How to get a sustainable maintenance spare parts management

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How to get a sustainable maintenance spare parts management?

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Abstract

This master thesis designs a process to assess an in-house maintenance spare parts organization to improve its sustainability by having a business strategy and being best in class. Maintenance spare parts organization is referred as MRO. We set MRO strategy, propose an outsourcing decision process, define best in class MRO organization and associated best practices for all MRO processes, based on Driessen et al. (2010) conceptual framework. Strategic issues are adapted to a multi-client environment. Assessment process is applied to the Dow Chemical company in Terneuzen industry-park site. Proposition for Service Level Agreements, external and internal Key Performances Indicators come to strengthen the assessment. Both technical and financial performances are examined. Recommendations and implementation plan are provided.

Preface

This report is the result of my master thesis graduation project. This project, conducted within Dow Chemical in Terneuzen site, is the final part of my double master's degree program between Eindhoven University of Technology for the master Operations Management and Logistics (Industrial Engineering and Innovations Sciences) and the Industrial Engineering school of Grenoble Institute of Technology for the master in Industrial Engineering. This final project was the opportunity for me to apply knowledge and skills to a real business situation. I learned a lot from this challenging experience and I would like to thanks all people that contributed to this project.

First of all, I want to thank Henny van Ooijen, my mentor from Eindhoven University of Technology, for his supervision since the project initiation. I also want to thank Gülgün Alpan, my supervisor from Grenoble Institute of Technology, for her encouragement and patience.

Within Dow Chemical, I want to thank Arjan Kesteloo for his supervision, openness, and encouraging support, in good and in less good times. I am also very grateful to Mario Roegiest for his daily help and patience for all questions I addressed him on Dow activities. I also thank Adrie Lambert for the constructive discussions we had. I also want to thank all other Dow employees I had to opportunity to interview or to work with for their time and openness in sharing thought, which helped me to understand the practical situation and to come up with relevant critics.

Finally, I want to thank my parents and my friends that supported me in my studies and this final project but also distracted me from it when I needed it. Last thank goes to my boyfriend for his encouragement and believing in me.

Florence Miroux
Terneuzen, February 2012

Executive Summary

This report is the outcome of a Master thesis project conducted within Dow Chemical at Terneuzen industrial site. The research assignment has been defined as:
Develop an assessment process to improve the maintenance spare parts management sustainability.
The considered MRO organization has the following characteristics:

- *Multi-product with high diversity;*
- *Multi-indenture structure;*
- *Single stocking location;*
- *Several customer companies;*
- *High risk environment leading to excessive downtime cost if the maintenance is not quickly and successfully conducted because of spare part unavailability.*

To achieve this objective, the 6 sigma methodology was used even if the project does not include implementation.

First, we defined MRO sustainability. Function and business strategies for the MRO organization were defined. Then, a best in class MRO organization with associated best practices was proposed. Answer to other sub research question *"What is a best in class MRO management in a multi-client perspective?"* was given: we kept Driessen et al. (2010) decision framework as an adequate control framework to manage MRO in a multi client perspective and for each MRO process, we proposed best practices and discussed issues raised when supplying several clients.

After defining best in class MRO organization and business MRO strategy, we measured and assessed the performance of the Dow MRO organization at Terneuzen site. External performance analysis was conducted. The MRO financial budget was examined for assessing the MRO financial performance. A MRO outsourcing process was proposed and answer to sub research question "*When does outsourcing support the MRO strategy?"* was given: we propose a outsourcing decision process taking into account the MRO strategy and used a cost criteria to decide whether to engage in outsourcing when the MRO management is business driven. We assessed Dow internal performance using defined best practices. Answer to sub research question "*Are there appropriate Key Performance Indicators KPIs to assess MRO internal performance?*" was given: we proposed and argued on internal KPIs that allows assessing internal performance for the different MRO processes.

From the gaps between the defined best in class MRO, MRO business strategy and Dow current situation for Terneuzen, we proposed improvement actions. Business awareness for MRO management and knowledge of people, tools and process were analyzed at the key improvement drivers. Short term and long term recommendations were formulated for Dow Chemical in Terneuzen to close the gap and to move its MRO management to sustainability by being best in class and business oriented. To help this implementation phase, we proposed ways to control the solution effectiveness and proposed ways to leverage the opportunity across Dow sites.

