour
RSPL:	Recommended spare parts list
SSL:	Strategic stock list
NPD:	New product development
LCM:	Lifecycle management
IOC:	Indicative operative cost
SOP:	Standard operative procedure
BOM:	Bill of materials
TC:	Teamcenter (Eng, software)
PMO:	Project management office
RTU:	Ready to use
SRU:	Service replacement unit
TSD:	Technical Service Desk
CSA:	Current state analysis
VSM:	Value stream mapping.

1 Introduction

Off-highway heavy equipment manufacturing company, spare parts forecasting, and inventory stocking are the most important process to make the new model entry into service successful in the market. New technologies and innovations in the off-highway heavy equipment manufacturing industry and the operational conditions at the site make spare parts planning a more critical process for original equipment manufacturers (OEMs) and customers.

An effective spare parts forecasting process allows new off-highway heavy equipment models to enter operation with sufficient spare parts as per operation, increasing the uptime of the machine and, at the same time, increasing the production of the site. A good spare parts forecasting process reduces inventory costs and allows for effective planned maintenance for the customer.

The key element of an effective spare parts forecasting process is having the correct quantity of spare parts at the correct time. It ensures that mining and quarry operations are operational in an efficient manner, and businesses can continue with the planned production and maintenance.

In a mining and quarry operation, the production cycle is interdependent on each machine operation, and one key machine breakdown can cost millions an hour. Spare parts unavailability at the site on time can lead to bigger problems and turn into big losses. On the other hand, keeping too many spare parts also increases the inventory level, and slow-moving items and surplus parts can lead to dead stock, which increases the inventory level and total operational cost of the machine.

This study focuses on the efficient spare parts forecasting process by reviewing the latest spare parts forecasting processes and tools used for it and determining the most suitable and adaptable process as per case company resources and new model operations at the site.

1.1 Business Context of the Case Company

The case company is a global, high-tech engineering group with more than 150 years of experience in off-highway heavy equipment manufacturing and strives to provide off-highway heavy equipment to customers with optimal solutions designed to increase their productivity and reduce their total cost of ownership—while ensuring reliability, efficiency, and safety through high technology.

The case company sells equipment globally to different countries, mine sites, and individual customers and provides aftermarket support through a broad offering of genuine spare parts and components covering the complete lifecycle of the machine. To support the parts business and spare parts availability by reducing the lead time, the case company has three central warehouses globally. Regional warehouses in each country get support from the central warehouse, and local case company warehouses (near site locations or industrial areas, where transportation is easy) and customer site warehouses get support from the regional warehouses.

Being a leader in innovation and technology and serving the fast-changing operational scenario and requirements of mining customers, the case company focuses on developing new products and services that help customers in every corner of the world mine safer and more profitably. Every year, the case company launches a new model in the market with new technology and innovative solutions. These machines go to the different sales areas: mining, tunnelling, and hydro project sites. For the new models to make a successful entry into the market and maintain efficiency and a low cost of operation, an efficient spare parts forecasting process is crucial.

1.2 Business Challenge, Objective, and Outcome

Due to the maintenance team’s experience and understanding of the legacy machines’ spare degradation rate as per operation and historical data of spare parts used in legacy machines, spare parts availability is accurate, and the

process is well adopted within the supply chain of the parts supplier, OEM, and customer. Customers have also developed the planned maintenance strategy and spare parts order points as per requirement and lead time of the spares, which keep the high uptime of their machine and reduce the production loss due to the unavailability of the spares at the site.

In the past few years, the case company has developed and launched new models of off-highway heavy equipment in different sales areas. At a few sites, the case company faced the challenge of a shortage of required parts on time. The case company was unable to help customers due to an emergency order and not forecasted. The high lead time of the spare parts supplier to the case company, resulted in a huge loss in customer production and raised the question of the reliability of the new model and the spare parts forecasting process.

New models with new technologies are designed with high-tech electronics spares, sensors, and modified mechanical structures and components. These spare parts and components have been developed by the manufacturer of the part (the supplier of the case company) for different applications, including mining equipment. There is no visibility of spares consumption, no accurate data on the life of spares in mining applications, and a lack of understanding of machine behaviour throughout the lifecycle raises the question of the maintenance program for the new model and spare parts forecasting to support maintenance.

The spare parts forecasting process needs to be effective to support customer operations. In the spare parts forecasting process, the main stakeholders are the customer maintenance team, the customer inventory team, the case company service and after-market team, and the logistics inventory/order desk team. Spare parts forecasting is supported by data, lead time, and availability provided by the order desk and the customer's maintenance plan as per their operation on-site case company has a service contract, such as an annual maintenance

contract (AMC) or Cost per hour (CPH) then the maintenance plan is the responsibility of the case company and the whole process of spare parts forecasting is part of the contract.

In this study, the author is part of the lifecycle management team and will consider one new model for this study. The study covers a few sales areas where this model has been delivered since 2022. These sales areas have no experience with the new model operation and its maintenance plan. SA team must have an effective spare parts planning process to support the customer.

The objective of this study is to recommend improvements for the existing spare parts forecasting process for the new model, and the outcome of the study is the spare parts forecasting process improvement recommendations for the new model. The outcome will allow the case company to support the customers with the required spare parts available at the correct time as per their maintenance plan and production plan.

1.3 Scope and Outline of Study

This study does not include the implementation of the improved spare parts forecasting process in the sales area and equipment division. It is limited to analysing the current state and developing the spare parts forecasting process for the new model at the case company.

This study consists of seven sections. Section 1 is the introduction of the case company, the business challenge, and the outcome of this study.

Section 2 describes the methods and tools used for the study, the research approach, the research design, and the data plan.

Section 3 describes in detail the current state analysis of the existing spare parts forecasting process in the case company.

Section 4 focuses on the recent efficient spare parts forecasting process by reviewing the latest literature and determining the most suitable adaptable able process as per case company resources and mining industry operations.

Section 5 describes the proposed process to improve the spare parts forecasting process for the new model in the case company, based on the current state analysis and the literature examples from Sections 3 and 4, respectively.

Section 6 validates the initial recommendations for spare parts forecasting process improvement based on stakeholder feedback.

Section 7 summarizes the thesis work and self-evaluation of the study.

2 Research Plan

Research methodology is the science of understanding how a researcher systematically designs a study to ensure valid and reliable results that address the objective of the thesis topic. It defines which research approach will be taken and why, which technique will be followed to collect data, what data to collect to support the research, and how to analyse it by choosing the correct technique and method. Research methodologies reflect the process and justify the selected methods and analysis. A set of principles and ideas that inform the design of a research study (Birks & Mills, 2011, p. 4).

Academic research follows different types of research methods, depending on the objective, and aim of the research.

2.1 Basic and Action Research

Basic research: Basic research is conducted without any specific decision in mind. Basic research is an investigation into the basic principles and reasons for the occurrence of a particular event, process, or phenomenon. It is also called theoretical research. The study or investigation of some natural phenomenon relating to pure science is termed "basic research." Basic research sometimes does not lead to immediate use or application. It is not concerned with solving any practical problems of immediate interest. (Habib & Pathik,2014,p.6)

Action/Applied Research: Applied research examines a specific set of circumstances, and its goal is to relate the results to a particular situation. Action research is the study of a problem that is related to existing processes, methods, and management in an organization or industry. Researchers solve this existing problem with the existing knowledge and research. (Habib & Pathik,2014, p-6)

Action research is participatory and collaborative, and it develops reflection based on the interpretations made by participants and the observations made by the researcher.

In action research, the researcher could be part of the team or group related to the defined problem. Research findings can be applied immediately to improve the situation. Action research is concerned with actual problems such as business processes, supply chain issues, logistical challenges, health care hospital problems, and so forth, Kemmis and McTaggart (2000: 595) describe it as "participatory research."

2.2 Qualitative and Quantitative Methods

Traditionally, research methodologies are broadly classified into qualitative and quantitative, especially in the social sciences. (Onwuegbuzie & Leech, 2005)

Qualitative method: is geared towards creating a complete and detailed description of researcher observation (Macdonald et al.,2008, p-9). The qualitative method depends on observations and descriptions. It is subjective and descriptive based on the smaller number of carefully chosen and relevant respondents. This kind of method is used to access the knowledge, attitudes, behaviour, and opinions of people depending on the topic of the researcher. In this type of study, the researcher's opinion and experience are not allowed to be used for any conclusion or solution.

Quantitative method: This approach is often used by researchers who follow the scientific paradigm (Haq, 2014, p.1). This research involves the collection of data, sample size, changing those data into numeric, form, and analysis of the data to conclude the result. In this research data quality is an important aspect along with the sample size of the relevant group determining which formula and methods will be used to validate the theory or hypothesis. It follows a structured data collection process, with data output in the form of numbers. In today’s digitalization and data-driven market, the quantitative research method is the most used.

2.3 Research Design

This research targets real organization challenges, and the objective is to recommend improvements for the existing spare parts forecasting process for the new model in the case company. As per the literature and discussion, action research will be most suitable to serve the objective of the research, and the outcome will improve the knowledge of the case company. Knowledge from this study will focus only on the specific challenges and weaknesses in the case company and will be drawn from the existing professional and research literature; it will be new knowledge in its context.

As the researcher is closely involved in the study and is part of the case company, a qualitative research approach will be more relevant. which allows the researcher to find the issues that are often missed by other approaches. Qualitative research is conducted to get the answer to research questions that specify a problem or question. Qualitative research represents attempts to identify why something happens, what causes some event, or under what condition an event occurs. (Sam Goundar, 2012, p. 23).

In addition to insider information from the case company, the researcher uses secondary sources. Secondary sources are information from scientific articles, journals, books, public data, and Internet sites (Habib, Pathak & Maryam, 2014, p. 4). For this research, the secondary data sources were obtained from public and informational data on the used spare parts forecasting process (off-road heavy equipment manufacturing), business literature, articles, websites, and Internet-based sources.

Table 1:Research Design

RESEARCH DESIGN	STAGE1	STAGE 2	STAGE3	STAGE4
OBJECTIVE	Recommendation to Improve Spare Parts Forecasting Process for New Model			
SATGE	CURRENT STATE ANALYSIS	LITERATURE REVIEW	INITIAL RECOMMENDATIONS CREATION	VALIDATION OF INITIAL RECOMMENDATIONS FOR SPARE PARTS FORECASTING PROCESS FOR NEW MODEL
DESCRIPTION	Analysis of the current spare parts forecasting process of new model	Best practice of spare parts forecasting for the new model	Co creation of initial recommendations for spare parts forecasting process improvement for new model	Validation of the initial recommednations for spare parts forecasting process improvement for new model
DATA	DATA 1		DATA 2	DATA 3
DATA /LITRATURE SOURCE	Existing process documents Value stream mapping Voice of customer Observation	Literature Articles Consultant documents Mining Industry journals	Development workshop Interview	Management Interview Sales area stakeholders interview Customer interview
OUTCOME	Summary of the CSA findings. strengths and weaknesses in the present spare parts forecasting process.	Concepts, methods, and tools for the present process have weaknesses..	Initial recommendations for spare parts forecasting process improvement for new model	Final recommednations for spare parts forecasting process improvement for new model

As seen in Table 1, this study contains four stages to review and decide on the relevant solution for the spare forecasting process of the new model. The first stage is the current state analysis (CSA) of the spare parts forecasting process for the new model in the case company along with available existing documents related to the spare parts forecasting, which provide information about the involved stakeholders and the strengths and weaknesses of the existing process. For the CSA, a workshop, an interview, and an email exchange are the mediums of conversation with different stakeholders.

After this, in the second stage, as per the weakness's findings in the CSA, relevant literature, research papers, and journals are summarized, and then, in the third stage, a conceptual framework is initial recommendations for the spare parts forecasting process improvement for the new model in the case company by eliminating the present weaknesses in the process. The fourth stage is the validation of the initial recommendations for the spare parts forecasting process based on the Aftermarket business unit management, logistic and inventory team, and case company service contract management feedback and critiques.

2.4 The Data Collection Process

Data collection in research is the process of collecting information and data from different relevant sources to find the answer to the research problem and evaluate the outcome. It is useful to have a systematic road map for gathering relevant and current data to answer hypotheses and research questions. (Q. Faryadi,2019, p. 773).

Primary data: is the type of data, which do not exist and is the direct drive from first-hand work that is peer reviewed and data collected directly from the sample population.

Secondary data: the type of data that already exists in the form of the available research papers, journals, books, case studies, and subject-specific available data in different official statics of an organization, industry, and researcher consultant. The collection of relevant and reliable secondary data is an extensive and crucial part of the research. Secondary data is used as a reference to compare the primary data and analyse it. (Q. Faryadi,2019, p. 773)

In both data sources, the data should be relevant and reliable. Data should be aligned with the core subject matter and not be on the periphery. The quality of

information depends on the degree of data processing that has been verified as authentic. (Habib, Pathak & Maryam, 2014, p. 4)

This study draws its data from a variety of sources, such as spare parts forecasting and aftermarket-related documentation, stakeholder workshops, and organized interviews. Three types of data are collected, respectively, in three rounds. Data 1 from the first collection round consists of the required knowledge to perform a current state analysis. Data 1 collection included exploring the existing process documentation, and observations while participating in daily, weekly, and monthly team meetings, one workshop, an email inquiry, and interviews with the process stakeholders.

Table 2 shows The Data 1 collection process for the current state analysis including internal documents examined and interviews.

Table 2: Data 1 Collection

Data 1 – Current state analysis						
Sl.no	**Source**	**Data type**	**Topic**	**Time**	**Documented**	**Remarks**
1	Aftermarket NPD gate stage model	Document (PDF file)	NPD project stage-based task for spare parts forecast.	15 Dec 2022	NPD Gate model	Pdf in Intranet
2	Parts & Service Sales Representative, Malaysia	Interview	Spare parts forecast for planned maintenance program & rebuilt	18 Jan 2023	Filed notes	Online Team meeting
3	PSSR Canada Operation readiness manager TSD team PU	Interview	Spare parts forecast for start-up and smooth operation	18 Jan 2023	Filed notes	Online Team meeting
4	Technical Offering Service Manager	Interview	NPD spare parts forecast process	24 Jan 2023	Field notes	Online Team meeting
5	Parts Specialist & Technical Service team	Interview	NPD final stage spare parts forecast process	24 Jan 2023	Field notes	Online Team meeting
6	Logistic Manager	Interview	Spare parts forecast for inventory	25 Jan 2023	Field notes	Online Team meeting
7	LCM team	Workshop	IOC creation process mapping	02 Feb 2023	Field note	Face to face
8	Asset maintenance software ,process & System specialist	Interview	Data processing	07 March 2023	Field notes	Online Team meeting

The Data 1 collection process was planned and gathered current spare parts forecasting papers that are available for analysis and observation, as shown in Table 2. The NPD aftermarket team, who are a part of the New Product

Development. Engineering and Sourcing teams oversee new product development aftermarket strategy and spare part/component decisions in the new machines and made the aftermarket New Product Development (NPD) gate stage model pdf document available.

Data 2 include interviews and workshops facilitated to co-create the initial recommendations for process improvement. four interviews and three workshops with different stakeholders in the sales area and product division were planned, as well as one workshop with the LCM team to understand the current spare parts forecasting for the new model in different sales areas. All interviews were held online, and team meetings and a workshop were done face-to-face. The following Table 3 presents the second round of data collection, Data 2 for creating the initial process improvement recommendations.

Table 3: Data 2 Collection

Data 2- Initial Recommendations						
Sl.no	**Source**	**Data type**	**Topic**	**Time**	**Documented**	**Remarks**
1	Asset lifecycle category Manager	Interview	Spare parts classification recommendations	06-Apr-23	Field notes	Online Team meeting
2	Service Operation Manager	Interview	Maintenance plan recommendations	06-Apr-23	Field notes	Online Team meeting
3	Component & portfolio manager, Sales area, Malaysia.	Interview	Maintenance plan & Spare parts forecasting recommendations	10-Apr-23	Field notes	Online Team meeting
4	Technical offering service Manager	Interview	Maintenance plan recommendations	10-Apr-23	Field notes	Online Team meeting
5	Asset lifecycle specialist ,Sales area, Canada Fleet Manager	Workshop	Spare parts life, Maintenance plan & Spare parts forecasting recommendations	13-Apr-23	Field notes	Online Team meeting
6	Global Asset lifecycle team	Workshop	Spare parts classification & Its life, Maintenance plan & Spare parts forecasting recommendations	14-Apr-23	Field notes	Face to face
7	Inventory planner, Asia Asset maintenance software, Data Analyst.	Workshop	Spare parts classification & Its life, Maintenance plan & Spare parts forecasting recommendations	17-Apr-23	Field notes	Online Team meeting

In the third round of data collection, Data 3 consists of feedback from the validation of the initial recommendations ,and the data collection is shown in Table 4.

Table 4:Data 3 Collection

Data 3- Validation of Initial Recommendations						
Sl.no	Source	Data type	Topic	Time	Documented	Remarks
1	Asset lifecycle Manager & Team	Workshop	Final recommendations for process improvement	18-Apr-23	Field notes	Online Team meeting
2	Sales Support Manager, Asia & Inventory planner, Asia	Workshop	Final recommendations for process improvement	19-Apr-23	Field notes	Online Team meeting

The final set of data was number 3. As shown in Table 4, the initial recommendations were confirmed with top management in two separate online workshops.

The findings of the current state analysis of the spare parts forecasting for the new model are presented in the following section of this study along with the Data 1 collection results.

3 Current State Analysis (CSA) of Spare Parts Forecasting Process

This section aims to provide a comprehensive picture of the current spare parts forecasting process for the new models in the sales area and analyse the current process to identify the strengths and weaknesses in the process. This section discusses the findings of the Data1 collection inputs from different stakeholders through interviews, workshops & present documents and which is explained in the previous section.

The objective of the current state analysis was to identify and engage the key stakeholders and develop a comprehensive understanding of the current state of the spare parts forecasting process for the new models in the sales area. One more important part of the same was to engage with the customer (end-user) through the sales area team and understand the gaps in the current spare parts forecasting process from the customer's perspective.

An overview of the current state analysis of the spare parts forecasting process visualization is presented in this section, followed by information on the process's inputs and their impact on spare parts forecasting.

3.1 Overview of the Current State Analysis Stage

To perform the current state analysis, the first thing was to identify the new model of the mining equipment for the thesis and the sales area by which it was purchased. the Second step was to identify the key stakeholders in the sales area, parts & service division key stakeholders, who are involved in the spare parts forecasting in the sales area.

Before stepping into the meetings with the stakeholders, this study went through the available printed process mapping documents in the divisions and on the intranet. These documents gave insight into the spare parts forecasting process for owners in different divisions and sales areas. Available documents direct me to the correct stakeholders in the equipment division responsible for spare parts

forecasting, aftermarket strategy, and then the sales area spare parts forecasting owner, spare parts planner, parts & service sales representative, and inventory planner. In different sales areas, these responsibilities fall on different people as per the sales area organization chart and fleet size.

Despite good documentation and process mapping of the spare parts forecasting, nothing specific was found directly related to the "new model" and mostly the generic spare parts forecasting process. During the analysis of the available document, the repetition of the same process in different forms was identified. To understand the real practical problems with executing the process, it was important to reach out to the responsible and accountable process owners.

Before our meeting, a detailed email was sent, and all identified stakeholders explained the purpose of the interview, and some basic open questions related to spare parts forecasting for the new models were asked. The purpose of the basic questions was to understand the stakeholder's in-depth understanding and knowledge of the subject of spare parts forecasting. Based on the answers, the stakeholders were filtered, and meetings were scheduled.

The first round of meetings was conducted with the sales areas of Malaysia, Canada, and India. The participants were interviewed online during team meetings, and in a few team meetings, the stakeholders allowed to record and transcribe, and for some, notes were taken during meetings. This data was used for the analysis in the next step.

One online workshop was held to keep the Sales area and equipment division stakeholders together to understand and analyse the current process pain points and its potential initial solutions.

The last step consisted of an analysis of the data collected through interviews and present documents, with the outcome of identifying areas of strengths and weaknesses and key findings that were used for the development of a future proposal for a new process.

3.2 Description and Analysis of the Existing Process

In process mapping documents, it is mentioned that spare parts forecasting for the new model starts during New Product Development (NPD) gates. The engineering team, with the support of the sourcing team, decides on the spare parts and components for the new models as per the application and introduces new technologies. The team prepared the Bill of materials for each machine and fed it into the Teamcentre (TC), which is visible and accessible as per the role and access rights of the Teamcentre.

After selling the machine, it is the job of the sales area to do the spare parts forecasting as per the model and operation of the machine on site. When any site or customer placed an order for the machine the sales managers inform the Parts and Service BLM (Business Line Manager) and other team members (Finance & Business Controller) about the deal. In the kick-off meeting, the sales manager needs to explain the following:

- Customer detail
- Project and Site detail
- Machine models & specifications and no. of the machine of each model
- Application of the machine(s) at site
- Expected date of arrival of each machine at the site

The sales area parts and service team, along with the inventory and parts planner, are doing spare parts forecasting for the new model. Parts& Service Sales Representatives (PSSR) request the recommended spare parts list (RSPL) from the technical service department in the equipment division (factory) and the indicative operation cost (IOC) document from the asset lifecycle team in the Parts and Service division. As per CSA, these two documents, RSPL and IOC, are the basis for whole-spare-parts forecasting for any new model in the sales area.

The technical service department prepares the recommended spare parts list (RSPL), which is based on the machine-specific serial number. RSPL consists of spare parts and component descriptions with the machine serial number and specific part numbers with quantity. These spare parts are categorized as critical, maintenance, service, and fast & fixtures and can be found in the Appendix 2. The quantity of the listed spare parts in the RSPL is showing the quantity of spare parts in the machine, not for stocking at the site.