The project key findings and conclusion were the following:

- MRO management is a multi-disciplinary activity that requires broad and specific knowledge in information management, supply management, planning, forecasting, inventory management, logistics, etc. Within companies, MRO management might not receive attention it deserves from high level management and suffer from lack of business awareness.
- The outcomes of the project are recommendations to the Terneuzen site of Dow Chemical. Implementation plan with data and risk analysis should reveal the effort and long term benefit of implementing the recommendations.

- Further scientific research areas are identified: consignment and vendor managed inventory stocks, MRO benchmarking study, differences and similarities between maintenance spare parts management and after sales part management, use of internet communication.

Among formulated recommendations to Dow Chemical for Terneuzen site, the most important, valuable and urgent to consider were the following:

- To have a relevant and used multi-criteria ABC classification based on criticality assessment and demand rate. This identification of homogenous groups of part facilitates supply and inventory management.
- To review and optimize the inventory replenishment parameters, which are the order points and order quantities.
- To force the MRO client to make use of a reservation process with its real need date for planned maintenance work orders.
- To have KPIs in place: external ones to measure the delivered service for availability, response time, quality and price performance, and internal ones to measure the internal use of resources for all MRO related processes.

List of acronyms

GMWP: global maintenance work process
KPI: key performance indicator
MSMS: Materials & Services Management System, the Dow MRO inventory management system
MRO: maintenance, repair and operation supplies. MRO and maintenance spare parts are synonyms.
MVP: Maintenance Value Park
OP: order point. This Dow acronym has the same meaning than s reorder point in Appendix J where inventory management policies are described
OQ: order quantity. This Dow acronym has the same meaning than Q fixed order quantity in Appendix J where inventory management policies are described
SEC: sustainable economic cost
SLA: service level agreement
TCO: total cost of ownership
VMI: vendor managed inventory

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Introduction

Maintenance spare parts are historically in-house managed by manufacturing companies to support their maintenance activities to keep their production up and running. Maintenance spare parts are further referred as MROs (maintenance, repair and operating supplies). In-house MRO management is the traditional situation for those manufacturing companies. However, the complexity of MRO management has increased over time due to business growth and specialisation. Over time, the number of MROs to handle has increased. Diversity of MRO has increased as well: cheap vs. expensive, none or slow movers vs. high movers, repairable vs. consumables[1], critical vs. non critical, standard vs. specific, supplier lead times. MRO management requires high and specialized expertise to handle catalogue management, inventory management, forecasting, supply management, return and repair flows etc. The recent emergence of specialized tools and companies to support MRO management confirms this increase in MRO complexity. Today, there is a real need for those manufacturing companies to rethink their MRO strategy and to assess their MRO performance from service and financial perspectives. Great cost savings or reliability service improvement might be achieved by outsourcing part of MRO management to third party companies. Vendor Managed Inventories and Consignment stocks are options to remove some MROs from in-house management.

This master thesis project proposes an assessment and improvement process to get a sustainable MRO management by being business driven and best in class. The study is conducted within Dow Chemical at Terneuzen industry-park site but the analysis and developed process will be valid for environments having the following characteristics: multi-product with high diversity, multi-indenture structure, single stocking location, several customer companies and high risk environment. This report describes the analysis and output of this master thesis project.

This report consists of 6 chapters. Chapter 0 introduces the project environment and Dow characteristics for Terneuzen site. Chapter 1 defines and analyses the project, investigates how the literature helps handling the project and identifies open research questions. Chapter 2 defines and characterises a sustainable MRO organization. Function and business strategies for the MRO organization are examined. A best in class MRO organization is proposed with a decision framework and best practices to handle MRO management in a multi-client perspective. Answer to *"What is a best in class MRO management in a multi-client perspective?"* is given. Chapter 3 measures and assesses the performance of the Dow Terneuzen MRO organization. External performance analysis is conducted. The MRO financial budget is examined as well for assessing the MRO financial performance. A MRO outsourcing process is proposed and answer to question "*When does outsourcing support the MRO strategy?"* is given. Internal MRO performance is as well assessed using defined best practices. Answer to questions "*Are there appropriate Key Performance Indicators KPIs to assess MRO internal performance*?" is given. From the gaps between the best in class MRO and business strategy defined in Chapter 2 and Dow current situation for Terneuzen analyzed in Chapter 3, Chapter 4 proposes improvement actions to be best in class and business oriented. Chapter 5 provided follows up guidelines for Dow Terneuzen to manage the change and ways to control and leverage the opportunity are proposed. Finally, chapter 6 concludes the project by answering the main research question, highlighting key outputs and recommendations, further actions for Dow and further open topics to be investigated by the research community.