The asset lifecycle team is responsible for the indicative operational cost (IOC) documents. These documents are model-specific, not serial-number-specific. This document has a list of spare parts categorized into the major components, service, maintenance, and critical parts categories, along with the life of each listed part. The given life values are the generic NPD phase values, given by the component’s suppliers or OEM, and are based on the ideal operating condition.

Apart from these documents, the inventory planner from the sales area's Parts & Service division requests the strategic stock list (SSL) from the Technical Service Department. This document contains a list of the high-value components categorized as insurance items, which have a high lead time. The listed parts are the critical parts that stop the machine if it fails. Due to the high lead time, the sales area team wants to keep these items in the nearest local warehouse, especially if the team has any service contracts at the site or with the customer, and for this, the team needs the approval of the sales area parts & service Business line manager (BLM) and technical service desk (TSD) team head. As per the total inventory cost, the approval hierarchy changes, and more stakeholders get involved in the process of approving SSL stockings in individual sales areas, the central warehouse, or regional warehouses. the Location of stocking also depends on many other factory-related inventory attributes and variables.

Value stream mapping of the current spare parts forecasting process for the new model can be found in Appendix 3.

To get a detailed in-depth insight into the current situation and practical tasks involved in the process of spare parts forecasting in different sales areas, following interviews and workshops held with sales area Malaysia and Canada.

3.3 Spare Parts Forecasting Process in the Sales Area Malaysia

In Malaysia, a new model has been sold, and the machine is going into operation for a small customer who is going to use this model for the first time and has no experience with such a new model. In the sales area, the technical support engineer (CSA Interview 1) is responsible for the spare part forecasting and supporting customers with the proper availability of required spare parts for smooth operation. In an interview, he explained that the sales area team also uses the same process for the new model's spare parts forecasting as for legacy model.

RSPL, IOC, and SSL are the base of the spare parts forecasting for the new models. After analysing these documents, the sales area team, depending on the customers and fleet size, ordered only maintenance items, such as filters and oil, and some critical items. The team does not have any service contracts with customers.

The RSPL list is good for maintenance and critical spare parts forecasting, and it is a serial number-specific part number. This reduces the chances of ordering the wrong spare parts from the sales area. These documents help in the selection of spare parts but do not indicate the accurate quantity of spare parts as per utilization and application. This is our own decision, which is not supported by any standard way of calculation or process.

The spare parts forecasting for the new model just depends on the average utilization of the machine and the listed components in the above-mentioned documents. The team is guessing and suggesting some spare parts and their quantity as per their own relevant experience with legacy models. The Utilization of machines keeps changing as per production targets or unavoidable situations

such as changes in site production plan or geographical challenges inside mines; however, such unexpected changes in utilization of machines create problems of either shortage of spare parts along with production loss or high inventory cost.

Getting approval for a strategic stock list (SSL) spare parts is tough, especially if the sales area doesn’t have any service contracts or a large fleet, as is the case in Malaysia for the new model. The new model is being introduced for the first time in the sales area and sold to the customer with a commitment to advanced automation and remote-control operation features, fast production, and low operation costs. The customer also took it as a test, and if it performed as promised, then the sales area team would have a chance for more orders in the future. For one single machine, huge inventories cannot be held at the local warehouse, which has a high chance of turning into dead stock in the future.

> *The spare parts forecasting process is well communicated, and teams are aligned and well-coordinated within the process. RSPL is good for maintenance, critical, and service spare parts forecasting.* (CSA interviewee 1)**.**

> *It is hard to plan major component forecasting and its quantity based on the life values provided in IOC documents, which are not actual values; all given life values are the generic NPD values, which are too optimistic. Due to this, the team cannot develop a proper maintenance program and plan parts accordingly*. (CSA interviewee 1)**.**

3.4 Spare Parts Forecasting Process in Sales Area Canada

Sales area Canada is covering different small regions and handles many mining customers. The sales area Parts & Service division has a dedicated team to serve each region and its customers. PSSR, Demand Planner, Component Forecasting and Planning, and Asset & Lifecycle Team are doing the spare parts forecasting as per business relationships with the customers, such as vendor-managed inventory, consignment stock, and service contracts. Large mine sites exist in

Canada, and some clients handle all maintenance and repair tasks independently. The team is assisted by the availability of spare parts and components based on site fleet usage and operational conditions.

An interview with Asset & Lifecycle specialist and PSSR from the sales area Canada team revealed that the team is adopting a slightly different process for the new models and relying only on the RSPL and SSL documents. A positive part for them is the availability of parts consumption data in Asset maintenance software and manually captured data from many operational mine sites with large fleet sizes, which helps them do the spare parts forecasting. In Canada, the new model has sold to a few customers, and many more will come. Considering the future upcoming machines and the increase in the fleet size of new models, the team can have a strategic stock list (SSL) of listed spare parts in the central warehouse that can be used from the different site's new models.

> *Parts consumption data in Asset maintenance software. (CSA, Interviewee 2)*

By explaining why, the team is not using IOC for forecasting, a sales asset lifecycle support specialist explained that the global lifecycle management (LCM) team from the factory is providing generic IOCs, and IOCs are not serial number-based, so it led us to place the wrong spare parts order, which is not used in the new model machine. the Same models may have different features and technologies as per the customer's operation and application of the machine at the site.

> *The Global Technical Team from the Product Line Division provides the RSPL, which is a machine serial number specific, followed by an updated Bill of Materials (BOM), and contains an accurate maintenance and critical spare parts list for the machine. This helps in the spare parts forecasting for the new models. (CSA, Interviewee 3)*

RSPLs are machine-specific serial number based and reduce the change of wrong part forecasting. (CSA, Interviewee 3)

IOCs are not machine serial number based. (CSA, Interviewee 3)

the Fleet Manager explained that to have proper spare parts insight for the new model machines, a maintenance program should be effective, including all major component changeout events throughout the lifecycle of the machine. At present, many small sites are following the Run to failure maintenance (RTF) type of breakdown maintenance, where repairs or replacement of spare parts and components are performed only after equipment becomes inoperable. Sometimes it's hard to repair the spare parts or major components if their extended life has been achieved or the repair cost is equal to or just below the cost of new components. The team needs a clear insight into all spare parts and components' lives and ages in different maintenance practices, with proper categorization of the spare parts as repairable and non-repairable. It would be a valuable addition if the team could have proper data on the life of the components and their optimum repair schedule to get the maximum life.

The maintenance manual provided by the product division contains only scheduled maintenance of the filters and oil in the machine. The Product maintenance manual should have complete major components and periodic changeout events schedule too.

Product manual having scheduled maintenance information. (CSA interviewee 4)

The maintenance program should contain all major components and periodic changeout events in the product maintenance manual." (CSA interviewee 4)

Spare parts categorization to support the maintenance and spare parts forecasting ((CSA interviewee 5)

In IOC, life values are not accurate, and it’s tough to develop a maintenance program based on the given life values in IOC. A poor maintenance program is not reflecting accurate part requirements as per the operation of the new model machines. A few times, the site asked for the parts earlier than planned due to the fast wear of the pump's internal components. The pump has a lower life than the lifetime value given in the new model IOC, or the site may have used dirty hydraulic oil in the machine during operation and maintenance. If the life value is more accurate as per site conditions, then the sales area logistic and inventory planner can plan it better with the site PSSR.

> *“IOC data quality should be more accurate for optimized maintenance program”. (CSA, interviewee 5)*

The sales area-based asset lifecycle specialist and his team are responsible for the local IOC documents. The team needs to translate the global NPD IOC into local TCO by giving the regional machines’ spare parts and components a life value as per the different mine site operation conditions in the sales area. The challenge in the Canadian sales area is that many mine site customers who have the new model and previous models are not sharing data on the parts consumption in the machines or any lifecycle data. the Team has a few service contracts in which machines are old and different than new models. These old machines do not contain the same parts as new models, especially major components. This challenge requires the sales area to rely on global IOC with NPD life values. These are not accurate.

Customers are using completely OEM spare parts and components; however, the purchase order cannot tell the exact machine serial number in which the purchased spare parts have been consumed by customers.

> *Customers are not sharing spare parts and component consumption data with OEM Parts and the service team. (CSA, Interviewee 5)*

> *Global IOC life values are not accurate, and the categorization of parts does not support spare parts forecasting. (CSA, interviewee 5).*

As per the demand planner, Salesforce is used to collaborate with the logistics team so that the logistics team can plan and order stock for upcoming opportunities. Opportunities are loaded in CRM or Salesforce with details on the customer, parts required, probability, and timeframe. Each month, the logistics team will retrieve a report from Salesforce, calculate stock requirements, and turn those requirements into orders to suppliers where necessary.

The team currently only uses this process for major components (since the start of 2022) but would like to extend it to include more major components like transmissions and axles.

Below is an example given by a component demand planner:

PSSR reviews the customer fleet and finds that in August 2024, 2 machines are due for an engine replacement (same part number) based on the hour usage and life cycle value of the engine from the IOC document and refers to some engine consumption history data from the other mine site. PSSR is not sure if the customer will purchase it but will put it into CRM to work with anyway.

> *IOC data and old consumption data were used for the forecasting (CSA interview 6).*

An opportunity is loaded in the sales force for 2 x PART#ABC @ 50% probability for August 2024.

The logistics team will review the report and calculate orders based on probability x quantity, so in this case, the team should generate an order for 1 x PART#ABC to be delivered by August 2024 (2 x 50%).

PSSR would keep that opportunity updated so everyone knows how the potential sale is coming along, and hopefully by August 2024, the team would receive a PO and the stock should, quite likely, be available to supply on time.

In Canada, the P&S team has a VMI contract with the customer, and the team discusses with the customer's parts planner to finalize the list of parts and their quantity in VMI. In Canada, teams have a low risk of long breakdowns of the new models due to the unavailability of spare parts. The challenge lies with high values major components, that are only available in the main warehouse. In one case, the team didn’t get parts on time due to the non-availability of parts in the main warehouse and the long lead time.

3.5 Spare Parts Forecasting Process for the Central and Regional Warehouse

The regional inventory planner explained the current process of the parts inventory in the central warehouses and how it supports the regional and local warehouses. The whole process is complex and software-based, which requires lots of input. In summary, it’s based on the time series consumption history data.

All parts have been categorized based on their consumption over the past rolling 12 months. Based on the categorization of the spare parts, the regional inventory planner decides their quantity and location in storage (central, regional, or local warehouse) with the help of the software.

Depending on the business cases, a strategic stock list (SSL) for the new models can be approved, and for better customer support, major components can be stored in regional storage. This location decision depends on the lead time from the central warehouse to the site. If the lead time of the spare parts from the central warehouse to the site is less than 48 hours, then strategic stock-listed parts must be stored in the central warehouse to reduce the inventory cost of regional warehouses and support other regional warehouses in the sales area through the central warehouse.

The selection of spare parts for inventory and their quantity at any warehouse depends on the serving sales area’s consumption of the parts over the past 12 months for the legacy models. Since the inventory team has good spare parts consumption data for the legacy models in the system, it gives a better trend of consumption, both customer and model-wise and makes it easier to plan spare parts for the legacy models.

In new models, now that there are updated hydraulic, electrical, and automation technologies and applications at the mine sites, many new parts have been introduced by the engineering team during its new model equipment development phase. These newly introduced parts in the machine have no consumption data in the inventory IT system, which makes them rely on the IOC document of the model provided by the Global Asset Lifecycle team in their respective production units.

For the new model spare parts forecasting, especially for the major components that are used for the first time in the machines, the regional inventory planner should follow the IOC given the NPD generic life values, which are not the actual life values of the spare parts as per the site operation conditions and applications of the machine. Based on the NPD life values and lead times of the spare parts, the team can calculate the order time and consumption quantity of the major components and parts in the complete life of the machine.

The challenge is the selection of the parts and life values in the IOC; if the life value is not accurate, then the consumption quantity calculation is not correct within the life of the machine.

Table 5:Spare parts forecasting based on IOC life values

SL . NO	Parts Name	Part number	life of components	present ENGINEhours	Average monthly utilization	week left for change the parts	date on which parts should be available at site	lead time in weeks	lead time in months	Average opeartion hours (average utilization per month 600 hrs)within lead time	order point in terms of operation hours	date on which order should be placed	order placing date
1	Part A	A11937791	10000	4000	600	10,00	13/01/2024	12	3	1800	8200	7,00	15/10/2023
2	Part B	A11928539	12000	4000	600	11,67	03/03/2024	20	5	3000	9000	8,33	24/11/2023
3	Part C	A11149149	8000	4000	600	6,67	05/10/2023	8	2	1200	6800	4,67	06/08/2023
4	Part D	A11351285	6000	4000	600	3,33	27/06/2023	28	7	4200	1800	-3,67	29/11/2022
5	Part E	121522-114	7500	4000	600	5,83	10/09/2023	10	2,5	1500	6000	3,33	27/06/2023
6	Part F	A11149163	5000	4000	600	1,67	08/05/2023	12	3	1800	3200	-1,33	07/02/2023
7	Part G	A11132911	6877	4000	600	4,80	09/08/2023	16	4	2400	4477	0,80	11/04/2023
8	Part H	A11132937	6500	4000	600	4,17	22/07/2023	23	5,75	3450	3050	-1,58	30/01/2023
9	Part I	A11134453	9000	4000	600	8,33	24/11/2023	8	2	1200	7800	6,33	25/09/2023
10	Part J	A11134499	10000	4000	600	10,00	13/01/2024	28	7	4200	5800	3,00	17/06/2023
11	Part J	121151-111	12000	4000	600	13,33	22/04/2024	10	2,5	1500	10500	10,83	07/02/2024
12	Part K	135423-117	12000	4000	600	13,33	22/04/2024	12	3	1800	10200	10,33	23/01/2024

A simple form of calculation is shown in Table 5, which is using the NPD life value of the components from IOC to calculate the consumption quantity every year, the expected date of the requirement, and the time of order as per the lead time of the components from the central or regional warehouse to the site warehouse over the lifecycle of the machine or approximately for 5 or 7 years.

3.6 Indicative Operation Cost (IOC) Document Creation Process

Interviews with different stakeholders in the sales area revealed that indicative operation cost (IOC), recommended spare part list (RSPL), and strategic stock list (SSL) are the bases of the new model spare parts forecasting, which have been provided by the product line division from the factory. In discussion with many stakeholders, such as regional inventory planners and PSSR, it was mentioned that the IOC document has more challenges and potential to support more accurate spare parts and component forecasting for new models, and in some cases, reduce the inventory cost with an optimum order of spare parts and components. To get detailed information on the current IOC document development process, one workshop was held with the Global Asset Lifecycle Team. the Workshops were held face-to-face, and discussion was noted and

documented later. In the next section, the whole VSM was documented, and Workshop with the Asset lifecycle team was held on the current situation analysis of the process of Indicative operation cost (IOC) documents

3.6.1 IOC Creation Process

This VSM is based on the New Product Development (NPD) for which every NPD is required to have IOC created.

A request for an NPD IOC from the factory for either of the identified product unit (PU) divisions originates at different stages (gates) of the NPD. The reason for late-stage involvement is believed to be based on the need for secrecy. A follow-up with the UGD PMO clarified that there is no need for secrecy but that the IOC has little value for engineering as it is more of a spare parts forecasting and sales document. Gate 3 (NPD gate stage system) is the final stage before the IOC is handed over to sales areas at gate 4, hence the late involvement. In line with the milestone checklist, the LCM is to be involved from gate 1.Followings are the stakeholders involved in the IOC document developments and explained their role and responsibility.

Technical Service Desk: The Technical Support Desk (TSD) is seen as the driver of NPD, providing historical reliability data (based on warranty data) and prices on specific parts to be used for the proposed construction by Engineering. The interaction between the LCM and the TSD is seen as working very well.

Follow up with the TSD team leader, who stated that the TSD is responsible for all spare parts (not only service items) and provides spare part recommendations (RSPL) to ensure sufficient stocking levels are maintained at the site or regional warehouse. The TSD (back line) works closely with the sales area (front line), via the sales force working with DI-inventory from the business unit (BU).

Central Inventory management ensures that the right spare parts are in the right quantity in the right stock room.

The BoM identifies spare parts in the following indicators:

- Not spare parts
- Spare parts
- Exclusive spare parts

The TSD manually adds a category such as:

- Critical
- Maintenance
- Service

Sourcing supports Engineering by providing the availability of spare parts and by conducting new vendor analyses. Benefits are expected to be created when the two divisions work closer together.

Engineering: Engineering determines the actual construction and provides a basic maintenance schedule. the Product factories utilize since last year Teamcenter to produce the Bill of Material (BOM) and Toolman to produce the factory maintenance schedule per serial number. Not all factories provide a BOM or maintenance schedule/manual in this format.

Technical Offering Support Manager: The Technical Offering Support Manager (TOSM) had an unclear input to the LCM due to the recent re-organization. The TOSM is intended to liaise between the Equipment Division and Parts & Services on the delivery of engineering design/technical expertise. Team will ensure that aftermarket considerations are included within the R&D of product development.

Lifecycle Category Manager

To construct an IOC :

- Take the BOM from MS Access and insert this in the IOC template Excel file

- Add the main components in the IOC template as identified by the Parts Manual & Identification card (Toolman/Teamcenter)

- Add quantity (Parts Manual) and lifetime information (Engineering reviews, Asset maintenance software data, other)

- Add the service parts and maintenance kits from the parts & maintenance manual (Toolman)

- Add quantities and replacement intervals (Toolman)

- Add ancillary parts, quantities, and replacement intervals (Toolman)

- Add a Global Price list

The Excel file is then made available on a SharePoint site and loaded into another internally developed tool called Maestro. Maestro is then used as input for other (non-NPD) IOC creations.

> *The IOC process for NPD is identical from gate 0 to gate 4. The produced IOCs are generic, the team is not providing a specific machine serial number. The team creates as per model and provides the same IOC as per model, irrespective of the serial number. The same model can have a different part number of spare parts as per the requested specification from the customers in the different sales areas, which may contain different options as per the applications and local safety and mining regulations. For example, the same machine model must have different engines in Asia and Australia*. (CSA, interviewee 6 and 7).

Value stream Mapping of the current IOC model creation process of the new model (can be found in Appendix 4) .

3.6.2 Data Accountability & Responsibility for the IOC Model

In given Table 6 the team has identified the available sources of data which has been used in IOC calculation. For IOC calculation, each attribute is required for calculation having a different source of data. Different sources provide data in different means and platforms from where the LCM team gathers the data and analyse it for further use in the IOC document. The Validation of the source and data are also listed in the below Table 6. In Appendix 5, IOC data flow from different sources is shown.

Table 6:Data sources for IOC

Data	Department	Means	Validated
NPD service request	Production Unit	E-mail or in person	-
Lifecycle		Access database	No
Lifecycle	Engineering	Engineering reviews, verbal then transferred to global NPD IOC	Yes (verbal)
Lifecycle	Sales area	Excel sheets from SA? Unstructured, but good (relationship based)	-
Lifecycle	Sourcing	Part of the engineering discussion	-
Lifecycle	TSD	Part of the engineering discussion	-
Lifecycle	Frontline	BI Global Service Dashboard (Esa report)	Asset maintenance software data
Price list	Sales	E-mail	Yes
BoM	Teamcenter	Copy & Paste	Yes
Service maintenance schedule	Toolman	Copy & Paste	Yes
Service maintenance schedule		TSD	
Labor requirement	Backline, product master	Flat-rate document	Yes
Labor requirement	Frontline	Asset Maintenance software	Yes, if entered and setup correctly
Labor requirement	Frontline	Excel sheets from SA. Unstructured	

Except for the data from the engineering team, which had been given to it by the supplier and other OEMs, none of the lifetime data in the Table 6 had been validated. These life numbers, which are standard and calculated in a lab, are given by suppliers and other OEMs. The sales area team and the original

inventory planner believe these estimates to be overly optimistic, which caused them to produce inaccurate spare parts forecasts for the new model, particularly for major components.

A second reliable source of lifecycle data could be Asset maintenance software asset management software, in which the site (service contract) team records all maintenance, breakdown, and rebuild job data along with the parts and manpower used to complete the job. At present, the software has some limitations in computing the life of spare parts and components.

The Asset Lifecycle division is dependable on multiple data inputs from various sources.

> *For transparency reasons the team must ensure that only data is used which is validated. (CSA, Interviewee 7)*
>
> *For accountability & responsibility reasons the team must ensure that only data is used which can be linked back to the actual source and which has been signed off.(CSA, Interviewee 7)*

3.7 Summary of the Current State Analysis

The detailed investigation of the current scenario of spare parts forecasting for a new model revealed numerous results concerning the benefits and drawbacks of the current procedure as well as the participation of various stakeholders from various departments in various sales areas and product divisions. the strengths and weaknesses are categorized in Table 7 by responsible division and source.