[1] We use consumable and non-repairable items as synonyms, as in the literature. In industries consumable might have a different meaning and refer to fast moving and shared spares.

0. The company description

This chapter introduces and discusses field data to allow us to understand the context in which the industrial problem occurs. We introduce Dow Chemical Company, provide key notions about Terneuzen Industry-Park, the central maintenance organization and MRO organization as well as the Maintenance Value Park (MVP) to ground our thesis and mission. Figure 1 depicts relationships between key entities. Appendix B provides further information on dynamic and growing MRO related topics. The Netherlands have active organizations in the maintenance and logistics fields and the worldwide market provides new software tools for managing MROs.

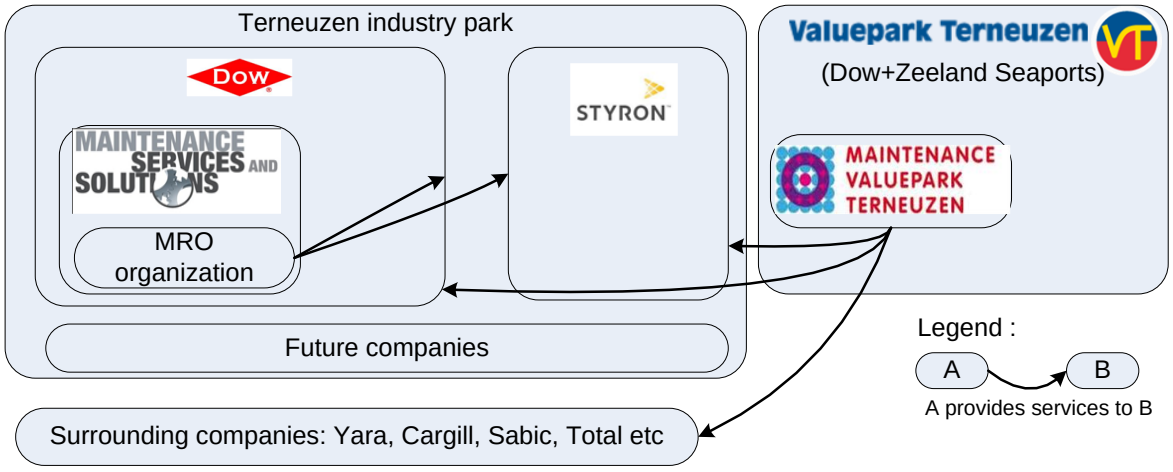

Figure 1 : Relationships in-between Dow, Styron, Terneuzen industry-park, the central maintenance and MRO organizations, Valuepark and Maintenance ValuePark.

0.1. Dow: Global and Benelux businesses

Dow Chemical is an American diversified chemical company operating in segments such as health and specialty materials, coatings and infrastructure, health and agricultural sciences, plastics, hydrocarbons. In 2010, Dow had annual sales of $53.7 billion and employed approximately 50.000 people across the globe. By innovating in sustainable solutions to their customers and products that are essential to human progress, Dow Chemical seek to be the most profitable and respected science-driven chemical company in the world.

Dow Chemical has a worldwide presence: more than 5.000 products are manufactured at 188 sites in 35 countries. The main manufacturing site is located in Midland, USA. Dow is implemented in the Benelux since 1955. Terneuzen site started in 1965. Today plastics and chemicals are produced in 7 locations and 23 plants across the Netherlands and Belgium. With 18 plants and 2.000 employees, Terneuzen site is the heart of Dow in the Benelux and is the second largest manufacturing site in the world with ethylene and propylene as the core products.