Table 7:Strengths and Weaknesses

Sl no	STRENGTHS	SOURCE
1	The spare parts forecasting process is well defined and communicated within the sales areas team and product manufacturing factory team	CSA interviewee 1
2	Recommended spare parts list (RSPL) is machine serial number specific and contains an accurate spare parts list of maintenance and critical items.	CSA interviewee 2
3	Mine site customers have spare parts consumption history	CSA interviewee 3
4	A strategic spare part list (SSL) is well prepared during the NPD project and supports high value with long lead time items forecasting of new models.	CSA interview in SA and CSA workshop with LCM team
5	Asset maintenance software database of the maintenance jobs of all machines in the service contract.	CSA workshop with the LCM team. (CSA
	WEAKNESSES	
6	A maintenance plan for a new model is not available with the major component changeout plan	CSA interviewee5 in SA Canada
7	Predictive operation cost (IOC) is not machine serial number specific and life data values of the listed components in IOC are not accurate life	CSA workshop with LCM team (IOC owner) and SA interviewee 1,3,5)
8	SA Canada customers are not sharing available lifecycle data with original equipment manufacturing (OEM) and the local Asset lifecycle team.	CSA interview with SA Canada
8	Asset maintenance software is not capable to capture the life of the parts and components.	CSA Workshop with LCM
9	No performance measures are used to evaluate the outcomes brought by different maintenance programs in spare parts availability.	CSA interviewee 7

3.8 Key Findings to Elaborate

Based on the strengths and weaknesses found in the CSA, all findings are categorized into four categories in Table 8. The literature review for Stage 2 of this study is based on the four categories, which also include all the weaknesses. The Stage 3 generation of the initial recommendations will still use the strengths in each category. Table 8 shows the category-wise strengths & weaknesses.

Table 8: Findings divided into categories for literature review

Category	Findings
Spare parts classification	Spare parts classification for inventory is standard and followed by all sales areas. The product division's technical service desk has standard spare parts classification for RSPL & SSL documents.
	In IOC, the spare parts classification is not standard and depends on the domain knowledge of the
Spare parts life data	Indicative operation cost (IOC) is not machine serial number specific and life data values of the listed components in IOC are not accurate life
	Asset management database has data of the maintenance jobs done in the fleet under the service
	SA Canada customers are not sharing available lifecycle data with original equipment manufacturing (OEM) and the local Asset lifecycle team.
	Asset maintenance software is not capable to capture the life of the spare parts and components.
Annual Maintenance program for spare parts forecasting	Recommended spare part list quality is good and reflects the initial requirement for spare parts for the new model maintenance and operation.
	The quality of the strategic stock list of spare parts (SSL) is good and supports the maintenance and operation of the equipment at the site.
	Run-to-failure maintenance program leads to poor spare forecasting and increases intermittent demands with long downtime and production loss.
Performance measures	No standard Performance measures of spare parts forecasting based on a maintenance plan.

the first category is spare parts life data, by improving the data set of the life value of the spare parts and components, the inventory and parts forecasting team can have better insight into spare part forecasting at an early stage for the new models and with the initial recommendation of standard process and clear accountability of capturing the manual data and development of IT tool to calculate the lifetime value from the maintenance data can enhance the quality and amount of the life values of spare parts

the Second category is spare parts forecasting, Maintenance programs are critical to proper spare parts forecasting. Adopting the correct and effective maintenance program will improve the spare parts forecasting for the new model and large fleet.

the Third category is spare parts categorization, to make a standard categorization process with proper guidelines of doing categorization in the IOC creation process will help to understand the criticality of the spare parts and their effect on the inventory as per the maintenance plan. the Fourth category is performance evaluation of the spare parts forecasting based on the effective maintenance program at sites. Fixing the parameters to measure effective spare parts forecasting will help to identify the required changes in the future.

In the next section, Section 4, suggestions for improvements were collected from the existing information in the academic literature. The literature review is carried out to find practical improvement suggestions for the current process's recognized weaknesses.

4 Existing Knowledge of the Spare Parts Forecasting

The conceptual framework was developed in this section by compiling the relevant prior information collected from the reviewed literature. The results of the current state analysis described in Section 3 were used to guide the literature search. To facilitate an efficient literature search for suggestions to address the identified weaknesses, the findings were summarized and split into three main categories.

Three subsections in this section break down the important findings of the literature review. Each subsection begins with a description of the pertinent theory, concept, or methodology, followed by a discussion and an explanation of why it is important to this study. The conceptual framework, which serves as the study's most crucial piece of knowledge, is finally visually summarized in the final paragraph of section 4.

4.1 Spare Parts Classification

Spare parts classification methods emphasized the understanding of the “important” spare parts for the plant or machinery at the site, which helps in the decision-making process of management. In many industries, spare parts classifications are different for maintenance and inventory purposes, however, the definition of “important” is different for both. In the end, the basic aim of spare parts classification is to forecast and stock those spare parts that have a high impact on the production and functions of the plant and machinery. Syntetos et al.(2009).

Multiple criteria should be considered while still maintaining the simplicity of the classification model. According to technical and financial criteria, including criticality, life cycle stage, delivery time, and price, parts can be categorized (Fortuin & Martin, 1999, p. 952). Criticality groups depend on the perspective of the business cases, equipment, and industries. Spare parts classification uses different rules accordingly. Macchi (2011).

4.1.1 ABC Classification

Inventory control managed widely by classification method based on the consumption of the spare parts using ABC inventory classification method of inventory forecasting and control. The Pareto principle of ABC classification says that there are a small number of things that contribute most of the inventory costs and a big number of items whose costs are relatively low. This is also known as the 80:20 rule, as approximately 20% of items contribute 80% of the costs and the remaining 80% of items account for only 20%. it is important to maintain tight controls on the 20% and moderate control on the rest (Waters, 1992). Therefore, Inventory items are categorized using the ABC analysis based on how significant a contribution as it makes to the annual cost of the system inventory. Items are defined as the inventory of a small number of things that make up a significant portion of the cost volume. Many low-cost consumption items are included in C items, while B items are an intermediate category of moderate cost-volume items.

CLASS	% OF TOTAL ITEMS PURCHASED	% OF TOTAL PURCHASE ($)
A ITEMS	10	70
B ITEMS	20	20
C ITEMS	70	10

Figure 1: ABC analysis (Chen et al. 2008, p. 36)

As shown in Figure 1, the majority of the spare parts items purchased in quantity are contributing the lowest percentage of the total cost of inventory and vice-versa.

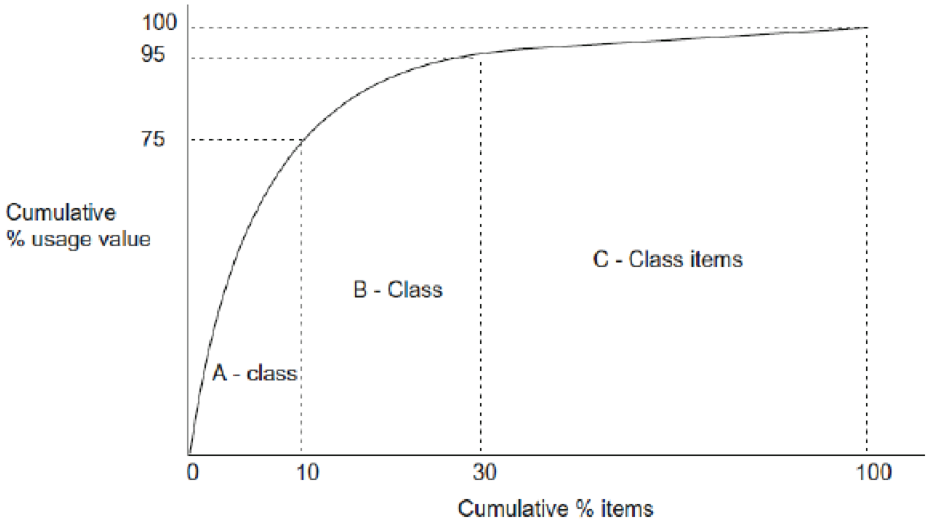


Figure 2: ABC-analysis presented in graphical form (Vrat, 2014, p. 41)

Large inventories of homogeneous spare parts can be categorized using ABC analysis. As seen in Figure 2 above, spare parts can be categorized based on how often these items are used. For instance, 20% of the overall demand can be categorized as group B items. ABC analysis, however, may provide challenges if the set of spare parts includes components with various characteristics, such as different life cycle phases, delivery schedules, or levels of criticality. For instance, a new model of equipment used many new spare parts during manufacturing and machine has not reached the mature stage of lifecycle then the spare parts consumptions history is not available. The ABC analysis reveals that it is a member of group B. However, it is still feasible that the component will be added in the spare parts forecasting, with the expectation of consumption in nearby future. This could lead to inaccurate assessments of inventory levels and excessive inventories for upcoming outdated parts.(Celebi et al.,2008).

4.1.2 Criticality Analysis Method

The multi-criteria classification technique was developed using the method suggested by Braglia et al.,(2004). The method's goal is to assess the criticality of spare parts efficiently and thoroughly and to categorize the parts according to their level of criticality. The technique seeks to develop a comprehensive spare parts classification scheme that may act as a transparent aid for asset and

maintenance managers. A crucial requirement for ensuring the dependable and secure operation of any contemporary industrial system is the identification of critical spares. Additionally, the degree of criticality can be a useful characteristic for establishing the need for storing inventory and figuring out service requirements.(Waeyenbergh et al.,2010)

The identification of pertinent criteria that have an impact on item criticality is the first stage in the multi-criteria classification process. It was determined to address item criticality from the two perspectives of process criticality and control criticality, as suggested by Huiskonen,(2001). A spare part is deemed process important if its malfunction or failure could have serious negative effects on the plant, such as negative effects on human life, environmental contamination, or production loss. The repercussions of failure or scarcity are unrelated to control criticality. When it comes to control criticality, a spare item is deemed critical if it is difficult to ensure its rapid availability.

A total of six attributes were selected as presented in Table 9.

Table 9: List of criticality criteria.

Criticality criteria	Description
Equipment criticality	Equipment criticality refers to the criticality class of equipment and is evaluated as the frequency of a failure of the equipment and the possible consequences of the failure.
Probability of item failure	The probability of failure is the likelihood of failure or breakdown of the spare part.
Replenishment time	The total elapsed time from when a material need is communicated until the item has been received, checked, binned, and is available for use.
Number of potential suppliers	The number of potential suppliers (off-site) who can deliver the specific spare part to the requestor.
Availability of technical specifications	The availability of the technical specifications (BOM, CAD-CAM drawing, and order text) of the article.
Maintenance type	The type of maintenance performed on the equipment.

Spare parts criticality criteria are classified into six attributes as shown in Table 9. These attributes are defining different aspects of the spare parts criticality required to consider during spare parts classification.

The VED (Vital, Essential, and Desirable) classification is based on the multiple criteria proposed by Gajpal et al.,(1994). Table 10 shows the criticality criteria and their categorization as per lead time and the number of suppliers.

Table 10: Categorical measurements of criticality criteria

Criticality criteria	***Categories***		
	Vital	***Essential***	***Desirable***
Equipment criticality class	Criticality classes A, B	Criticality classes C, D	Criticality classes E, F
Probability of item failure	≥1/year	≥1/5 year and <1/year	<1/5 year
Replenishment time	>1 month	>2 days and≤1 month	≤2 days
Number of potential suppliers	Only 1 supplier	>1 and ≤3 suppliers	>3 suppliers
Availability of technical specifications	Not available	General specifications available	Detailed specifications available

As shown in Table 10, the most *desirable* situation in terms of replenishment time is that the spare part can be available for use within two days. The replenishment time becomes *essential* if the item is available between two days and one month. If it takes longer than one month to replenish the item, this criterion is ranked as *vital*.

Criticality levels

Criticality levels are divided into four levels based on multiple criteria ranging from highly critical (criticality level 1) to non-critical parts (criticality level 4). The levels high, medium, and low are assigned to items with a certain risk involved , whereas the risk of non-critical parts is controlled to a large extent, Porras and Dekker,(2008).The different criticality levels are described in the Table 11.

Table 11: Criticality level

Level	Description
1: High	• Unavailability of the item causes an unacceptable condition, either operational or concerning safety or the environment. • Immediate supply of the materials is required. • Risk in the process of ordering and stocking is not tolerated.
2:Medium	• Unavailability causes an unacceptable condition, either operational or concerning safety or the environment but the consequences can be corrected or controlled. • Material should be supplied within a short period. • A calculated risk in the process of ordering and stocking.
3: Low	• Unavailability causes an acceptable condition, either operational or concerning safety or the environment. • Supply of materials after a longer period. • Risk in the process of ordering and stocking can be justified.
4: No	• Unavailability causes no effect on the processes or the safety of the people and the environment. • Supply of materials after a long period of time. • Risk in the process of ordering and stocking is normal.

The availability of spare parts and how it affects safety, machine functioning, people's health, and the environment are the most crucial factors, which result in significant production losses. Table 11 illustrates the criticality level of spare

parts. Secondly, the lead time of spare parts is also considered crucial to fulfilling emergency orders for spare parts. Lastly, there is a risk of ordering and converting dead stock, which typically occurs with high-value major components due to poor forecasting due to the lack of historical consumption data and information on the life of the spare parts.

4.1.3 Lifecycle Phase-based Multicriteria Classification

Persson and Saccani (2009) describe the case of one of the world’s leading manufacturers of heavy equipment. A hierarchical multi-criteria spare parts classification method has been adopted by the company, based on:

The linked final product's life-cycle phase: Parts are divided into four groups (launch, prime, decline, and phase out) based on how long the final product has been manufactured for or how long it has been since production ceased.

Volumes: Depending on the demand from the prior year, portions that fall within the prime, decline, or phase-out categories are categorized as fast-moving, medium-moving, or slow-moving.

Criticality (high or low) determines the required service level: Main components, subassemblies, and remanufactured parts are the three categories based on the criticality of the spare part considering its adverse consequences.

Competition: Only the 'launch' lifecycle phase, where volumes are ordinarily low, is used for this dimension. "Competitive" parts are those that are sold independently or by other companies and require a high level of customer service to compete. (Persson and Saccani, 2009).

Table 12: Spare parts reorder points in different phases of the lifecycle of the equipment.

Lifecycle phase	LAUNCH	PRIME	DECLINE	PHASE OUT
Inventory policy	Re-order point (s) policy with safety stocks (s, Q): Q = the order quantity	Fast-movers: continuous review policy with safety stock and re-order point (96% to 99% target service level)		'Moving' Parts: Make-to-order or purchase-to-order policy, with no safety stock and re-order point equal to zero
		Medium and slow movers: re-order point policy with safety stocks (90% - 94% target service level)	Medium and slow movers: re-order point policy with no safety stocks (back-orders are tolerated)	No-movers: not serviced

To establish inventory management policies and procedures as well as the required service level for the parts (availability at the warehouse), managers use the classification created by Persson and Saccani (2009), as shown in Table 12. According to the target service level of the inventory, fast, medium, and slow movers require various reorder policies and safety stock levels. According to a case study conducted by Persson, dealers' locations or local warehouses should keep fast-moving parts with medium- to a low value in the stock. The corporation directly supervises the replenishment of these parts using vendor-managed inventory (VMI). Since dealers don't keep slow-moving parts in stock, prompt deliveries are required. (Person and Saccani, 2009)

4.2 Maintenance Program to Improve Spare Parts Forecasting

The requirement for spare parts inventories is dictated by maintenance policies rather than client demand. For instance, replacing the damaged part or repairing it are two options for getting a machine that has a broken portion back to work. The choice between repair and replacement has a significant impact on the maintenance inventory levels. The amount of redundant equipment to incorporate into a machine is another choice. If there are many redundant parts, it might be reasonable to replace all broken parts at once and have a few spares on hand for emergencies; if there are few redundant parts, the requirement for instantly accessible spare parts is greater.(Wang, W,1997)

Maintaining a specific quantity of spare part inventories that is balanced with the demand for spare parts is necessary for the proper execution of the maintenance process. Two primary forms of maintenance—scheduled or preventive maintenance and unscheduled repair—require different inventory control procedures. The demand for spare parts is predictable during planned maintenance, making it possible to order them just in time for usage and maybe eliminating the need for spare parts storage. However, for unscheduled repairs, a safety stock policy is required since the effects of stock-outs frequently result in maintenance activities being interrupted. Spare parts should be kept in a variety of places and in sufficient quantities to minimize the risk of a service failure and to reduce the expense of transporting spare parts, which are two competing objectives when creating a strong spare parts strategy. (Wang, W,1997)

4.2.1 Delay Time Method

The relationship between failures, inspection, and preventive replacement can be captured since the delay time as described offers a window for inspection and preventive replacement, assuming that defective components are always replaced. In Baker and Wang (1991), Christer et al. (1995, 1997), Pillay et al. (2001), and Akbarov et al. (2008), the delay-time concept and related modeling methodologies are applied to diverse industrial plant components.

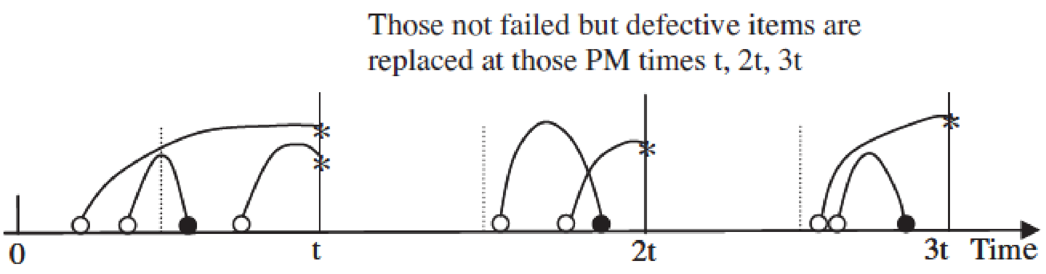


Figure 3:The process of defective item’s arrival s, failure, and replacement of defective parts at PM times where an arc linking s and represents the delay-time and an arc linking s and ⁄ is the censored delay-time due to preventive replacement.(Wang, W,2012)

In the case of a complicated system with several components, Figure 3 demonstrates the delay-time idea and how it is used to establish the connection between the number of failures and the PM interval. As can be observed from Figure 3, PM interventions result in the preventative replacement of four damaged components and the reduction of seven possible failures to three. One extra defective item might be found and replaced if the PM inspection period was cut in half from the current interval shown in Figure 3 (shown by dotted lines). This demonstrates how the PM interval affects the frequency of failures; specifically, it demonstrates how, in the absence of an inspection, all seven defective items would result in failures.

A two-stage failure process that appears to share some similarities with the delay process was also employed by De Smidt-Destombes et al. (2006). The two-stage failure process utilized by de Smidt-Destombes et al. (2006) differs fundamentally from the delay-time process in that it used a Markov chain to describe the failure process of a single item with three states. A pooled process of components, each following a two-stage failure process that is not necessarily Markovian, is used in this delay time method. De Smidt-Destombes et al. (2006) also employed an indefinite time frame. The contrast between a delay-time-based model and a Markov chain-based multi-stage failure process model was discussed by Christer et al. in 2001.

4.2.2 Age-based Spare Parts Replacement

In industrial maintenance practice, the age-based preventative replacement policy for stochastically deteriorating equipment is well recognized, and it has received extensive treatment in the literature. This policy states that a product must be replaced either when it reaches a certain age or when it fails, whichever comes first. The ideal preventative replacement age is established in the original mathematical model created by Barlow and Proschan,(1965) by reducing the predicted total replacement cost per unit of time. The spare provisioning policy has not been considered in this model or in any other replacement models that

are comparable to it, implicitly presuming that a spare item will always be provided upon request.

In practice, however, it is impossible to disregard the impact of a spare provisioning policy on the replacement policy because spares are frequently bought and transported in limited quantities.

A new ordering policy developed by Osaki and his research team optimizes both the ordering process and the timing of replacements based on the age of the components and spare parts. Team has developed several mathematical models under various sets of circumstances. The ordering policy in the typical situation is as follows: A spare part order is placed at a certain time, and upon delivery following a fixed lead time L, the spare is retained in stock up until another specific time t_1 (> t o + L). Spare parts are ordered right away if a component or the spare part fails previously. The spare part from the stock is used to replace the operational unit if it fails between t o + L and t1.

By minimizing the projected total inventory cost (i.e., ordering, holding, and shortfall costs) per unit time, the jointly optimal ordering time t_0^* ($0 \leq t_0^* \leq \infty$) and replacement time t_1^* (t_0^* + L or ∞) are found. To account for lead time variability, Park and Park, (1986) extended the generalized ordering policy model to the case of random lead time.

Ordering policies as currently practiced have several serious disadvantages. First, these are predicated on one running unit and a single spare unit as the maximum authorized stock. However, there are frequently numerous similar units operating in the quarry, such as pumps and motors, etc. in the same models. Implementing a single-unit ordering policy will result in a large number of pointless orders and higher ordering expenses. If the holding cost is significantly less than the ordering and shortfall costs, carrying more than one spare may even be economically justified for the one-unit scenario. Second, merely taking inventory costs into account yields the best ordering strategy. This disregards the

significant trade-off between inventory-related expenses and replacement-related costs. (Kabir et al.,1994)

Because there is a greater demand for spare parts, preventive replacement policies have higher inventory costs than 'failure replacement only' policies even when replacement costs are lower. This was noted by Acharya et al.,(1986). In contrast, the inventory cost is lower, and the replacement cost is higher for the failure replacement strategy. So, it stands to reason that the replacement interval for a jointly optimal replacement and spare provisioning policy would differ from that determined by considering either of the two types of costs. (Falkner, 1969, p. 287–295) has also demonstrated that adding replacement costs reduces the ideal inventory.

Kabir et al.,(1994), presented a new inventory policy that incorporates a continuous review (s, S) type inventory policy, where s is the reorder level and S is the maximum stock level. This policy would allow for the joint optimization of age replacement and spare provisioning. The policy can simply be referred to as a "stocking policy" because maintaining enough spare parts inventories is a key concern. This policy's guiding philosophy can be summed up as follows: When the inventory level reaches s, an order for (S - s) spare units is placed.