0.2. Terneuzen Industry Park

Dow Chemical is working with other companies to support business and enabling growth on what is called an Industry Park. An Industry Park is a Dow-managed, multi-business site where non wholly-owned Dow tenants receive services from Dow or contract suppliers. Those tenants may be suppliers, third-parties, contractors or affiliates. The shared services between Dow and the tenants are the following global functions: Analytical; Emergency Operations & Planning; Energy Systems; Environment, Health and Safety; Environmental Operations; Industrial Gases; Administration;

Infrastructure; Integration and Coordination; Maintenance; Operational Excellence and Learning; Site Logistics.

Dow Terneuzen site is an Industry Park in which 500 employees from Styron work with the 2.000 Dow employees. In Terneuzen Industry Park, Dow owns 18 plants and 10 others belong to Styron. An Industry Park adds value through competitive services and delivery.

0.3. The maintenance organization

In Terneuzen, the name of the central maintenance organization is Maintenance Services and Solutions. Its goal is to achieve high reliability at a low service cost, high quality, high technology level and low response times to support the 18 Dow operating on-site plants and 10 non Dow plants. Shutdown of the plants could lead to costly losses. Financial losses are evaluated at 1 million per day for the most critical plant. There are no formal service level agreements in place for the maintenance activities. Reports are created to measure reliability performance of mechanical assets. Equipment failure rate is around 1 to 2%. Losses are reported. The organization is client driven: the businesses objectives and company strategies drive the maintenance strategy. The proportion of planned and unplanned maintenance intervention will depend on the maintenance strategy that balances preventive and reactive work orders.

0.4. The MRO organization

In the global maintenance organization, the MRO group is responsible for the total management of warehouses, logistics, receiving and distribution of spare parts and ordered materials. The MRO organization objective is to assure that the right part is available when needed. Availability allows the maintenance intervention in one of the plants. The part must be at the right place, in good working condition and at the best possible price to achieve high service. In Terneuzen, procedures for the stored MRO, describing steps, roles and responsibilities, are regrouped under the following topics:

- manage inventory addition request ;
- manage existing inventory ;
- issue and return ;
- stock take ;
- inventory receipts.

We identify later on in Figure 12 how the current Dow industrial practices coincide or not with the eight processes for MRO management identified in the literature review. The eight processes are assortment management, demand forecasting, parts return forecasting, supply management, repair shop control, inventory control, spare parts order handling and deployment. For each process, we must identify the related procedures, rules and involved roles and organizations. The eight processes described in details in the literature review come from Driessen et al. (2010) general framework to handle the MRO management decisions.

0.5. The MRO supply chain

In Dow, many roles and actors intervene at different steps in each of the sub processes among the reliability engineers, and the inventory coordinator/controller. The reliability engineer's role is to build reliability models, assess risks and to define predictive preventive maintenance and MROs needed. The inventory coordinator/controller is responsible for managing MRO inventory at the site level. Ceva is a third party company working for the maintenance organization. Ceva has the responsibility to receive, store and distribute the MROs. The MROs are stored at two locations. The first location is the central warehouse (store 0) located in the middle of Terneuzen Industry-Park. In

the central warehouse are stored the fast moving and rather small MROs. The second location is at Sluiskil, a place which is about 10 km from the Industry-Park. At Sluiskil are stored the slow moving and rather big MROs as well as the MROs dedicated for projects. All the receiving from MRO suppliers that will be stored is also done in Sluiskil site, limiting the movements within Terneuzen site.

To handle the MRO management problem, the flow of MROs and repaired items within the organization must be specified. The following picture depicts the MRO supply chain for Dow Terneuzen. We have adapted Driessen et al (2010) standard MRO supply chain to Dow Terneuzen practices.

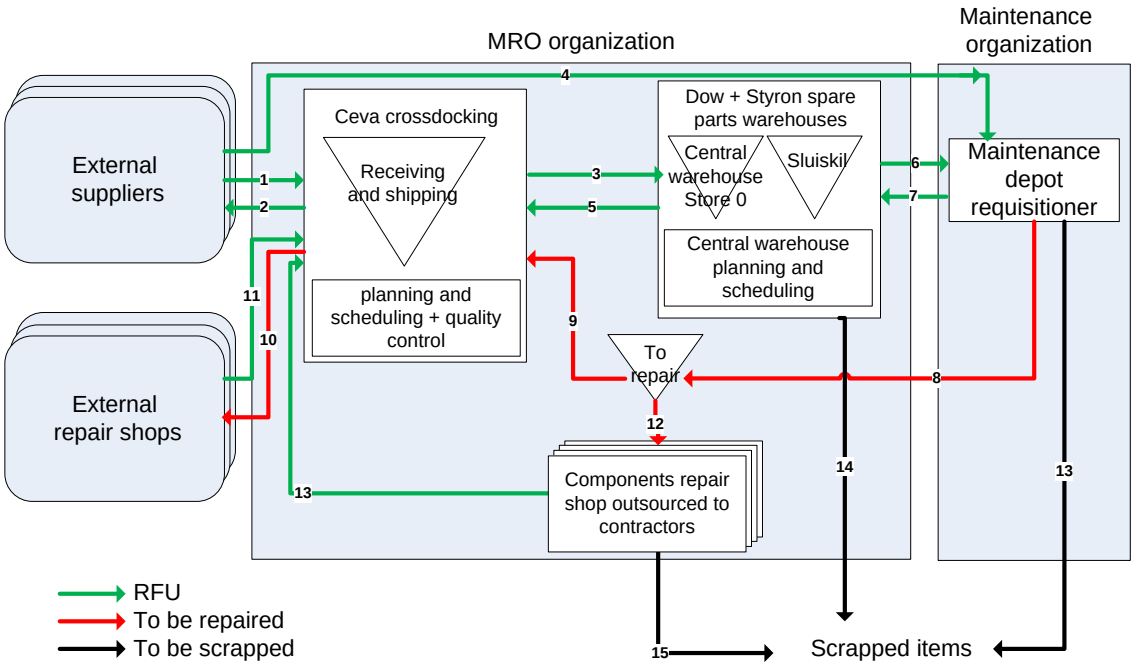

Figure 2 : Dow Terneuzen MRO supply chain

In this section, we describe the MRO flow depicted in Figure 2 . By arrow 1, the material arrives from the external suppliers to Ceva at Sluiskil. If too many MROs are received, overshipment is send back through arrow 2. Overshipment is due to supplier's errors. MROs are temporary stored by Ceva. Quality control can be done at this step for the items that will be stored in Sluiskil. Some received MROs are used for projects. The planning and scheduling support team schedules work orders for the central workshop. Ceva platform operates according to the cross docking principles. Then, Ceva transports the MROs to the appropriate warehouse i.e. to the central warehouse or to Sluiskil (arrow 3). When the MRO is needed by the maintenance organization, the item flows from the warehouse to the requisitioner (arrow 6). Some MROs that are urgently needed and were not kept in stock will flow directly from the supplier to the plant: the delivery and storing processes are bypassed (4). When the requisitioner orders more MROs than needed, the unused MROs are returned to the warehouse (7). Too many MROs are ordered when it is not known which parts will be needed for the maintenance intervention. Unused MROs are sent back to the warehouse. This return process described in more details in the literature review in the parts return forecasting section. On a regularly basis, the slow moving MROs will be checked and the obsolete ones will be sold back on the market for investment recovery purposes: the obsolete MRO is carried through Ceva receiving and shipping (5). When a part breaks down in the plant, the broken MRO will either be scrapped (13) or send to repair (8) if it is a repairable MRO. The repairable MRO will either be repaired onsite by one of the 4 repair workshops

(12) or offsite by and external repair shop (9 and 10). The cost to repair a MRO by an external shop does not exceed half of the price to buy the new equivalent MRO, otherwise a new MRO will be ordered to the supplier. Once the MRO is repaired, the MRO is send back to the warehouse (3) via Ceva platform (11 or 13).

To have a better idea how important the MRO business in Terneuzen is, we give a few figures. Annually, 40.000 items are delivered from the warehouse to the plants representing a value of 30 million Euros in total (flow in arrow 6). Among those 30 million issues by the plants, 10 million will be returned to the warehouse without being used (arrow 7). For Dow, in June 2011, 65.000 MROs were kept on stock i.e. 55 million Euros. Another 15.000 spares (5 million) are on stock for Styron. For Dow, the turnover is about 0.5 which mean that a MRO stays on the shelf about half a year in average. In the near future (2012), the resources (people and equipment) of the repair workshops will be outsourced. To keep control over the MRO process and reliability of their assets, the MRO resources may remain under Dow responsibility.