The operating unit is replaced preventively at t1 (considering t1 as the optimum age of the spare) provided a spare is available. Otherwise, the unit is replaced as soon as the stock is replenished. If the operating unit fails before t1, the failed unit will be replaced as soon as a spare is available. The order lead time is randomly distributed. Optimal values of the decision variables (tl , S, S) are determined by minimizing the expected total cost per unit of time, where the cost components include both replacement and inventory-related costs.

4.2.3 On-Condition Maintenance Tasks as Advance Demand Information (ADI)

On-condition maintenance tasks are the primary driver of spare part demand for many maintenance businesses. The demand for spare parts fluctuates for a variety of reasons, including unequal distribution of maintenance jobs over time, which makes managing spare parts inventory extremely difficult. Using the maintenance plan, or the anticipated repair tasks, as a source of advance demand information to partially solve these difficulties. Zhu et al.,(2020,p.5).

When using this type of Advance demand information (ADI) to manage spare parts inventories, two challenges must be overcome. On-condition maintenance tasks are a type of incomplete demand information, to start with: It is only apparent after examination whether an on-condition maintenance activity requires a spare part. Utilizing the maintenance plan, therefore, requires handling this underlying uncertainty. Secondly, while logistics planning mandates that enterprises schedule on-condition maintenance tasks in advance, this plan is only dependable and available a few months out. (Zhu, et al. ,2020, p.5)

The break-down maintenance is the most basic type of maintenance, run-to-failure. Contrarily, preventative maintenance comprises a wide range of maintenance procedures meant to stop breakdowns. In time-based maintenance, a part or component is changed regularly, such as every six months, or every 10000 km drive, depending on usage or time. Time-based maintenance is simple to plan for and does not require condition information to be used, but it has the drawback of perhaps underutilizing the usable life of the replaced parts. Companies, therefore, inspect asset pieces when it is economically feasible to do so before determining whether to replace them; the part is then only replaced if degradation is beyond a certain threshold, hence the phrase "on-condition maintenance task." (Zhu, et al., 2020, p.3)

The planned (but not necessarily periodic) on-condition maintenance tasks are suggested to be used as spare parts ADI under the notion of ADI on spare parts. This general concept can be used by a variety of maintenance groups. The

fundamental and sole prerequisites of the suggested solution are that information on previous on-condition maintenance jobs and associated spare parts consumption be stored, as well as that on-condition maintenance activity be known in advance (for example, one month into the future). The first need is typically met in high-tech asset maintenance settings because a wide range of on-condition maintenance jobs may be correctly predicted in advance and because data gathering is frequently required due to traceability requirements. Indeed, asset maintenance must be planned in time to organize the availability of the asset, qualified mechanics, tools, maintenance hangar, etc. (Zhu, et al., 2020, p.3)

Usually, the extent of asset maintenance is also known in advance. Therefore, using data on the on-condition repair work is particularly advantageous from a cost viewpoint for those assets that have a high percentage of planned maintenance tasks. The possibility and necessity for on-condition maintenance job prediction have grown as a result of the growing use of asset maintenance software, which has made data on the maintenance plan available in formats appropriate for automatic decision-making. The applicability of the technique for assets with a modular design is that many ready-to-use units (RTUs) that can be replaced during asset maintenance are present in assets with a modular architecture. (Zhu, et al.,2020, p.5)

RTUs are normally taken out for inspection regularly. There is a specific inspection interval and scope for each RTU. This scope comprises the ongoing maintenance duties performed on RTU components that collectively make up the inspection. The manufacturer of the RTU normally specifies both inspection intervals and deterioration limitations for on-condition duties and bases these specifications on quantitative analysis in so-called reliability-centered/risk-based maintenance studies. After being removed from the asset, RTUs are routinely inspected in specialized repair facilities. As a result, shop-replaceable units (SRUs) are the common name for RTU components that are replaced based on their state.

Example: The truck gearbox (RTU) manufacturer suggested having an inspection after every 5000 engine hours /six months and changing if any gear (SRU) has crossed the specified wear limit. This on-condition maintenance task is a predefined and on-time planned activity. Which allows forecasting the SRU in advance and extends the life of the RTU.

The maintenance schedule, and in particular the jobs that can be generated from it for on-condition maintenance, is used as a forecasting tool for spare parts demand. Maintenance plans can be made years in advance, but plans are not reliable very far out. This could happen as a result of changes in the plan, the cumulative anticipated consumption (such as flight hours/km) deviating from the actual cumulative usage, etc. However, in the short term (e.g., A few months into the future instead of years) cumulative usage can be more correctly projected, making such discrepancies unusual. Another reason for the plan to be more trustworthy in the short term is because variations in the short term generate operational disruptions as well as unavailability and/or idle time of bottleneck resources. Zhu et al.,(2020), proposed to base ADI on this reliable time horizon and developed a method that reverts to time-series forecasting for periods beyond this horizon.

Example: The gear in the gearbox has historically been replaced in one out of three repairs. Based on two planned removals of the gearbox per year, an expected demand of 2/3 = 0.67 gear per year is forecasted for the next two years.

4.3 Performance Measure

Spare parts forecasting performance measure help to understand the how well spare parts forecasting process is working and supporting the maintenance plan of the fleet at the site as planned. However, the maintenance team has different KPIs to measure the maintenance performance such as planned vs actual maintenance cost, downtime, and many others. Total cost of ownership and lifecycle cost is the measuring parameters that have been used in many different business cases. The following subsections describe the concept and calculations

included in both concepts which can be related to spare parts availability and forecasting.

4.3.1 Total Cost of Ownership and Life Cycle Cost

The creation of TCO and LCC is predicated on the notion that costs must be evaluated from a long-term perspective. Both techniques consider all costs in addition to the initial investment. Pre-action costs are included in the LCC, but it has a smaller domain than the TCO. In that TCO places more emphasis on costs that will impact the buyer and user of an asset, it adopts a slightly different approach than life cycle cost theories. TCO is a relevant life cycle term when analyzing costs from the standpoint of the customer. (Bladh & Storm,2008,p 27)

Before making a purchasing decision, the TCO study places a strong emphasis on capturing all actual expenses. Effective and efficient supplier selections and increased productivity are the results of taking important cost elements that affect the costs of crucial purchasing decisions into consideration. (L. M. Ellram, 1995b; Gass et al., 2014). According to Jardine and Tsang (2006), the optimal equipment replacement age is when the overall cost is at its lowest point. The expenses related to owning equipment in the mining sector can be divided into the following categories: original purchase, installation, direct downtime, maintenance and running, financing, and cost recovery on disposal. The entire sum of these expenses is what it will cost to own the mining equipment. (Hall, 2007).

4.3.2 Life Cycle Cost

The specification, design, manufacturing, operation, and maintenance of an asset, as well as its replacement or ultimate disposal, are all included in the equipment life cycle. The total of all the above-mentioned expenditures is the life cycle cost. The life cycle cost approach can be applied at any point in a project's life cycle, but because future costs are determined in the planning and design stages, the best results are often attained early on. For the equipment replacement analysis methodology application in the replacement phase (end of

life), during the definition of the optimal fleet to achieve decreased production costs, and for the supplier selection LCC analysis applied in the first stage. (Kayashami & Junior, 2018)

Equipment lifetime cost (LCC) includes all equipment decision-making procedures, replacement studies, and replacement models. Depending on ownership and operating costs, a piece of equipment in a mining project's fleet may need to be fixed, overhauled, or replaced. The two components of equipment life cycle costs are ownership and operation expenses. Initial expenses, depreciation, insurance, taxes, storage, and investment expenses would all be considered ownership costs (Peurifoy, and Schexnayder 2002). Operating costs would include repair and maintenance, tire, tire repair, fuel, operator, and any other consumable equipment costs (Gransberg et al., 2006).

Equipment Ownership Costs: The ownership expenses and operating costs that make up the total cost of the equipment are two distinct elements. Except for the one-time capital expenditure for purchasing the machine, annual ownership costs are fixed expenses that apply whether the equipment is in use or not. The expenses incurred only when the equipment is in operation are known as operating expenses. Ownership costs are recurring expenses. These expenses, which are almost all yearly in nature, include the initial investment price. The initial investment represents, on average, around 25% of the total cost that will be made over the course of the equipment's usable life. (Douglas 1978). The initial cost is often used as a basis for calculating other ownership and operating costs, and in most cases, this cost can be determined with accuracy. The following components make up the initial cost: the price at the factory, additional equipment, sales tax, shipping, assembling, and erection.

Depreciation: Depreciation represents the decline in the market value of a piece of equipment due to age, wear, deterioration, and obsolescence.

Generally, the asset costs are known as:

- Initial cost: The amount needed to acquire the equipment.

- Useful life: The number of years it is expected to last.
- Salvage value: The expected amount the asset will be sold at the end of its useful life.

Investment (or interest) cost

Investment (or interest) cost represents the annual cost (converted to an hourly cost) of capital invested in a machine (Nunnally 1987)

Insurance Costs, Taxes, and Storage Costs

- Insurance cost represents the cost of fire, theft, accident, and liability insurance for the equipment.
- Tax cost represents the cost of property tax and licenses for the equipment.
- Storage cost includes the cost of rent and maintenance for equipment storage yards, the wages of guards and employees involved in moving equipment in and out of storage and associated direct overhead.

Equipment Operating Costs

Construction and mining equipment operating costs are a key cost category that should not be disregarded. These costs are incurred when a piece of equipment is in use. Costs only come into play when the machinery is in action. Because costs vary on several variables, including the equipment utilized, the location of the activity, and the working conditions, operational expenses of the equipment are also known as "variable" costs.

Maintenance and Repair Cost

The biggest running expense for construction equipment is typically the cost of maintenance and repairs. Equipment can sustain significant wear and tear during construction operations, although the degree of wear varies greatly depending on the specific pieces of equipment utilized and the nature of the project. As equipment ages, maintenance and repair costs typically increase. Equipment

owners will concur that proper maintenance can increase equipment life and even lower operating costs by limiting the effects of unfavorable conditions. Good maintenance includes periodic wear measurement, prompt attention to recommended service, and daily cleaning when conditions warrant it.

It is possible to express the annual cost of maintenance and repairs either independently of depreciation or as a proportion of the annual cost of depreciation. By dividing the annual cost by the number of operating hours per year, one can determine the hourly cost of maintenance and repairs.

Consumable Costs: Consumables are those components needed for a piece of equipment to function, but which are used up during operation and production. These include lubricants, gasoline /fuel, and other petroleum products, but not only. Filters, hoses, strainers, and other minor parts and items that are used when the machinery is operated are also included.

Special Items Cost: The cost of replacing high-wear items such as bushing, Pin, bearing, buffer, jaw, and scraper blade cutting and end bits, as well as ripper tips, shanks, and shank protectors, should be calculated as a separate item of operating expense. As usual, the unit cost is divided by the expected life to yield cost per hour.

Equipment operator cost Operator’s wages are usually added as a separate item after other operating costs have been calculated.

Douglas D. Gransberg,(2015), derived in his study the following formula to calculate the asset LCC.

LCC= Operating cost +ownership cost

Where:

LCC= Life cycle cost

Operating cost = R&MC +FC+TC+TRC

R&MC= Repair maintenance cost

FC= fuel cost

TC = Tire cost

TRC=Tire repair cost

R&MC = (Repair factor) x (straight-line depreciation cost)

Years R&MC =($(Year\ Digit/Sum\ of\ Years\ Digit)\ x\ Total\ repair\ Cost) + R\&MC$

Where:

Year Digit = year taken in ascending order

The sum of the year digit = Sum of the years' digit for the depreciation period

Total repair cost= repair factor x (List price -Tire cost)

Repair factors are shown in Table 13. Repair factors are given based on the different operating conditions of sites and the different equipment's applications.

Table 13:Repair Factors (Atcheson,1993)

Equipment Type	Operating Conditions		
	Favorable	Average	Unfavorable
Scrapers-All Types	42%	50%	62%
Front-End Loaders-Rubber-Tired	45%	55%	62%
Haulers	37%	45%	60%
Bottom Dumps	30%	35%	45%
Crawler Tractors (by Application)			
Industrial	10%	25%	75%
General Contracting	40%	60%	80%
Quarrying	50%	85%	115%
Mining	70%	110%	150%

As shown in Table 13, the highest repair factor for the equipment in mining applications, it reflects that operation cost is the correct selection as performance metrics and how important it is to keep it on the lower side to have lower Lifecycle cost.

4.3.3 Total Cost of Ownership

The total cost of ownership (TCO) is both purchasing tool and philosophy, which strives to understand all the costs that will occur during the lifetime of an asset up

to the disposal of the asset. TCO is concerned about life cycle analysis but holds a slightly different approach than LCC.

When determining TCO, pre-transactional, transactional, and post-transactional expenses should be considered. Pre-transactional expenditures, such as supplier selection, take place before the acquisition. An asset's transactional costs are those incurred during its acquisition, whereas post-transactional costs are those incurred over the asset's lifetime as well as during its disposal. It's vital to note that TCO studies only consider the purchase price and not any potential development expenses incurred by the manufacturing company. (Ellaram ,1993, pp. 49-50)

The TCO study won't give precise numbers, but it will be helpful as a comparative tool for making investment decisions and determining whether it's time to continue operating or replace the equipment. (White,2006, pp:28)

How a machine is used affects how frequently it needs maintenance and service causes difficulty. A TCO study can lead to better preventative maintenance procedures and help avoid costly emergency repairs. (White, 2006, p 30). The costs related to downtime, or when a machine is not operating due to breakdown, repair, or servicing, are additional expenses that have a significant impact on TCO. There will be a fee for an alternate method or a loss of revenue during downtime. (Foneseca ,2001, pp. 1-2).

Bladh & Storm, (2008), concluded based on other studies on the Total cost of ownership that there is no commonly used definition of TCO across industries. The Conclusion was to consider and emphasize only those costs in the calculation which contribute more than 5 % to the total cost. Different industries are following different costs as per the specific nature of procurement and asset. Below is the TCO calculation by the Govt of Newleland for their asset procurement.

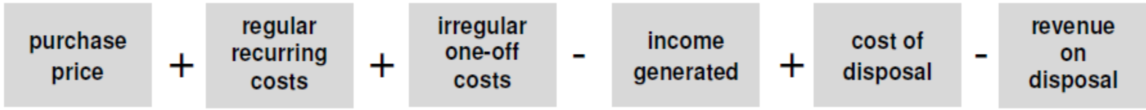


Figure 4:TCO's different costs

Bladh and Strom (2008) suggested in Figure 4 the costs connected to the purchase, operation, and disposal of equipment should be included in a TCO calculation

In their study, TCO costs are the following:

a) Cost of acquisition (COA)
b) Cost of ongoing production(COP)
c) Cost of maintenance (COM)
d) Cost of downtime (COD)
e) Cost of Disposal (CVOD)

TCO= COA+COP+COM+COD+CVOD

4.4 Spare Parts Life Calculation

Data-driven spare parts management makes spare parts forecasting easier and more accurate and allows the maintenance planner and parts planner to do forecasting the spare parts as per equipment or fleet utilization at different sites. Many asset maintenance software providers are providing solutions to calculate spare parts life as per the spare parts utilization. In the next subsection, the described concept of rotating and non-rotating assets is given by IBM.

4.4.1 Rotating and Non-Rotating Asset

Engines, motors, pumps, cylinders, and other rotating components are replaceable components. Both an inventory item number and a unique asset number are assigned to rotating assets. While the asset number is useful to track individual instances of the asset as it is moved from one location to

another and from one site to another, the item number enables the system to track assets as a group as spare parts are moved in and out of inventory and other types of locations. (B. Portaluri,2012)

Non-rotating assets do not move in and out of storerooms. A non-rotating asset has a unique asset number but does not have an item number because it is not tracked in the inventory. (B. Portaluri,2012)

Rotating assets

- Rotating assets are interchangeable assets.
- Rotating assets have a unique asset number and an inventory item number; the item must be marked as rotating. Service items cannot be marked as rotating; the items found in the Item Master or Tools application can be marked as rotating.
- Before the system can create a record for a rotating asset, the rotating item record must first be created in the Item Master application.
- Rotating assets can be located in a storeroom, either an item storeroom or a tool storeroom.
- Rotating assets can also exist in labor and courier locations where these have been set up to maintain the balance of an item. Non-rotating and rotating assets can exist in operating locations, vendor locations, salvage locations, and repair locations.
- Rotating assets can have an Item Assembly Structure (IAS) applied. The IAS can be considered as a template for a hierarchy of assets, saving time when creating many similar asset hierarchies.

- The classification of a rotating asset is determined from its rotating item. If the attribute values are updated on the rotating item, it also changed on all rotating assets that belong to this rotating item.

- During the receiving process rotating assets have to be given an asset number.

Example of a rotating asset: A company might have four identical (same make, same model) centrifugal pumps, so all four pumps would have the same item number. To track the use, the repairs, and the locations of each pump, each pump has its own, unique asset number.

Non-rotating assets

- Non-rotating assets can be purchased, received, and issued directly to the person who requisitioned the item.

- Non-rotating assets are not associated with an Item.

- Non-rotating assets do not have to share a common classification.

4.4.2 Data Collection

Information gathering regarding a certain topic is referred to as data collection. It's essential to make sure collected data is accurate during the collecting stage and that it was gathered in a morally and legally correct manner. If not, the analysis won't be correct and could have serious repercussions. (Cote,2021)

In general, there are three types of consumer data:

- First-party data is information that the company has obtained directly from users.

- Second-party data, also known as data, shared by another company about its consumers (or first-party data),
- Third-party data, or data that has been compiled and rented or sold by companies unrelated to company business or users.

Although there are uses for second and third-party data, first-party data (that the company has acquired) is more important since the company gets knowledge about the attitudes, behaviors, and feelings of its audience from a reliable source.

Data can be either qualitative (contextual) or quantitative (numeric). Many data-gathering techniques can be used for either category, although some are more appropriate for one than the other.

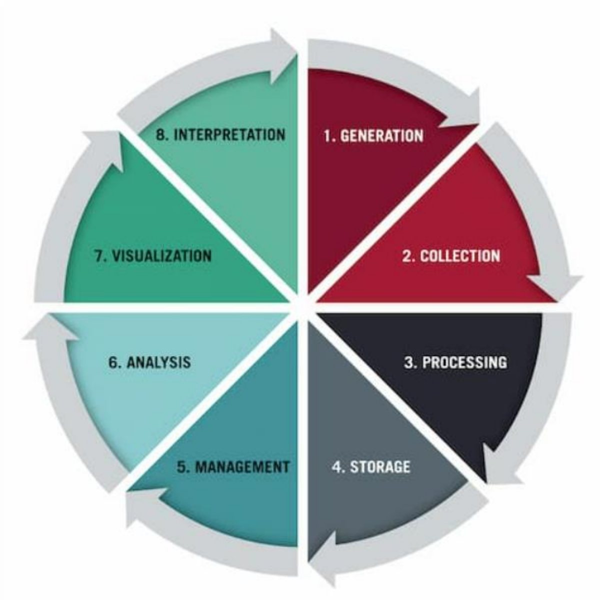


Figure 5:Data lifecycle (Source: Harvard Online Business Insight)

Figure 5 shows the lifecycle of the data and each step from generation to interpretation. To create the reports at site the data collection is an important step. The second step in the data life cycle is data collection. For the team to utilize the data that has been generated, it must first be collected. After that, it can be handled, managed, analyzed, and visualized to support decision-making inside the organization.

Before collecting data, several factors need defining

- The question aims to answer with data
- The data subject(s) need to collect data from
- The collection timeframe
- The data collection method(s) best suited to organization needs
- The data collection method selection should be based on the question that the organization wants to answer, the type of data the organization needs, the timeframe, and the organization's budget.

The Importance of the Data

Data collection is crucial to the success of a business since it allows us to make sure the information is accurate, comprehensive, and pertinent to the operation and the problem at hand. Organizations can examine previous plans and stay up to date on what needs to change thanks to the information obtained.

Data-driven insights can increase awareness of the company's efforts and provide concrete measures to enhance numerous initiatives, from revising marketing, service, and product upgrade plans and analyzing client complaints.

Making decisions based on erroneous information can have far-reaching negative effects, so it's critical to have confidence in data collection methods and skills. Business professionals can feel confident in their decisions by ensuring proper data collection. (Cote,2021)

7 Data Collection Methods Used in Business

1) Survey 2) Transactional Tracking 3). Interviews and Focus Groups 4) Observation 5) Online Tracking 6) Forms 7) Social Media Monitoring

Tracking Transactions**:** Keeping track of this information might help better understand the consumer base and make judgments about focused marketing campaigns.

The ability to save data as soon as it is collected is frequently provided by e-commerce and point-of-sale platforms, making this seamless data-collecting technique that can be profitable in the form of customer insights. (Cote,2021)

4.5 Conceptual Framework

The conceptual framework for this thesis is created to address the areas of weaknesses highlighted in Section 3 of the current state analysis. By putting it together, these frameworks will form the foundation for the structural framework that is proposed for the case company's spare parts forecasting for the new model.

The conceptual framework and its essential elements are described in Figure 6, with a connection to the results from Section 3. In Figure 6, in each categorized area the info in red color shows a weakness identified from the current state analysis containing no spare parts life data, no standard spare parts classification, a Maintenance program not supporting spare parts forecasting, and no standard performance measures.

The second component of the conceptual framework consists of the improvement areas, concepts, and methodologies chosen for the new process for forecasting spare parts for the new model. These steps are detailed in the blue blocks along with the literature sources that were utilized to determine the typical strategies that various industries have employed to address challenges of a similar nature in other, more established as well as more recently founded businesses in related industries.

the Third element is the output of the study and proposals for better spare parts forecasting, which can improve spare parts availability for new models. the Forth element is the arrows showing the flow of work & time of the study.

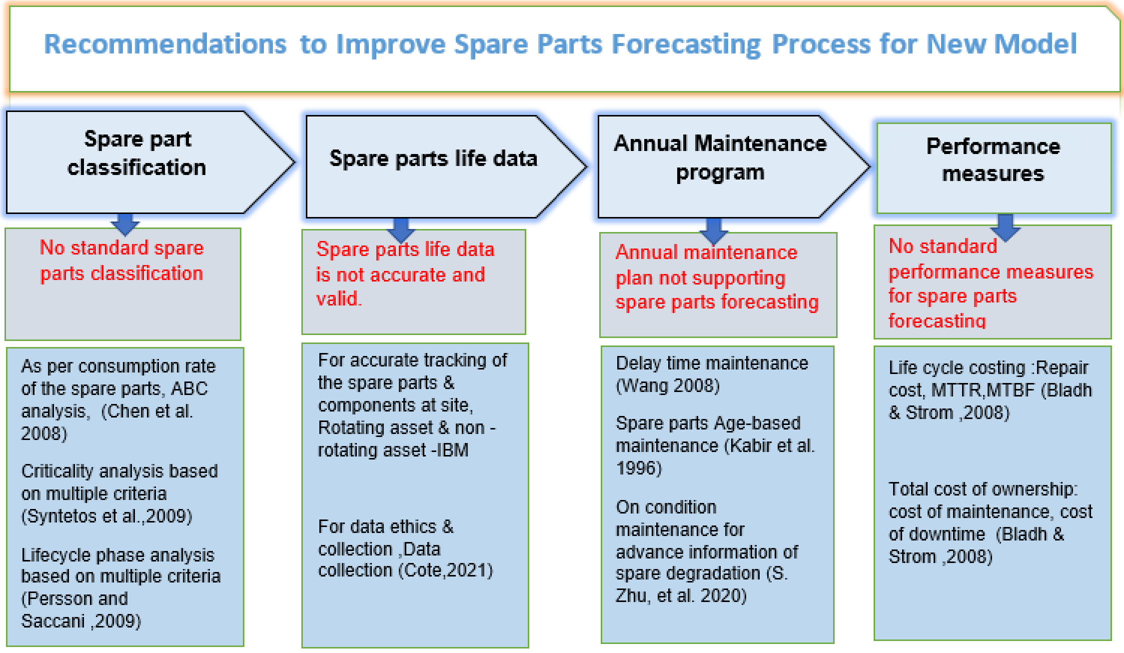


Figure 6: Conceptual framework

The conceptual framework is used to develop the initial process improvement suggestions in Section 5. By incorporating the acknowledged process strengths and removing the weaknesses discovered during the current state analysis, the conceptual framework is utilized to solve the spare parts forecasting process challenges for the new model.

5 Initial Recommendations of the Spare Parts Forecasting Process Improvement

By combining the results of the current state of analysis, Data 1, and the outputs from the conceptual framework, this section explains the initial recommendations of the spare parts forecasting process for new models. Moreover, a synopsis of the initial recommendations, a description of the co-creation process, and an outline of the data collection procedure are described in this section. The appropriate stakeholders and IT team were involved in the process of gathering the data-2 for the initial recommendations.

5.1 Overview of the Recommendation Co-Creation

For the joint development of the initial recommendations, four interviews with all stakeholders and three workshops were already scheduled. Following the completion of stage 2, the team was informed via email, before the scheduled workshop and interview dates, with the conceptual framework as well as the important CSA findings, which were divided into four practical process-related issues. This assisted the participants in comprehending the connection between weaknesses and potential solutions described in the literature before our sessions.

To gain a clear understanding and minimize topic overlap, stakeholders were arranged in meetings according to the same pattern as the categorization of weaknesses. The conceptual framework and available solutions for each weakness in that category were briefly explained at the beginning of meetings and workshops. To ensure that everything was completed quickly and efficiently, these sessions were always conducted online and in small groups.

The divisional stakeholders who were specifically accountable for the identified weaknesses participated in the first two seminars online. During the sessions, the team engaged in lively discussion and debate about the recommendations. A few stakeholders attended the previous workshop online. To obtain the initial

proposal of suggestions for ways to improve the spare parts forecasting process, all stakeholders were invited from across all divisions and allowed to assess and recommend other stakeholders' thoughts and recommendations in the last workshop.

Field notes were taken during each meeting and workshop, and then the initial recommendation for the spare parts forecasting was prepared. Initial recommendation categorization was easy since meetings and workshops were done with small groups of responsible people who categorized weaknesses. All the initial recommendations are presented in the following summaries:

5.2 Summaries of the Initial Recommendations

During the current state analysis, it surfaced that the indicative operative cost (IOC) document needs spare parts classification to identify the correct spare parts for overall predictive operation cost calculations of the new model, and the same spare parts can be used for maintenance planning, including the major component changeout plan. Figure 7 shows the initial recommendations for the spare parts classification with current state analysis findings and a conceptual framework.

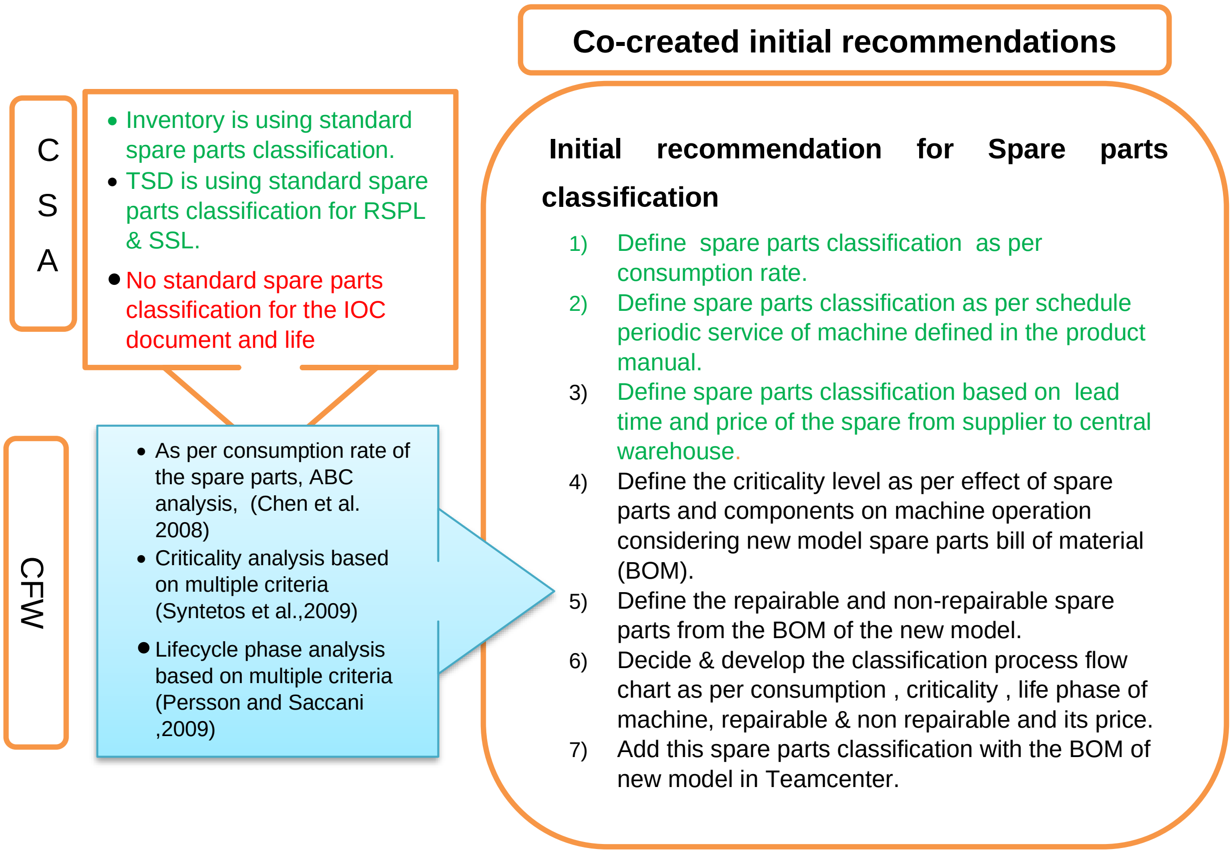


Figure 7:Summary of the initial recommendations for the spare parts classifications

The initial recommendation shown in Figure 7 is the spare parts classification process to have a proper understanding of the criticality of the spare parts based on different criteria, which will allow accurate selection of the spare parts for the indicative operation cost (IOC) calculation. The whole classification process is like the filtration of spare parts from the bill of material (BOM) of a new model. Recommendations are also in the order of filtration criteria.

The first recommendation for classification is based on the spare parts consumption rate globally in the last three years. This classification will indicate the consumable spare parts that were consumed in the equipment as per the utilization target at the site. These spare parts are low in price and high in volume as inventory at the site warehouse.

The second recommendation for classification is to identify the listed spare parts for the predefined scheduled periodic services of the equipment provided in the product manual. This classification will allow for proper insight into required spare parts like filters and seals for predefined periodic services throughout the lifecycle of the equipment as per its utilization and can be forecasted.

The third recommendation for classification is based on the lead time and price of the spare parts, which classify the spare parts that are high in price and have a long lead time. These spare parts need more attention to be planned as per the lead time and their expected requirements as per the utilization of the equipment.

The suggested initial first three recommendations needed data on spare parts consumption globally, lead time, and price of the spare parts, which were easily available with our inventory and logistic team.

The fourth recommendation was to classify the spare parts based on their effect on the equipment's operation. In another context, the team needs to analyze the effect of spare parts unavailability on equipment operation, which will reflect its criticality and loss in production.

The fifth recommendation was to define the spare parts as repairable and non-repairable and how much it is worth repairing considering the time and cost of repair. This classification will be limited to high-priced and critical spare parts and components.

The sixth recommendation was to decide and define the process flow chart of the classification by combining all the previous five defined classification criteria and classifying the whole bill of material of the new model, and the seventh recommendation was to add these classified spare parts categorizations of the new model bill of material in the Teamcenter.

The initial recommendation for the spare parts life calculation is shown in Figure 8. Spare parts life calculation requirements surfaced during discussions with LCM and the sales area team.

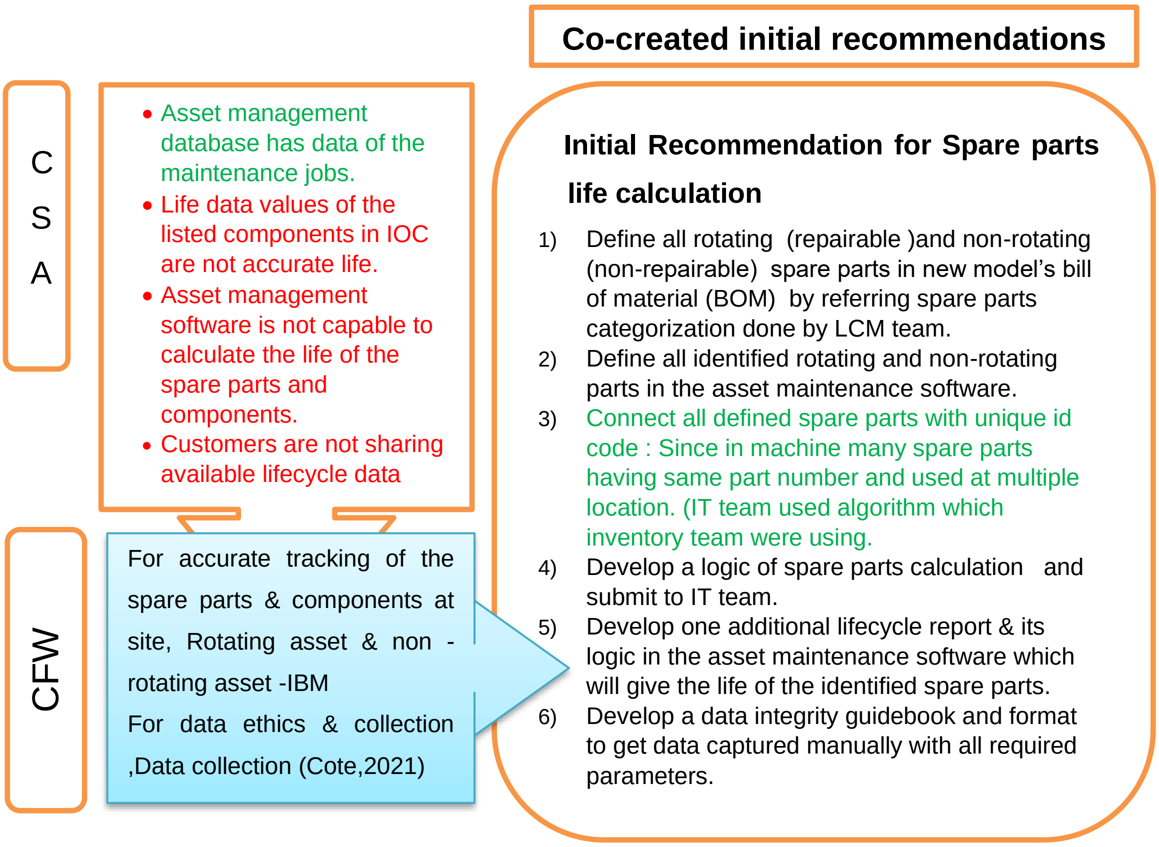


Figure 8:Summary of the initial recommendations of the spare parts life calculation.

The first recommendation was taken from spare parts classification and needed to identify the spare parts that should be selected for the life calculation in asset maintenance software. It follows the same classification criteria based on repairable and non-repairable assets; however, in IT terminology, it is called a rotating (repairable) and non-rotating (non-repairable) asset.

The second and third recommendations refer to defining all classified spare parts as rotating and non-rotating assets in the software and assigning them a unique ID code.

The fourth and most important recommendation was to develop the spare part life calculation logic in the software based on the different maintenance criteria and utilization reports. The fifth recommendation was to develop a report format and logic that will report the life of the defined spare parts inside the software for life calculation.

The sixth recommendation was for the manual data capture process; it refers to developing a data integrity guidebook and format for the manual entry. To get the proper life value, the format must have all the required parameters and attributes that the team needs to calculate the life of the spare parts and components. Integrity guidebooks explain the need for each parameter and how it is different for different models.

The co-created initial recommendations for an annual maintenance plan for the new model are summarized in Figure 9, as are the preceding current state analysis findings and conceptual framework topics also given in Figure 9

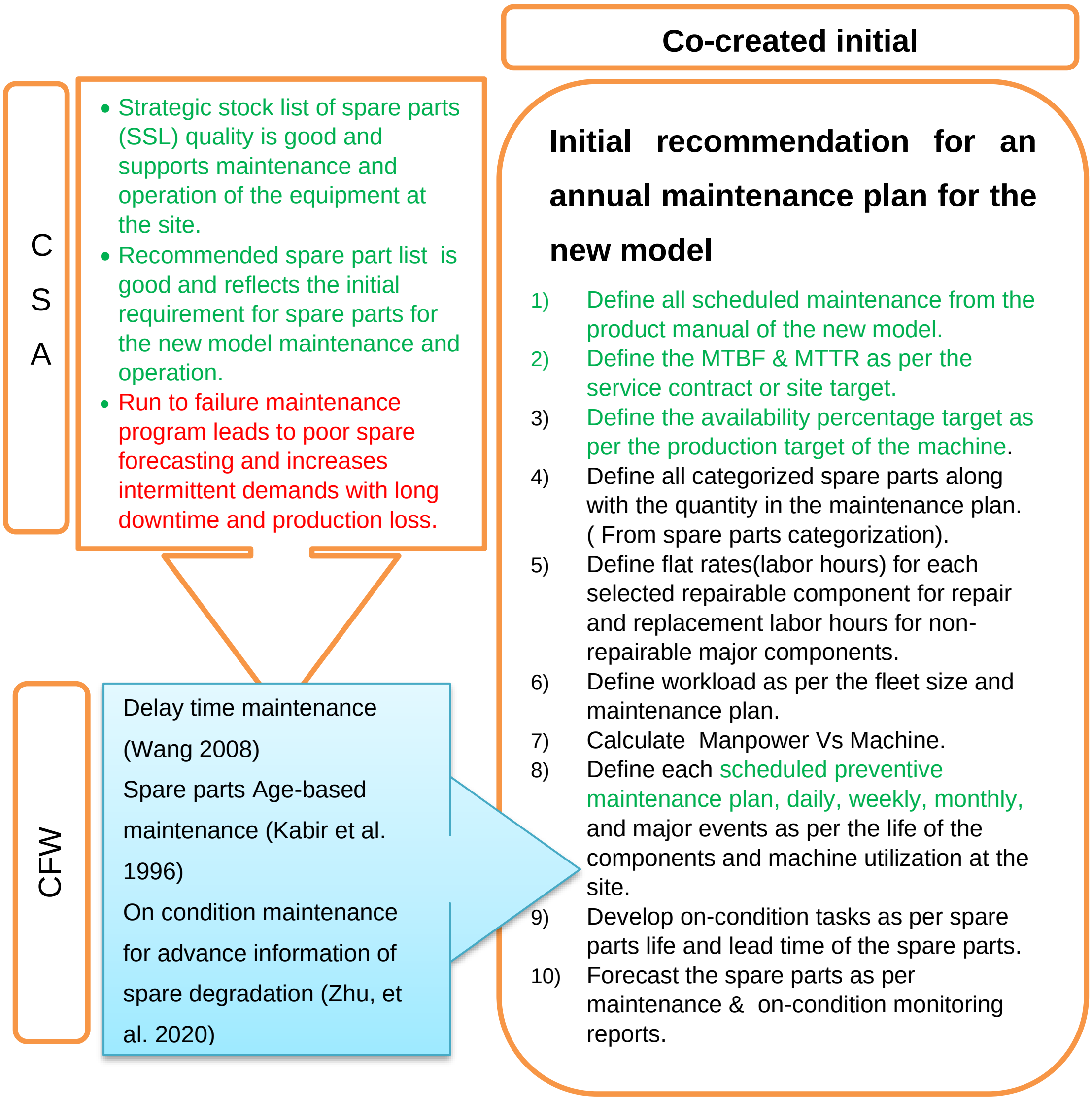


Figure 9:Summary of the initial recommendation of the annual maintenance program

The first three initial recommendations are about to include a schedule for periodic maintenance referring to the product manual and a calculation of Mean time to repair (MTTR) and mean time between failures (MTBF) is part of the current maintenance program and can be easily accomplished in the process. It will give a clear indication of the maximum allowed the availability of the machine agreed upon as part of the service contract or required as per targeted monthly or yearly production.

The fourth and fifth recommendations are together referred to as including all classified spare parts and their labour hours of replacement in the maintenance

plan after the planned periodic maintenance plan. In the first spare parts classification workshop, the team classified spare parts in the BOM of the new model as Service spare parts, Repairable and non-repairable major components, Critical spare parts, Maintenance and wearable spare parts, and the rest as False. For the annual maintenance plan, participants decided to include only major repairable and non-repairable classified spare parts to simplify the whole planning and calculations.

The sixth recommendation refers to defining the workload as per the number of operational machines at the site. This calculation considers each major repairable and non-repairable component (from the spare parts classification) and its expected changeout as per the life of the components (from the spare parts life calculation) throughout the expected lifecycle of the equipment at the site.

for example, let’s assume five years maintenance plan should include

- Planned maintenance intervals and the required time(labour hour) to perform them.

- Include all categorized repairable and non-repairable spare parts in the new model BOM along with the calculated life from the asset maintenance software, the manually captured life values of the components, and the expected life values of the new spare parts and components given by the engineering and sourcing teams to the LCM team for IOC creation during the NPD project of the same model.

It will indicate the required quantity of spare parts in the first five years of the operation of the equipment by getting the utilization hours from operation team.

The seventh recommendation refers to the calculation of manpower vs. machine based on the calculated workload, which is crucial in maintenance programs. This calculation will determine the downtime of the machine, the manpower required to perform any task or maintenance, and the machine's availability.

The eighth recommendation was to finalize the complete maintenance plan by including all required maintenance and services as per the daily utilization to achieve the production target of the customer. Maintenance and operation teams need to align and coordinate with each other to have a proper communication channel with updated daily, monthly, and yearly targets. It will allow the maintenance team to plan the daily, weekly, and monthly maintenance plans as per the minimum required availability to achieve the production target.

The ninth recommendation was to implement on-condition maintenance for the major spare parts before placing the order, given the lead time and age of the major spare parts. Performing proactive on-condition maintenance at regular intervals can give a more accurate time for the replacement or repair of the spare parts. As per the expected age, the parts planner can conclude the required quantity; however, on-condition maintenance will tell a more accurate time to place the order for the spare parts and will improve the forecasting accuracy and quality.

The tenth recommendation in the Figure 9 refers to the forecasting of the classified spare parts as per the maintenance plan and on-condition maintenance tasks reports. It will be the outcome of the eighth and ninth recommendations together.

In Figure 10 , the co-created initial recommendations for performance measures for spare parts forecasting are shown. Figure 10 also includes the preceding current state analysis findings and conceptual framework topics.