0.6. The ValuePark and Maintenance ValuePark MVP

Logistics Valuepark Terneuzen is a public-private logistics park initiated by Dow and Zeeland Seaports. Between the main ports of Rotterdam and Antwerp in the heart of Europe, south west of the Netherlands, Valuepark Terneuzen aims to become a major European hub for the chemical production and distribution. Valuepark is located in the surrounding of Industry Park offering partnerships to several companies. Among others are VSL Vos Logisitics, Bertschi and Katoen natie. Those partners benefit from Dow extensive petrochemicals facility as well as the expertise of Zeeland Seaports concerning park infrastructure and regional economic development. 140 hectares of land are available for further investment. Valuepark has an excellent logistic infrastructure with multimodal transport facilities: train, water, pipeline and road. This integrated chemical site offers opportunities for economies of scale, reducing handling and transport activities and strengthening one's position by joining forces. For instance, Dow makes use of services provided by Katoen natie and VSL to store and load their semi-finished and finished goods off-site at a lowest price.

In this Valuepark, a Maintenance Valuepark MVP has been launched and is still in a development phase. The first building of this MVP is planned to be build in 2013. The aim of the MVP is to create a high-quality, specialised industrial estate in order to stimulate innovation and cooperation in the maintenance field. The 25 contractive maintenance firms operating today from the onsite contractor park will have the opportunity to move to this future MVP. The partnership will not be limited to the business contractors but extended to engineering companies, process industries, government and knowledge institution. The main tool owners will be Dow, Cargill and Yara. A construction company, Moens, will own the facilities and buildings and rent them to Dow, Cargill and Yara. This multi-actor partnership adds value to the project through knowledge and experience sharing. From the offsite future MVP site located at an adjacent location with Dow Industry Park, the maintenance companies will still provide their services to Dow and Styron. But they will also have growth opportunities to maintain other non-chemical process industries in the surrounding region. A feasibility study has shown that other companies in the region are interested in the MVP project. The clustering will lead to innovation but also to economies of scale and cost savings. For the MVP project, a subsidy has been received from the Dutch Ministry of Economic Affairs. The World Class Maintenance programme also supports the initiative. The MRO organization will be moved to this MVP.

1. Problem and project description

Chapter 0 had introduced the context in which the project takes place.

Chapter 1 describes the industrial project origins, the project's main objective and sub-objectives. In this chapter, main useful insights from the literature are summarized and our contributions to the research are highlighted. First, section 1.1 defines and analyses our project (opportunities, alignment with corporate strategy, scope and boundaries) in its industrial context. Then section 1.2 identifies the project's main objective (main research question), proposes a project methodology, decomposes the main objective into smaller objectives and identifies sub-research questions that are investigated through our project. Analysis and answers to research questions are the added value of our work for the research community.

1.1. Project definition and analysis

This section defines and analyses the project for Dow Terneuzen. First, section 1.1.1 provides the initial project description. Section 1.1.2 explains the project origins and its relevance. Last, section 1.1.3 analyses the project: objectives, opportunities, scope and boundaries are given.

1.1.1. The initial project description

Initially the project was formulated by Dow as follows:

Business Profile

The Terneuzen manufacturing site (the site) of The Dow Chemical Company (Dow) was built in 1964 and production started in 1965. It is the second largest Dow site in the world. The heart of the site consists of cracking units which produce ethylene and propylene. There are 18 businesses at the site (28 plants, including Styron), and the site manufactures over 800 different products, producing approximately 7.3 million tons of plastics and chemicals per year. The site employs approximately 2,000 Dow employees and 500 contractors.