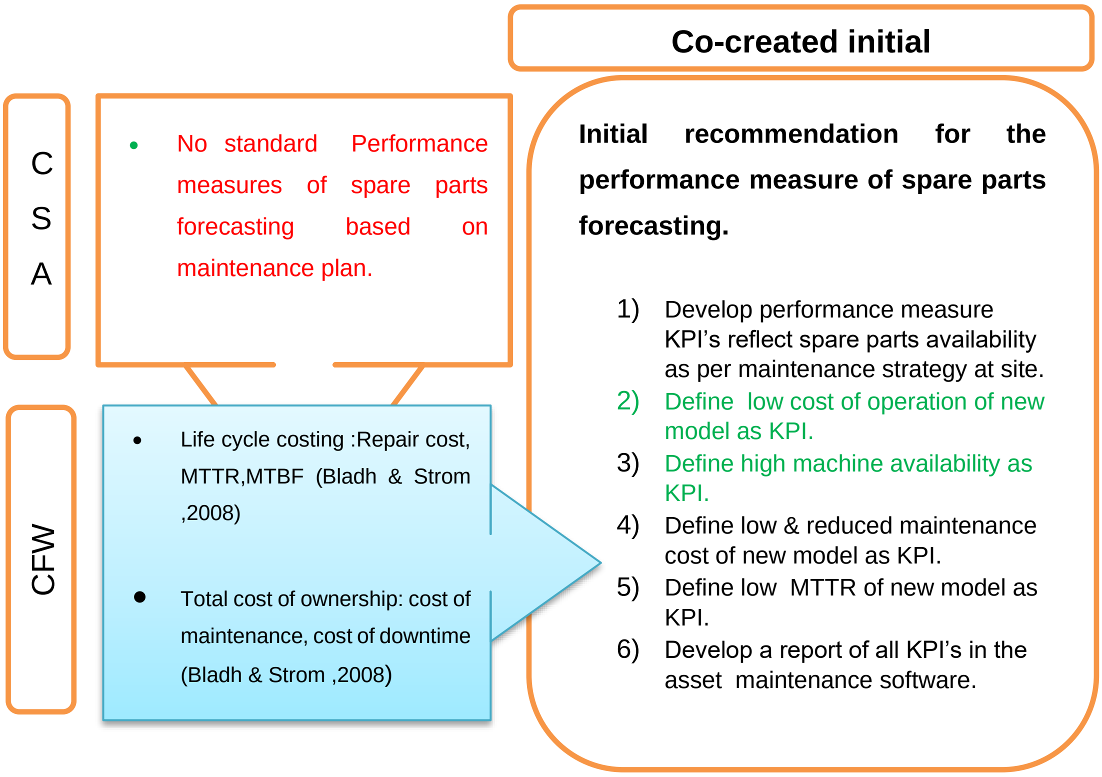


Figure 10:Summary of the initial recommendation of the performance measure

All initial recommendations in Figure 10 refer to set KPI parameters such as low cost of operation, high machine availability, low maintenance cost, and low MTTR. These parameters depend on a few other variables as well; however, the major effect on these values depends directly on the high availability because of improved forecasting of spare parts as per the planned maintenance program for the new model.

The last recommendation refers to the requirement of the report, which indicates all the mentioned KPI parameters and calculates them within the asset maintenance software for each asset or machine every month and analyses them to improve the whole cycle of spare parts forecasting.

5.3 Description of the Co-Creation of Initial Recommendation Process

The next three subsections describe the creation of the initial recommendation through online meetings and workshops. The LCM team and other stakeholders

went through the CSA and conceptual framework provided in an email. The team co-created the whole process of spare parts forecasting for new models.

5.3.1 Developing Spare Parts Classification

In our first meeting with the LCM team, who are responsible for the indicative operation cost (IOC) document, the team suggested that classification should be aligned with the actual spare parts consumption pattern in the equipment and define all the spare parts that are high in criticality for operation purposes, so that operation cost calculation should be more accurate, and the same parts need to be considered during the development of the maintenance plan.

> *IOC should reflect those spare parts that the maintenance team has been replacing and repairing during scheduled maintenance, breakdowns, half-life maintenance, and full life rebuilds. (Interviewee No. 1)*

The team also emphasized the spare parts and components that have been replaced or rebuilt once or twice throughout the lifecycle of the equipment; however, their contribution to the total cost of operation is high considering the high price of these spare parts and components.

> *Considering the total cost of operation of equipment throughout its lifecycle, only a few high-value components contribute a major part of the total cost of operation. Those components should be classified and included in the IOC. (Interviewee No. 2)*

In the last workshop, a recommendation was suggested by the sales area team on spare parts classification that it should indicate the spare parts that are repairable and non-repairable so that the maintenance and inventory teams can plan child spare parts from the repairable spare parts and reduce the overall parts cost. The LCM team also supported and accepted this recommendation for spare parts classification.

> *At present parts planners sometimes don't know which spare parts can be repaired and what the child items or kits are available for that repair. (Interviewee no-3).*

Stakeholders agreed to keep the complete spare parts classification of the new model visible to all other engineering and maintenance teams to maximize its potential benefits. Initially, it will be done manually by the LCM team for each model parent BOM and transferred to the Teamcenter, where it will be visible to all other users and can be utilized for other purposes in the future.

> *The classification should be visible and available on a common platform where other stakeholders can take advantage of its potential benefits. (Interviewee no-4)*

These were the initial recommendations given by the stakeholders on spare parts classification based on the weaknesses found in the CSA and conceptual framework.

The classified spare parts are named below:

a) Service spare parts: scheduled periodic service requires spare parts such as filters and breathers.
b) Maintenance and consumable spare parts: high-consumable and low-priced spare parts Such as pins, bushes, bearings, and bushes.
c) Repairable major spare parts: low-consumption spare parts throughout the lifecycle of the equipment; without its equipment, it can't be operated; repairable; and high-priced spare parts. Such as the engine, transmission, axle, and gearbox.
d) Non-repairable major spare parts: low-consumption spare parts throughout the lifecycle of the equipment, without which the equipment can't be operated; non-repairable; and high-priced spare parts. Such as the cradle, inner tube, and beam.

e) Critical spare parts: high consumption compared to major items, low in price, without a particular function or application, or could impact whole machine operation, such as sensors, hydraulic valves, and circuit breakers.
f) False: No impact or machine operation and very low consumption, such as structure, frame, bracket, or pipe.

Figure 11, shows the co-created initial proposed spare parts classification process flow chart, including all criteria recommended for classification.

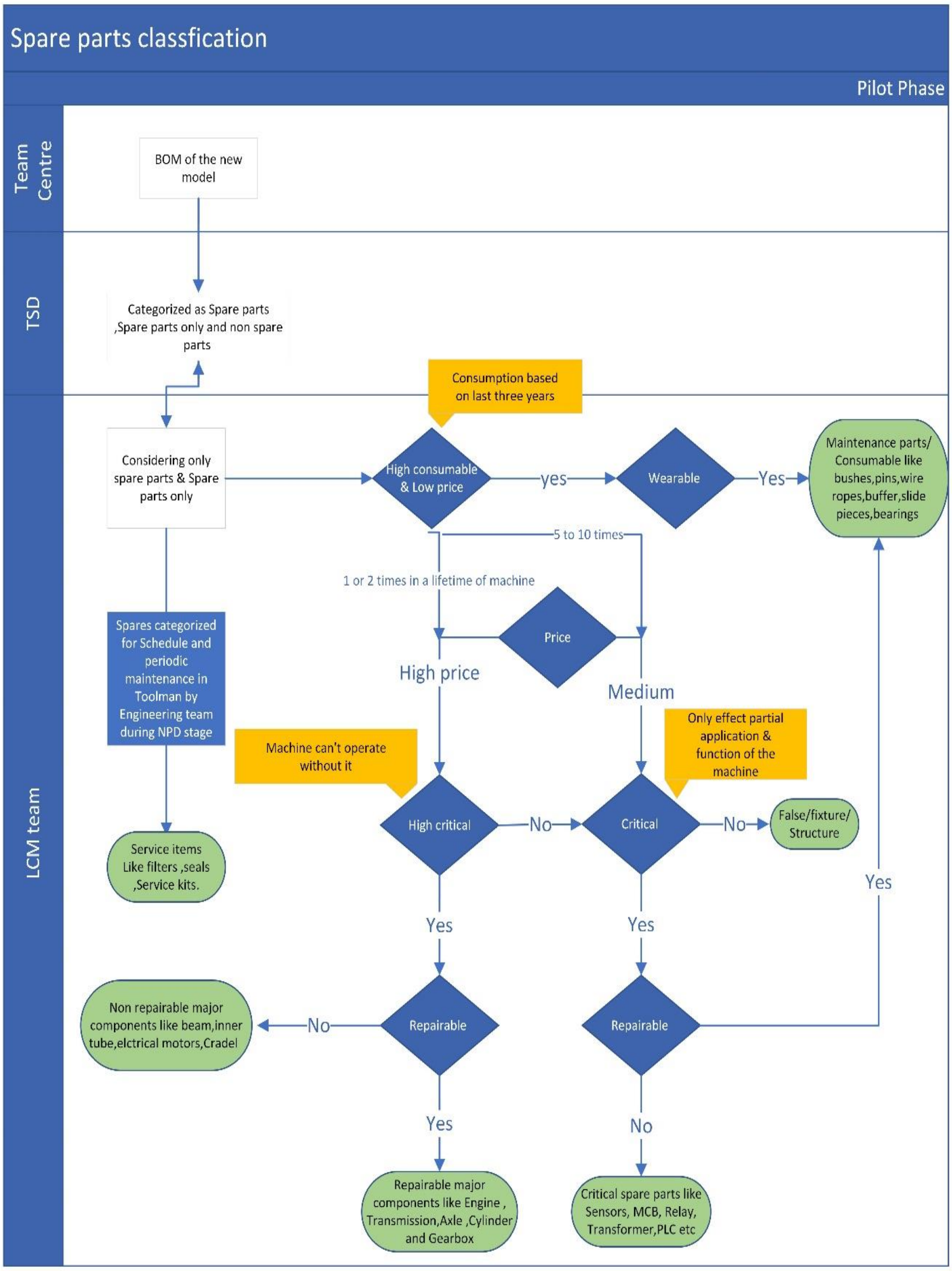


Figure 11: Process flow chart for the spare parts classification

5.3.2 Developing Spare Parts Life Calculation Tool

Stakeholders already agreed during CSA about the need for the lifecycle division to have the means to collect, analyze, store, and retrieve lifecycle data to gain the required insights to construct transparent, consistent, and reliable indicative operating cost (IOC) models.
After discussion within the team on the finding, it was found that SA's team doesn't understand the proper meaning of component life and what attributes are needed to calculate the valid life of the parts and components of different machines and with different operating hours. The team has drafted a guidebook that guides them on how to capture the data and what the attributes are to have valid and accurate life values on different machines.

> *SA's team needs more guidance on the meaning of spare parts lives and how it should be calculated. A guidebook on data integrity and manual data entry formats can help a lot. (Interviewee 5)*

Item life is measured by the "hours in service"-based interval with unit hours and sublocation-specific hour meters.

For example, heavy off-highway equipment uses legacy diesel units for two different types of hours: engine hours and transmission (driveline) hours. Choosing the most relevant hour type for measuring the item life is essential for optimized item life accuracy. In this example, engine hours (ref. unit hours) cumulate to enable the unit to be functional, representing 100% of overall unit hours, while engine hour sub. location driveline hours represent "mobilized hours". During operation, units are often parked, and the engine is idle. For driveline components, overall cumulated engine hours are way less accurate and measurable than transmission hours.

In underground drilling equipment, life hours calculation is complex and needs operational hours meter's location based. The most common practice is to capture only percussion, engine, compressor, and part consumptions. To get

proper life, the system needs to capture the location of each part or component changeout along with the specific location operation hours.

For understanding:

For carrier or driveline parts or component life, need the diesel engine hours (BEV: power pack hours).

For boom and feed parts and component life: in jumbo, many common parts (with the same part number) in both booms (in 3 boom jumbos in all 3 booms), location, and operational hours record will give the correct calculation of life. System need to capture both the location and the same boom percussion hours.

For utilization and total operation cost, power pack hours give proper utilization of the machine and the life of the power pack, water pump, and coolers. New-generation units such as BEV will most likely come out with totally new hour types to measure.

Drafted data capturing format and required parameters to get the proper life, team need to capture it manually, where SA's don't have asset maintenance software. The drafted report format is presented in Table 14.

Table 14:Drafted format to record data manually for proper life calculation

Accuracy of life calculation	***Unique MC Serial.***	***Unit type***	**Site ID**	***Region***	***Part ID.***	***Parts Description***	**QTY**	***Location hrs. (Eng/LP/RP/C)***	***Work type***	Date	Remarks
100 %											
A part number specific accurate recorded item life with location-specific hrs. available with Region, Site ID, Unit type, Unit serial, Item Description, Item qty, Item part number, date											

Table 14 shows the parameters required to calculate the accurate life of the spare parts and additional information which tells the reason for spare parts change such as work type: preventive maintenance, breakdown, damage, and warranty.

The second thing the team understood was that asset maintenance software has the potential to do the life calculation based on the maintenance data, which the sales area team(s) have been using for asset maintenance data entry and reports.

A life calculation tool in asset maintenance software is considered a possibility to fulfill the requirements. Stakeholders have already discussed and agreed to upload spare parts classification into the Teamcenter software, where it will be visible to all and available for all. To calculate the life of spare parts from the available maintenance data history in asset maintenance software, team need to use categorized spare parts only, and for now, the team will use only repairable and non-repairable spare parts, which are high in price and contribute a high percentage to the total operation cost of equipment.

The Life calculation tool is expected to handle various inputs, like:

- Teamcenter data
- IOC identifier: This will come from the spare parts classification done in the previous section.
- Part number: Product manual
- Baseline lifecycle data
- Local sales area price data
- Replacement data of service agreements maintained in asset maintenance software

Drafted logic of life calculation of any spare parts in asset maintenance software.

Drafted and suggested solution:

1. Extract all fleet-classified spare parts from the BOM along with their hierarchy as per the serial number of each machine.
2. With the BOM hierarchy, parent-child relationships are automatically stored in the system.

3. IT needs to assign a unique ID to each of the listed classified parts and components in the BOM of each machine.
4. The user will get all available unique ids related to part numbers for the selection of the specific unique id as per the location of the item.
5. The life calculation tool will do the life calculation as per the unique ID, not the part number.

For instance, if steering cylinder A, part number A12345, has two locations in the machine, then there will be two unique ids assigned to each location. Let's say the left and right steering cylinders have part numbers A12345. So unique ID of

Left steering cylinder: Part No. A12345 and Unique ID: UN12345
Right steering cylinder: Part No. A12345 and Unique ID: UN22345

Each time the user enters part number A12345, the software will show these two unique ids and ask to confirm the location. As per selection, the present respective hours will be tagged with the changeout of the steering cylinder, and life will be calculated. The system should restrict the user from saving the entry without selecting the position.

Life = present changeout hours minus previous changeout hours

For single-location spare parts, the same calculation logic will be applicable, and a unique id code will be auto-populated by the system for the users to calculate life.
Data integrity logic with WO job type Damage and Warranty.

The life of those parts registered in software under WO of damaged and warranty type will be calculated but not considered as the life of the parts.
The tool will reflect it in a different color and notify team that it is not approved.
Life calculation logic for damaged parts:

- The life of the next changeout of the same part should consider the time stamp of the previous changeout of the same part in the DA/WA job type.
- Scenario Part A: Part Number: Light1122 of Equipment Sl. No.: LD0123
- First time change out of light in maintenance at engine hour: 1256 hr.
- WO: BD: Life data1: light1122 = 1256 hours.
- If the technician has changed the same light as damaged at engine hours of 2456 hours,
- WO:DA: Life data 2: light1122 = 2456-1256 = 1200 (engine hours: 2456)

This calculated life value of light will be shown in "red" in the data set, not stored as a data point in the database for further life-value analysis and shown as "not approved."

Next time, the same light changed at engine hours: 5437 hr.
WO > PR: Life data 3: light1122 = 5437-2456 =2981 hours. (The system is considering the time stamp of the last change out of light in damaged WO.)

Calculated Life value analysis

The life calculation tool is expected to analyze classified component replacement data automatically based on customer-defined criteria and manually for data that does not meet the automated criteria.

Automated analyses

In the life calculation tool, there are customer-defined filter settings that allow the collected data to be analyzed and recorded based on part number-specific settings. Settings like:

- Reason for replacement: damaged, warranty (should be excluded from the calculation)

- Reason for replacement = Predictive Maintenance (PM), Schedule Maintenance (SM), and Breakdown BD (these are the only job types included in the life calculation).

If classified spare parts replacement meets all the relevant criteria, the data will be recorded in the Life Calculation Tool database and identified as auto-classified. If the classified spare parts replacement does not meet all the relevant criteria, it will be made visible in the manual classification screen.
Note: The modification of data will only apply to the data saved in the Life Calculation Tool database and will not change the original entered data. Every modification will identify the responsible LCM and require a comment field to explain the modification.

5.3.3 Developing Annual Maintenance Plan-based Forecasting

For the annual maintenance plan, participants from the sales area maintenance planner and parts planner were selected. Inputs from them in the co-creation workshop were also discussed among the other team members. The main focus was to create a maintenance plan that supported spare parts forecasting. The team suggested including all classified spare parts and their life to get visibility of upcoming parts replacement and repairs, and accordingly, the team can plan the machine, spare parts, and other required resources to perform the events with efficiency and minimum downtime. Such an annual maintenance plan with classified spare parts with life allows the maintenance team to have better communication with the operation team, be aligned with the production plan, and use the idle time for corrective or opportunity maintenance.

> *The maintenance plan must include classified spare parts with life, especially the major repairable and non-repairable spare parts, and components (maintenance plan workshop participant 1).*

The participant emphasized the proper workload and machine vs. manpower calculation. These initial calculations have a huge impact on the overall

maintenance plan and downtime of the machine. Workload calculation requires the required labor hours to perform each task as per the scheduled preventive maintenance plan, daily, weekly, monthly, and major events as per the life of the components and machine utilization at the site. Asset maintenance software has those labor hours for each task, which can be used in the maintenance plan workload calculation for each machine and then for the fleet. It is understandable and accepted by all that the team can’t calculate or plan accurately since unexpected breakdowns cannot be predicted or planned. To make an effective and accurate maintenance plan to keep unexpected breakdowns to a minimum, it is important to implement the maintenance plan as per planning with the operation team's coordination and keep maintenance compliance to a minimum of 85%.

> *The maintenance plan must have a proper workload calculation, which will be applicable in deciding the machine vs. manpower ratio as per fleet size. (Maintenance plan workshop, participant 2)*

Continuing the discussion, participants moved to develop the maintenance plan after having all previous data, such as classified spare parts of the new model with their life values and manpower vs. machine ratio. Based on these values, it was easy to calculate the machine availability as per the agreed MTBF and MTTR with customers. (The calculation sheet can be found in Appendix 6).

Mean Time Between Failures (MTBF) = (total up time) / (number of breakdowns)
Mean Time to Repair (MTTR) = (total downtime) / (number of breakdowns)
Availability = MTBF/(MTTR+MTBF)
"Mean Time" means, statistically, the average time.

Integrating on-condition maintenance into the maintenance plan is considered the core of functions to get advanced information on degradation and potential failure, which adds more value to spare parts forecasting. Participants want to incorporate on-condition maintenance into the present maintenance plan for the new model and legacy model as well. On-condition tasks and their frequency must be planned, depending on the life of the spare parts. Following the on-

condition maintenance tasks as advance demand information (ADI) for spare parts forecasting can improve maintenance and accurate spare parts forecasting. The on-condition maintenance task must be cost-effective and should reduce the operational consequences. It should focus on the critical major repairable and non-repairable spare parts, which have high operational consequences.

> *On-condition Maintenance must be an integral part of the maintenance plan to get the proper health information on the critical and major components and help in advance forecasting. (Maintenance plan, participant 3)*

The team suggested planning on-condition tasks as per the life of the spare parts, and the frequency of tasks must be equally divided throughout the expected life, and additionally, do one brief inspection before its lead time duration.

In addition to that, team now need to add and plan all major events, repairs, and replacements as per the age of the spare parts and components and the machine's average monthly utilization as per the production target. It will give the real picture of the required major spare parts in advance as per the age of spare parts and equipment utilization.

Let’s assume spare part A has an expected life of 10,000 engine hours and machine life is five years. As per operation and the production target, machines will be operated on average for 10 hours per day, 70 hours per week, 300 engine hours per month, and 3600 engine hours in a year. It indicates that spare parts A will be required in the third year of operation if all assumed conditions and the operating rate remain the same. The team can develop an Excel sheet that can indicate the live requirement of spare parts as per the present operation hours of the equipment.

Performing on-condition monitoring considering the lead time of the spare parts will improve forecasting and reduce the inventory load.

Continuing the previous assumption,

Spare part A has an expected life of 10000 engine hours.

Lead time: 4 weeks

Average monthly/yearly operation hours: 300–3600 engine hours

Date of commissioning of the machine: 1 January 2023

Date of replacement of spare part A: 10000/300 = 33rd month

Order placing date: (10000-4*70)=9720 engine hours. This means that when the machine will reach 9720 engine hours, the team should place the order for spare part A. It will be achieved in 32.4 months after commissioning.

If the maintenance team performs the on-condition maintenance in the 31st month after commissioning, then the team can check all health parameters of components and conclude whether spare part A is required now or not. Such practice will improve forecasting and reduce the inventory load and chance of dead stock. On-condition maintenance tasks can be done either the "run to death or "rebuilt" maintenance strategies.

5.3.4 Developing Performance Measure

Performance measures for spare parts forecasting were new for all since the maintenance team has been using different parameters for the maintenance plan and the inventory team has the same for spare parts inventory. To develop and agree on common parameters to see the direct relation between spare parts availability, maintenance plan, and machine performance plan and the inventory team has the same for spare parts inventory. To develop and agree on common parameters to see the direct relation between spare parts availability, maintenance plan, and machine performance, participants had a good discussion

on the direct effect and its calculation, which reflect spare parts forecasting as a major factor.

> *Machine cost of operation, machine availability, machine maintenance and repair costs, and downtime costs due to spare parts unavailability (loss in production as agreed in the contract) are the important parameters that indicate a direct relation between spare parts availability and machine performance. (Performance measure meeting participant 1)*

The low cost of operation of the machine is considered the basic KPI, which indicates good maintenance and parts planning. It indicates on-time spare parts changed as per the life and planned on-condition task reports. There are no major consequences of failure on other functions and spare parts of the machine.

Machine availability is directly related to spare parts availability during planned preventive maintenance and breakdowns. Accurate spare parts forecasting as per the maintenance plan will improve spare parts availability, which ultimately leads to increased machine availability. Using on-condition maintenance reports enhances spare parts forecasting, which can reduce hidden and potential failures in machines and increase machine availability by eliminating unexpected breakdowns.

Machine repair and maintenance costs also indicate spare parts availability because of good forecasting based on planned maintenance and on-condition tasks. Identifying the upcoming failure, taking a timely repair decision, and forecasting the required parts will reduce the machine repair and maintenance costs. Machine downtime cost due to spare parts unavailability is also considered a KPI to see the improved spare parts forecasting.

Lastly, the team has agreed to set up a new KPI report in asset maintenance software. The report will be visible and accessible to all stakeholders who are related to the specific service contract. To develop a report, the IT team suggested having a new code that users need to add whenever punch the

breakdown and cost due to the unavailability of spare parts in system. It will trigger and separate entered data for all asked KPIs in the report and will do the required calculations in the background.

5.3.5 Draft of the improved spare parts forecasting process

By collecting all suggested initial recommendations, the author of this study created a flowchart of the improved spare parts forecasting process and shared it with all stakeholders and the final validation team to update them with the outcome of the meetings and workshop. (Flowchart can be found in Appendix 7).

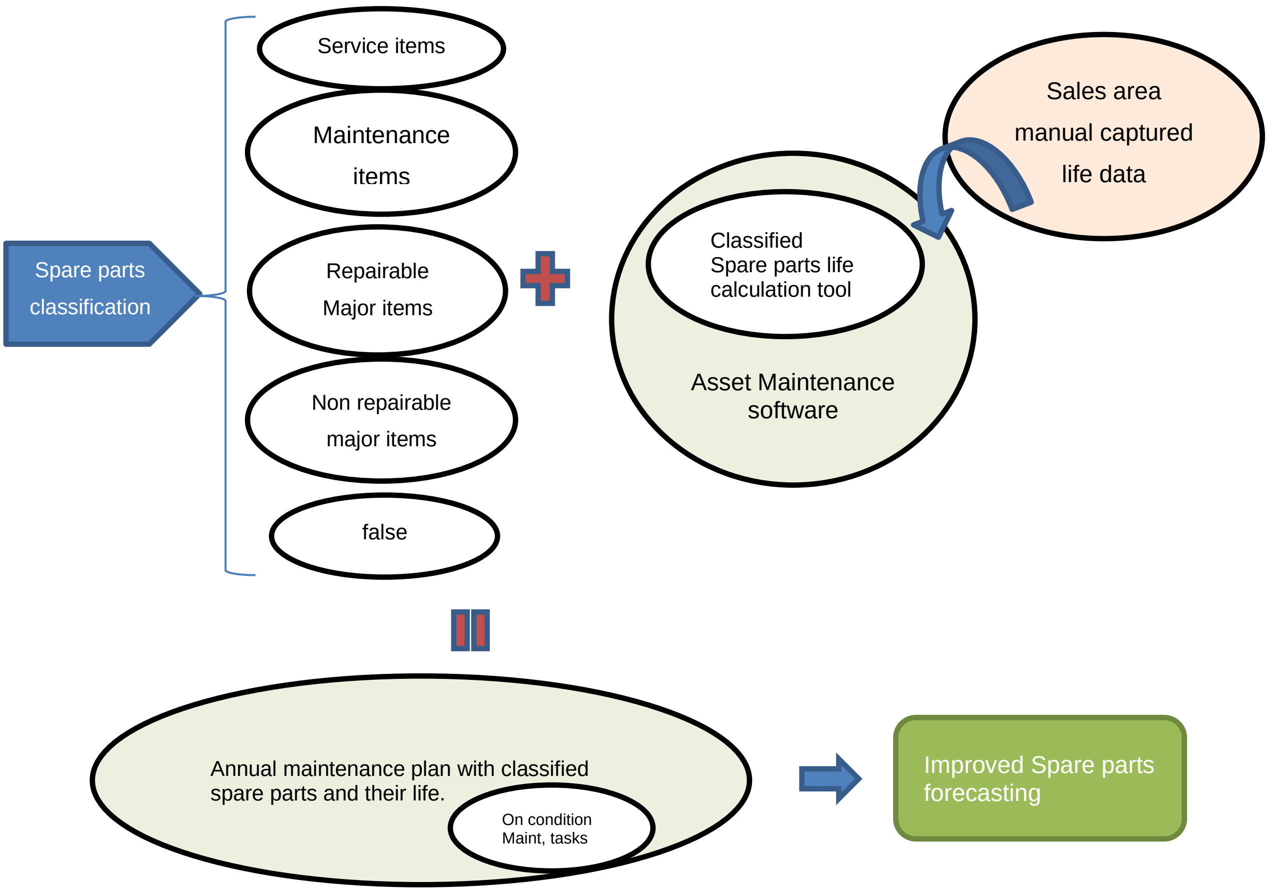


Figure 12: Annual Maintenance plan base concept

The final agreement among participants was to develop a maintenance plan of equipment that must have all information on all spare parts requirements in its

lifecycle and plan all changeovers and repairs as per spare parts life. Figure 12 shows the base concept of the annual maintenance plan by including all classified spare parts of the new model from its BOM and then using data of calculated life of the same spares from asset maintenance software, manually collected data from different sales areas and provided by spare parts supplier during NPD projects, which is available in IOC documents. Each step result will be used in the next step to accomplish the initial recommendations to improve the spare parts forecasting for the new model.

Initial recommendations and the procedure for gathering them are discussed in this section. Throughout discussions and workshops, 28 initial recommendations were created. The comments from the stakeholders addressed the current state analysis and all areas of weakness, including spare parts forecasting, spare parts life calculation, annual maintenance plans, and performance measures for spare parts forecasting. Section 6 describes how these initial recommendations were validated.

6 Validation of the Recommendations for Spare Parts Forecasting Process Improvement

Validation of the initial recommendation is described in this section. First, the structure of the validation process is described in this section then the outcome of the validation discussion and critiques. Then the change was done in the initial recommendations and finally the outcome of the study.

6.1 Overview of the Validation of the Recommendations

In the validation process, few stakeholders were the same as in the initial recommendation phase along with senior managers of the case company selected for the final feedback and critique on the initial recommendation. These senior managers were already informed and got a brief introduction of the study, CSA & initial recommendations in an email. The selected stakeholders are directly responsible to make any decision in the categorized weaknesses process and methods and most relevant assessing the initial recommendations and suggest required corrections for implementation to improve the spare parts forecasting process.

Two face-to-face workshops were held for the validation of the initial recommendations, and a few participants from the sales area joined it online on Teams. Both workshops started with a brief introduction of the whole study, an explanation of the current situation analysis findings, and then a conceptual framework. To get Data 3, initial recommendations were explained in detail to get the proper feedback from the senior managers and other stakeholders. All comments and feedback were noted down during the meeting and transcribed after the workshop for the thesis.

6.2 Management Feedback from the Final Validation Workshops

During the initial recommendation presentation and discussion on each classified weakness, the feedback and comments were coming from the stakeholders. The complete study and the process to get the initial recommendations were appreciated by senior managers and acknowledged as good work and a feasible solution for the aftermarket key issue of spare parts forecasting for the new model.

> *Happy to see that the whole study is aligned with company actual existing problem and suggested recommendations look feasible with available resources. It reflects that the CSA phase was done with the correct stakeholders. (Sales Support Manager, Asia)*

During the initial recommendations for spare parts classification, the LCM team and Asset Lifecycle Manager gave feedback on the chosen criteria for classification. The team wanted to keep more precise and quantitative criteria on a few classifications. Below is the feedback referring to initial recommendations for spare parts classification

1. Define spare parts categorization as per consumption rate.

   Need to analyze customer-wise; data varies a lot on the customer/site level (Inventory Manager)

2. Define the criticality level as per the effect of spare parts and components on machine operation considering the new model BOM.

   Need to develop quantitative criteria: (Asset Lifecycle Manager)

3. Add this spare parts classification to each asset's BOM in the TC.

   Need to develop a process for it: (Data and market Analyzer)

Feedback received on the spare parts life calculation was related to the practical implementation of the tool considering inconsistency in the available maintenance history dataset in the asset maintenance software. As per the Data

specialist, available data is not accurate for the repairable major components, since at sites teams are not following proper tracking and the data of inventory in & out, and sometimes machine data in which it used are missing.

4. *For life calculation, concentrate initially only on non-repairable spare parts, which are replaced only with new ones. Repairable spare parts are missing some required parameters for life calculation due to a lack of inventory in and out processes at sites in between repair shops, stores & sites. (Data Specialist & Sales Support Manager)*

Feedback received on the annual maintenance program was focused on the to get more visibility of future requirements of spare parts which lead to effective forecasting. Required labor hours data for

5. Define flat rates (labor hours) for each selected repairable component for repair and replacement labor hours for non-repairable major components.

   Need to have site-related data to have more accurate planning. (Sales Support Manager & Asset Lifecycle specialist)

6. Define each scheduled preventive maintenance plan, daily, weekly, monthly, and major events as per the life of the components and machine utilization at the site.

   Consider consumable and wearable items also in the maintenance plan and estimate the flat rates and labor hours for those. (Asset Lifecycle Manager)

7. Develop on-condition tasks as per spare parts life and lead time of the spare parts.

   Need to check options for real-time monitoring and its effect on the extension of the life of components: (Asset Managers and LCM team)

Feedback on the Initial recommendations for the performance measure of spare parts forecasting was positive and it was accepted as it is.

6.3 Final Validation of Suggested Feedback

All participants agreed to discuss the feedback that came in the first workshop as per its feasibility and implementation with final recommendations. After brainstorming on the required resources and time to perform the tasks, participants decided to keep a few points as a spin-off project for later on and a few as a part of the final recommendations. Table 15 is the summary of Data 3 as final recommendations. Among seven feedbacks, only four feedbacks were considered as part of the final recommendations and three were considered for the spin-off projects.

Table 15:Decision taken by the stakeholders on feedback

Categories	sl. No	Suggestion & Feedback	Decision by stakeholder	Originated from	Accountable	Responsible	Date
Spare parts classification	1	Analyze consumable spare parts. customer wise, data varies a lot on the customer /site level	Accepted	Inventory team	LCM team	LCM team	June
	2	Need to develop quantitative criteria for spare parts effect on operation	Spin off				TBD
	3	Need to develop process for updating spare parts classification in Teamcenter .	Spin off				TBD
Spare parts life calculation	4	For life calculation concentrate initially only on non-repairable spare parts ,which replaced only with new one	Accepted	LCM team	LCM team	LCM team	June
Annual Maintenance program	5	Need to have site related data to have more accurate planning	Accepted	SA :Asset lifecycle specialist	LCM team	LCM team/ SA	July
	6	Consider consumable & wearable items also in maintenance plan and estimate the flat rates/labor hours for that	Accepted	Asset lifecycle Manger	SA/LCM team	LCM Team / Maintenance & parts planner	July
	7	Need to check options for Real time monitoring & its effect on extension in life of components.	Spin off				TBD

Table 15 shows the accepted final recommendations task responsible and accountable team and the timeline to get it done for the implementation purpose. Spin-off projects are taken for later on and not considered as part of this study.

Overall, the process worked well, and the objective has been fulfilled as an improved spare parts forecasting process by taking into consideration the case company's weaknesses, strengths, and stakeholders' expectations. The seventh and final section of the study summarizes the work, recommends the next steps toward the implementation of the improvements, and provides a self-evaluation of the study.

7 Conclusions

This section summarizes the study and evaluates its success by comparing the business problem to the solution provided by this study to improve spare parts forecasting for the new model in the case company. This final section contains the executive summary, a self-evaluation of the study, and the final closing words.

7.1 Executive Summary

The case company has been facing challenges in the aftermarket business for the new models of heavy off-highway equipment. The case company has been struggling to full fill the spare parts availability at the service contract sites, consignment stock, and VMI contracts as per machine operation and production targets. The objective of the study was to recommend improvements to the spare parts forecasting process for the new model of the case company. The outcome of the study is the recommendation to improve the present spare parts forecasting process for the new model at service contract sites and VMI.

The study used a design-research methodology using qualitative data collection techniques. There were four stages of the design research. A current-state study, which outlined the process's strengths and weaknesses, was the first stage. Based on the results of the first stage, the second stage involved literature research and the creation of a conceptual framework using pertinent prior information. The earliest recommendations for process improvement were created during the third stage, which involved co-creation with important stakeholders. The study's final suggestions for process improvement were developed during the fourth and final step, which involved a validation round of the initial recommendations and feedback from senior management.

The current state analysis was performed through the stakeholders' interviews, workshops, and emails. The findings were divided into four categories to make it easier to understand and find relevant literature. The first category was spare parts classification, which refers to the strengths and weaknesses related to the

requirement of understanding spare parts criticality from the perspective of machine operation and maintenance planning. The second category was spare parts life calculation tools, which refer to the requirement of life data for accurate indicative operative cost (IOC) calculation and ultimately support the parts planner at sites in spare parts forecasting. The third category was the annual maintenance plan, which focused on the inclusion of classified spare parts with the expected or calculated life value to get clear visibility of future requirements for spare parts as per the planned annual maintenance plan. The fourth category was performance measures to define the KPI of spare parts forecasting accuracy. The categories of existing state weaknesses served as the foundation for the literature review. The conceptual framework incorporates best practices and current information aimed at addressing the weaknesses found.

Initial recommendations were co-created with the relevant and key stakeholders in the spare parts forecasting process. All sessions were held with specific categories of weaknesses and initial recommendations for them. In total, 29 initial recommendations were suggested in four interviews and three workshops, which were again categorized with the same logic used to categorize strengths and weaknesses.

Spare parts classification got seven initial recommendations based on the ABC analysis, the criticality analysis approach, and multiple criteria based on the effect on machine operation. The focus was to classify the spare parts according to their criticality and use in the machine throughout the lifecycle of the machine, considering their maintenance, half-life rebuild, and full-life rebuild programs.

The Spare Parts Life Calculation Tool category received six initial recommendations that refer to the calculation of spare parts life based on the available maintenance history data in asset maintenance software and can calculate the life of spare parts with new entries at sites that have been using it at different service contract sites to keep the maintenance and rebuilt data of the fleet. These recommendations include the rotating asset concept to calculate the life of spare parts.

The annual maintenance program category received around ten initial recommendations, which included spare parts age-based replacement and a condition-based concept for maintenance programs to have better visibility of the future requirement of spare parts in advance and forecast accurately. The last category of a performance measure, spare parts forecasting, received six initial recommendations that related to the different KPIs based on the key elements and parameters of the total cost of ownership.

The final recommendations were finalized after the validation of the initial recommendations by senior managers and relevant stakeholders in two workshops. In the final validation, senior managers appreciated the whole set of recommendations and found them feasible and implementable to improve the spare parts forecasting process with seven feedbacks. Among the seven recommendations, only four were accepted as feasible by the stakeholders to have more site-specific data-driven recommendations to improve the accuracy of spare parts forecasting. Three recommendations were decided as spin-off projects, which will be decided later after the first pilot implementation of the final recommendations at any service contract site with key customers and analysed for their effect on the whole spare parts forecasting process's accuracy.

7.2 Self-evaluation of the Thesis

The objective of this Thesis was to recommend improvements in the present spare parts forecasting process for the new models from the perspective of aftermarket businesses such as VMI and service contracts in the case company. The outcome of this Thesis is provided in Section 5.2 as initial recommendations divided into four categories to improve the spare parts forecasting process for the new model. These initial recommendations were validated by the relevant and key stakeholders of the case company. Among the 29 initial recommendations, only four feedbacks were suggested and included in the final recommendations with the requested changes. This indicates that the objective of the study was fully met by the final recommendations.

These small changes as final recommendations also indicate the correct identification of weaknesses in CSA with the correct stakeholders and understanding of the weaknesses and the relevant selection of literature as per its implication and alignment with the case company's present processes and resources. Being part of the lifecycle asset management team, the involvement in processes and communication with stakeholders was easy, and at the same time, it taught me time management skills and working under pressure with a large team, considering the short time to complete the Thesis. Being a team member, the CSA team was transparent and honest in its feedback and made it happen within short notice to key stakeholders. The time factor was important to complete the whole study and could help to get better results.

The evaluation of this Thesis, from the four categories of validity, reliability, logic, and relevance of research is described in the following sub-sections.

7.2.1 Validity

Lincoln and Guba (1985) used the trustworthiness of a study as the naturalist's equivalent for internal validation, external validation, reliability, and objectivity. In qualitative research, trustworthiness is achieved by credibility, authenticity, and transferability. To operationalize these terms the trustworthiness of a study is the naturalist's equivalent for internal validation, external validation, reliability, and objectivity. In qualitative research, trustworthiness is achieved by credibility, authenticity, and transferability. To operationalize these terms, need triangulation of data sources, methods, and investigators to establish credibility.

Credibility and authenticity were established in this thesis by triangulation. Data sources were the relevant key stakeholders responsible for and directly connected with the subject of the thesis. Data 1 was collected by engaging all relevant stakeholders of the case company in the current state analysis. Initial recommendations as Data 2 were collected in four meetings and two workshops with the different stakeholders and process owners in their respective categories

of weakness as defined in the conceptual framework. After each data collection stage, the outcome was circulated to all involved stakeholders and senior management to keep them informed of the updates. Senior managers and sales support managers, who hold global positions and look after different sales area aftermarket challenges, were involved in the final recommendations' data gathering workshops.

The whole study was done by considering only specific new models and aftermarket situations with specific service contracts in the specific sales area of the case company. Considering fast-changing technology, different site uniqueness in terms of operation conditions, and respective customers' requirements, the outcome of this study is not transferable to another off-highway equipment manufacturing company or another context.

7.2.2 Reliability

The reliability of the Thesis is reflected throughout the report text by describing each execution phase in detail and sharing all the data collection process detail and its sources. Section 2 described the research design; Section 3 described the current state analysis along with each noted data point and its source details; and Sections 5 and 6 explained the details of the initial and final recommendations and involved stakeholders' feedback details and their context.

7.2.3 Logic

The logic was set by identifying the correct research design as per the real business challenge in the case company. Finding the weaknesses in CSA by involving relevant stakeholders in the case company Searching relevant and applicable practice-based literature, developing the conceptual framework, and creating the initial recommendations with diverse participants from different business areas to improve the present process challenge. Acceptance of the initial recommendation and approval of it with some suggested changes by the senior manager makes more sense of the logic of this Thesis.

7.2.4 Relevance

The thesis is relevant as identified. The thesis topic is the actual challenge faced by the aftermarket business in different sales areas. The objective of the study was to improve the real problem in the spare parts forecasting process for new models in the case company. Relevance of the Thesis is ensured by involving relevant key stakeholders in each stage of data collection, as described in Sections 3,5, and 6.

7.2.5 Closing Word

The spare parts forecasting process is the key to the successful execution of the maintenance plan and machine operation at the site of off-highway heavy equipment. Suggested improvement is achievable with enhanced team integration and coordination among the sales area, inventory planner, and asset lifecycle team. Its implementation and accuracy depend on many different sites and customer-specific variables and available spare parts life data in asset maintenance software. Manual capture data is very limited and will take time to grow. Each implementation project will be unique and need the attention of key stakeholders to achieve the result of accurate spare parts forecasting.

Reference List

Acharya, D., Nagabhushanam, G., and Alam, S.S. (1986). Jointly optimal block-replacement and spare provisioning policy, IEEE Transactions on Reliability 35, pp.447-451.

Atcheson, D. (1993). Earthmoving Equipment Production Rates and Costs. Norseman Publishing, Venice, FL.

Barlow, R.E., and Proschan, F. (1965). Mathematical Theory of Reliability, Wiley, New York.

Bladh & Strom. (2008). Master’s thesis, Total cost of ownership - Revealing the true cost of owning and operating equipment.

Chen, Y., Kevin, W., Levy, J., Hipel, K. & Kilgour, M. (2008). A Rough Set Approach to Multiple Criteria ABC Analysis, pp. 35-52.

Cote, C. (2021). 7 Data collection methods in Business Analytics Available from: https://online.hbs.edu/blog/post/data-collection-methods (Accessed on 29 March 2023).

Douglas D. Gransberg . (2015).Major Equipment Life-cycle Cost Analysis. pp. 25-57.

Ellram, M.L . (1993). A framework for a total cost of ownership, International Journal of logistic management, No2.

Falkner, C.H. (1969). Optimal spares for stochastically failing equipment" Naval Research Logistics Quarterly 16. pp.287-295.

Fortuin, L. & Martin, H. (1999). Control of Service Parts. International Journal of Operations & Production Management, Vol. 19 pp. 950-968.

Gajpal PP, Ganesh LS, Rajendran C. Criticality analysis of spare parts using the analytic hierarchy process. Int J Prod Econ 1994;pp. 35

Habib, M., Banik Pathik, B. and Maryam.H. (2014). Research Methodology Contemporary Practices. pp. 1-44.