Maintenance, Repair, and Operations (MRO) inventory is used for general maintenance of plant equipment. The site had approximately $76 million (€56 million) in MRO inventory as of September 30, 2010, of which $54million was classified as inventory and carried on the balance sheet; and the remaining $24 million was classified as expense. There is one main building onsite for storing MRO items and several offsite buildings within a nearby industrial park. Approximately 10-14 offsite buildings are leased within the industrial park for MRO storage. MRO inventory management is primarily handled by a third-party company (CEVA) with oversight by a few Dow employees. Most of the MRO value is in large, critical parts retained to avoid shutdown of the plant. This inventory is purchased, received, issued, and tracked using a system called Materials & Services Management System (MSMS).

Study

Review current MRO process with "state of the art" day to day MRO process in the market
Deliverables: Recommendation/Improvements on current MRO process related to "state of the art" day to day MRO process in the market
Review impact of Industry-Park strategy on current MRO process
Deliverables: Recommendation/Improvements on current MRO process related to industry-Park strategy
Review impact of Global Maintenance strategy on current MRO process
Deliverables: Recommendation/Improvements on current MRO process related to Global Maintenance strategy

1.1.2.Problem definition: where does the project come from? Why is it relevant?

First need for this project comes from the industry-park multi user environment. The current Dow Terneuzen MRO organization is supplying both Dow and Styron clients. As the MRO organization is delivering its services to non Dow clients, the MRO organization needs to be business oriented i.e. delivering the right service level required by its clients and to deliver it at a lower cost. A business strategy is also relevant for Dow clients so that the MRO organization is considered as a value creating organization and not as a cost center. To be considered as a supporting and adding value organization instead of a cost center, the all maintenance organization needs to move from a function service oriented organization to a business oriented organization. This strategic reorientation in moving from a function to a service focused business model is a global trend in the industrial companies that want to maintain their competitive edge. This trend is known as "servitization", "tertiarisation" or "servicizing". The same need applies for the MRO organization. The way to decouple the MRO from the remaining maintenance organization is a service level agreement specifying constraints on the (expected) system availability, i.e., constraints on the availability of the equipment at the customer (Kranenburg, 2006). The MRO organization wants to move to a business strategy i.e. delivering the needed service at the lowest cost. Characterisations and definitions of function and businesses strategies will be provided later in section 2.1.

Second need for the project comes from the future competitive maintenance value park. The MRO organization will be moved to the maintenance value park that will be opened to competition. The MRO organization then needs to be best in class in order to deliver adequate service levels to their clients.

To summarize, the MRO environment is changing by being more open to MRO competition and by having more clients. As the MRO environment is changing, the Dow Terneuzen MRO organization needs to change to ensure its long term sustainability. Its durability is not ensured, growth opportunities are possible. Business oriented strategy and best in class performing organization ensures long term sustainability over the crisis and boom times of the economic cycle. The two project objectives are shown in Figure 3. Being a best in class MRO organization and having a business perspective will have two direct measurable effects for Dow:

- It allows having a better position on the market. Indeed being best in class and having assessed processes generates transparency and trust with the customers. The customer receiving MRO service from Dow needs to know he is paying the best price for the service he has asked for.
- It allows lowering the cost for the MRO activities for Dow. Having a business perspective aims at minimizing the cost at a given service level. Lowering the MRO cost also benefits to Dow as the MRO is Dow-managed and provides its services to Dow plants. Saved money can be used further for development and sustainability.