Kaio, N., and Osaki, S., (1978) Optimum ordering policies with a lead time for an operating unit in preventive maintenance, IEEE Transactions on Reliability 27 pp. 270-271.

Kaio, N., and Osaki, S. (1981). Optimum planned maintenance policies with lead time, IEEE Transactions on Reliability 30 pp.79.

Lin X., Basten RJI, Kranenburg AA, Van Houtum GJJAN. (2017). Condition-based spare parts supply. Reliab Eng Syst. pp.168:240–248.

Macchi, M., Fumagalli, L., Pinto, R. & Cavalieri, S. (2011). A Decision-Making Framework for Managing Maintenance Spare Parts in Case of Lumpy Demand: Action Research in the Avionic Sector. Service Parts Management, pp. 171-202.

Ministry of Business, Innovation & Employment, New Zealand. Total Cost of ownership.<https://www.procurement.govt.nz/assets/procurementproperty/documents/guide-total-cost-ownership.pdf> (Accessed on 28 March 2023).

Osaki, S., Kaio, N., and Yamada, S. (1981). "A summary of optimal ordering policies", IEEE Transactions on Reliability 30. pp.272-277.

Park, Y.T., and Park, K.S. (1986). "Generalized spare ordering policies with random lead time", European Journal of Operational Research 23 pp. 320-330.

Poppe J., Basten RJI., Boute RN, (2017) Lambrecht MR. Numerical study of inventory management under various maintenance policies. Reliable Engineering System pp.168:262–273.

Qaris Faryadi. (2019). Ph.D. Thesis Writing Process: A Systematic Approach—How to Write Your Methodology, Results, and Conclusion.

Rotating & Non-Rotating Asset. IBM <https://www.ibm.com/docs/en/mamsaas?topic=SS8CCV/com.ibm.mbs.doc/inventor/c_rotating_asset.htm>,(accessed on 28 March 2023) <https://bportaluri.com/2012/04/Asset maintenance software-rotating-assets-type.html>(accessed on 28 March 2023).

Sam Goundar. (2012). Chapter-3: Research Methodology and Research Method. Available from:<https://www.researchgate.net/publication/333015026>.

Wang, W., (1997), Subjective estimation of the delay time distribution in maintenance modeling, European Journal of Operational Research, 99, pp.516-529.

Wang, W., (2012), A stochastic model for joint spare parts inventory and planned maintenance optimization, European Journal of Operational Research, 216, pp.127–139.

White, L., (2006).Determining total cost of ownership, Food service equipment, and supplies

Appendices

Appendix 1:Research Questions

Subset questions from each team

a) What is spare parts forecasting means in your business context?

b) Who are the key stakeholders involved in the spare parts forecasting process and their roles and responsibilities?

c) What are the key factors that need to consider in the spare parts forecasting process?

d) How product division coordinate with the sales area in the spare parts forecasting for the new model?

e) Is it different with a service contract and without service contract sites?

f) What is the process of spare parts forecasting at service contract sites?

g) What are the identified challenges with the new models' spare parts forecasting process?

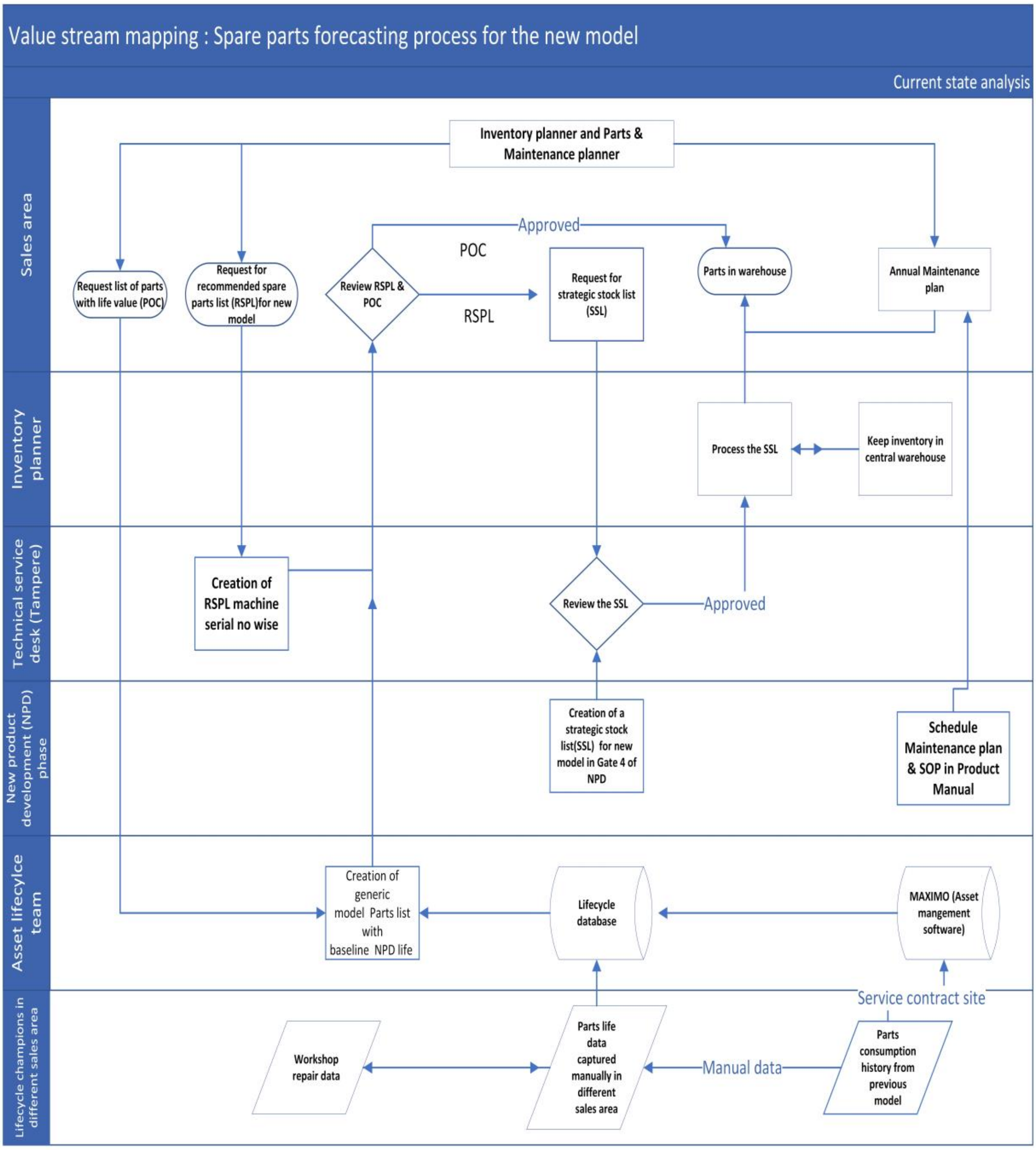
h) Free words.

Appendix 2:Recommended spare part list (RSPL)

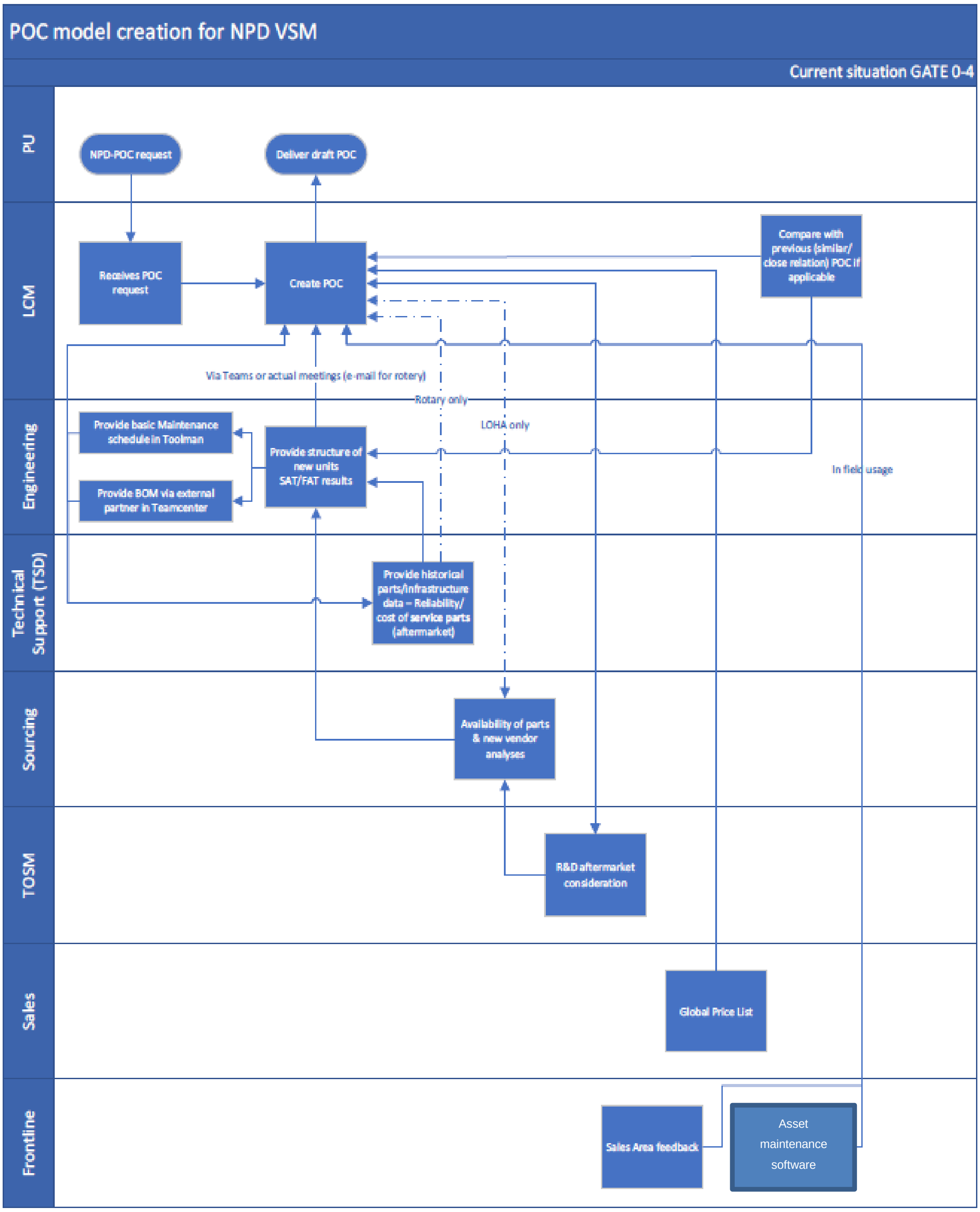
Recommended spare parts for
DT[illegible]2i / 121P65037-1

Part number	Name	Description	Qty per uni
Rock D			
Part number	**Name**	**Description**	**Qty per uni**
BG00934992	Service Kit	Endurance kit	4
BG00810827	Service Kit	Flushing Kit, incl. Seal kit	4
09260298	Diaphram	Stemless type, D120	4
80759069	Valve - Charging		6
86973329	O-ring, Valve	14,0x2	6
52213490	O-ring	129,5x3	4
81953209	O-ring	64,5x3	4
Boom			
Part number	**Name**	**Description**	**Qty per uni**
55179600	Slide frame		4
26509688	Slipper pad		4
20841018	Shim		28
20782568	Adjusting screw	M70 x 2	14
20782438	Locking screw	M70 x 2	14
32159708	Flange		4
32159838	Wiper		2
55007452	Wire Rope	2mm, 7X19, A4, Boom zoom sensor wire rope.	4
52216670	O-ring	36,2X3	24
AF25020508	O-ring	69.5x3.00	24
55165318	Seal kit	160/90	4
81859389	Seal kit	125/50	6
55196044	Seal kit	D125 d50	2
Feed			
Part number	**Name**	**Description**	**Qty per uni**
55159156	Wire Rope	L=3368, Pull	4
55038504	Wire Rope	L=6600, Return	4
55017281	Frame, Slide	L=501	4
26337508	Frame	L=250	4
55179600	Slide frame		4
33001698	SLIPPER PAD	TF and TFX slide piece	24
86798699	Bearing, Ball, Deep Groove	D90 d40 L23	8
20611688	Shaft		4
20902718	Lock screw	A=56	10
55055045	Seal Kit	Seal kit of feed cylinder	2
86798699	Bearing	D90 d40 L23	4
80008339	Spring pin	8X36	2
20611688	Shaft		2
42229200	Circlip	90X3	2
BG00672477	Bearing, Ball, Deep Groove	D95 d60 L18	2
BG00672478	Bearing, Ball, Deep Groove	D90 d55 L18	2
BG00672355	Bearing, Ball, Deep Groove	D165 d130 L18	2
55185389	Shaft seal	70x85x8	2
55185393	Seal	160, (RB by 09373263)	2
AF00101443	Hexagon head bolt (half thread)	Feed beam Front side bolts, M20x90 - 8.8	8
85128339	Washer, Lock, Double	Feed beam washers, M20	16
AF00101443	Screw, Hexagon Head, Partial Thread	Front centralizer bolts, M20x90	20
AF03000036	Washer, Lock, Pair	Washer for front centralizer and rock drill, NL 20	20
[illegible]	Hexagon head bolt (half thread)	Middle centralizer bolt and nut and washers, M20X150 m8.8	4

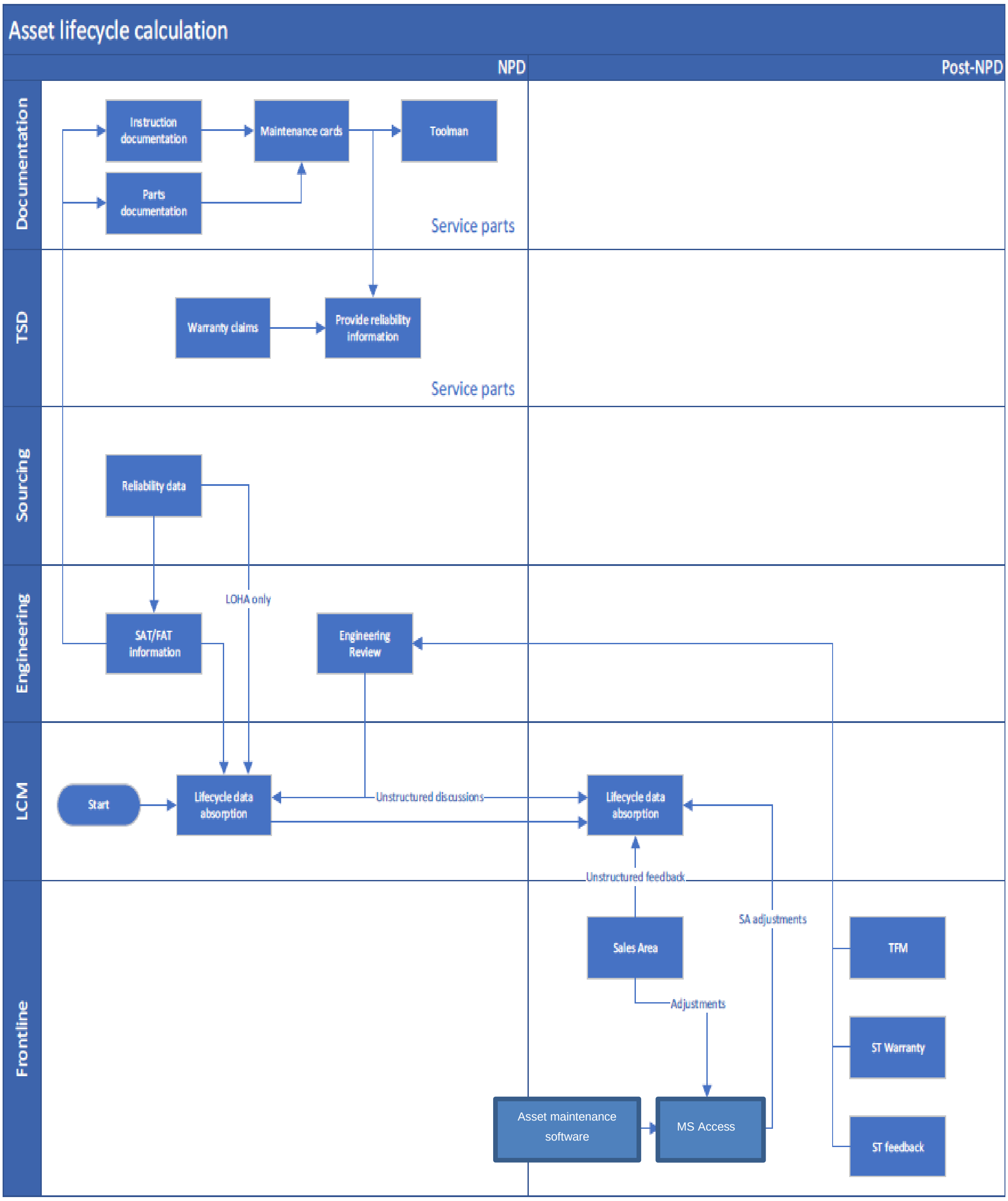
Appendix 3:VSM of the current state of the spare parts forecasting for the new model



Appendix 4:Value Stream Mapping of the Current IOC model creation process of the new model



Appendix 5:Asset lifecycle data flow



Appendix 6: Drafted format of Maintenance plan and spare parts forecasting based on the classification of spare parts and its life.

Table 1: Maintenance plan sheet for spare parts forecasting and labor hours calculation

Annual maintenance plan for spare parts forecasting with spare parts life				Time added to previous service	QUANTITY / 1500 HOURS					
					Jan-23	Jan-24	Jan-25	Jan-26	Jan-27	Jan-28
					0	1501	3001	4501	6001	7501
					1500	3000	4500	6000	7500	9000
Work description	SERVICE LABOUR	QTY_hrs	LIFE	QTY_hrs						
Preventive Maintenance	Shift Service	0,5	5	1,5	450	450	450	450	450	450
250 percussion hours service		0	250	0	0	0	0	0	0	0
500 percussion hours service		3	500	3	9	9	9	9	9	9
1000 percussion hours service		5	1000	2	2	4	2	4	2	4
Weekly		32	35	32	1344	1376	1376	1376	1376	1376
250 Engine hours service		1	250	1	6	6	6	6	6	6
500 Engine hours service		2	500	1	3	3	3	3	3	3
1000 Engine hours service		4	1000	2	2	4	2	4	2	4
0		0	0	-4	0	0	0	0	0	0
	TOTAL PM			44272	1816	1852	1848	1852	1848	1852
Engine		0	0	0	0	0	0	0	0	0
Engine MB 110kW Tier3		40	8000	40	0	0	0	0	0	40
Turbo Charger		3	4800	3	0	0	0	3	0	0
Injectors		4	5600	4	0	0	0	4	0	0
Starting motor		2	4000	2	0	0	2	0	0	2
Alternator		2	4000	2	0	0	2	0	0	2
Cooler		16	4800	16	0	0	0	16	0	0
0			0	0	0	0	0	0	0	0
Powertrain			0	0	0	0	0	0	0	0
Gearbox + Converter		24	7600	24	0	0	0	0	0	24
Torque Converter		24	4400	24	0	0	24	0	0	24

Total manhours required to perform the replacement job of classified spares.

Spare parts calculated life from Asset maintenance software at Sales area sites.

Calculated yearly manhours required to perform the planned jobs : WORKLOAD

Classified spare parts

Scheduled preventive maintenance in product manual & Site planned maintenance

Table2: Indicative operation cost

PART NO	DESCRIPTION	TOTAL QTY	QTY	ENGINE Hours life	PER YEAR / 2000 INTERVALS 0 2000	2001 4000	4001 6000	6001 8000	8001 10000
		0			0	0	0	0	0
	Engine	0			0	0	0	0	0
AA212831	Engine MB 110kW Tier3	6	1	8000	0	0	0	1	0
AA212832	Turbo Charger	10	1	4800	0	0	1	0	1
AA212833	Injectors	48	6	5600	0	0	6	0	0
B1A07B47	Starting motor	12	1	4000	0	1	0	1	0
B1A07730	Alternator	12	1	4000	0	1	0	1	0
AA1A713A	Cooler	10	1	4800	0	0	1	0	1

Table 1 is indicative operation cost sheet of the machine as per the calculated life of the classified spare parts and based on the expected yearly utilization of machine. Column B is classified spare parts as per final recommendations ,column E is the calculated life of the classified spare parts from the asset maintenance software and manual life data from sales area. Column F to J are the consumption of classified items for the next five years ,considering yearly utilization of machine is 2000 engine hours.

Table 3 : Forecasted spare parts list year wise

SHEET WILL GIVE LIST AS PER UTLIZATION				
REQUIRED SPARE PARTS AS PER MACHINE UTILIZATION & SPARE PARTS LIFE				
1ST YEAR	2ND YEAR	3rd YEAR	4th YEAR	5th YEAR
			AA212831	
		AA212832		AA212832
		AA212833		
	B1A07B47		B1A07B47	
	B1A07730		B1A07730	
		AA1A713A		AA1A713A

Table 2 is the output and interlinked with the maintenance plan sheet and Indicative operative cost. It gives a final list of spare parts per year, in shown tables it is for major repairable and non-repairable spare parts of engine. Same sheet can be prepared month wise to have proper follow up of the required spare parts and create KPI.

Formulas and calculations are developed to use it as live calculation as per present utilization hours of the machine and updated life values of the spare parts as data grow in the asset maintenance software.

Appendix 7:Improved Spare Parts Forecasting process