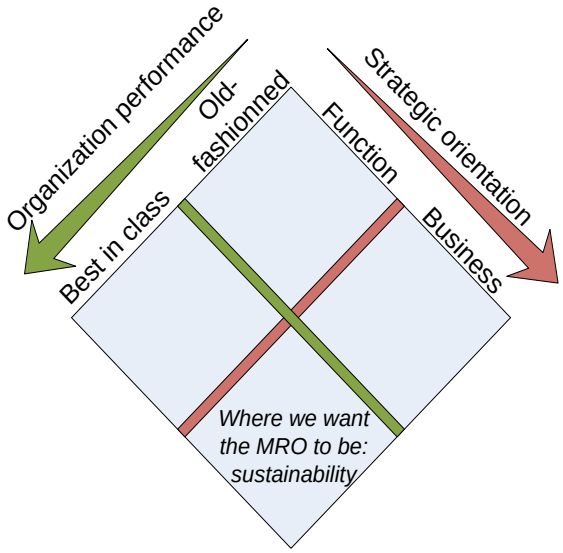

Figure 3 : the project objectives

A balance needs to be found in between the two objectives. Being business oriented strives for low cost while being best in class strives for high service performance. Two contradictory forces are involved when managing spare parts inventories. On the one hand, managers may want to increase the stock levels to ensure great availability and avoid downtime cost if the required spare part is unavailable. Indeed when an unplanned breakdown occurs and if the needed spare part is not detained, the overall downtime could be very long, up to several years in the extreme case of very specific parts. The downtime is composed of the following times: administrative delay time to contact and negotiate with the supplier, time for the supplier to produce and deliver the part, and finally the active repair time and start-up time. This downtime could have direct consequences on the company profit (Sarker, R., & Haque, A., 2000). But on the other hand, the inventory holding cost and obsolescence risk tend to lower the stock levels. Hence, as shown by Figure 4, a compromise must be found between those inventory holding costs and unavailability costs in order to minimize the total cost.

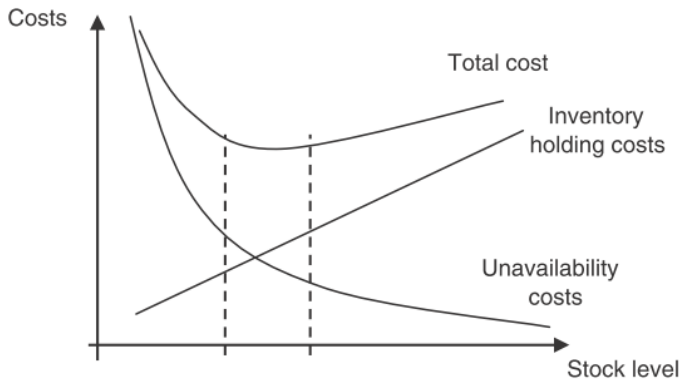

Figure 4 : Finding the right level of stock is a compromise between inventory holding costs and unavailability costs. A balance between inventory cost and delivered service.

To keep the right level of inventories – neither too high nor too low – it is crucial to manage and control inventories in an effective way. The balance between the cost (business oriented) and service (best in class) objectives depends on the maintenance strategy i.e. balance between preventive and corrective maintenance. The more corrective maintenance, the more important the service objective. The more preventive maintenance, the more important the cost objective.

1.1.3.Problem analysis: what is the project for Dow?

The initial description of the mission is provided in section 1.1.1. Since this initial formulation, the project has been clarified and detailed. In this section, we analyze the project. To analyze it, we describe in more details how project will benefit Dow, how it is aligned with the corporate strategy and by setting the scope and boundaries of the project.

This master thesis project is entitled as follows: "How to get a sustainable maintenance spare parts management?". The project for Dow leads to gap closure actions to achieve sustainability. To be sustainable, two objectives must be achieved as shown in Figure 3. First objective for the MRO organization n of Dow Terneuzen is to be business oriented. Second objective is to have a best in class MRO organization. Only the combination of a strategic business orientation and a best in class performing organization will ultimately allows sustainability and competitive growth in the future.

The main opportunities for Dow in this project are a financial impact and market advantage. It can be argued that the project also has image advantage by making the business relationships between the Dow MRO organization and its (potential) customers more transparent and trustful. Moreover, our study has meaningful input information for coming projects within Dow. First major coming event planned in 2013 will be the use of SAP system. Other major event is the maintenance value park: the main spare parts storage onsite building is planned to be moved offsite to MVP. This relocation is the opportunity for the maintenance logistics organization and also for the maintenance organization to be more competitive and to add more value to the company by changing the maintenance orientation to a service-provider perspective (in contrast with a machine-owner perspective). Indeed maintenance must be viewed as an investment in productive capacity instead of a necessary evil – a cost center (Campbell, J.D.,& Reyes-Picknell, J.V., 2006).

As just seen the project is meaningful as it presents opportunities for Dow. Moreover, the project supports and is aligned with the corporate strategy. At the globe level , Dow wants "to be the most profitable and respected science-driven chemical company in the world". At a lower level, Dow has a strategy settled for Terneuzen site. Regarding reliability and financial aspects, Terneuzen wants to "implement innovative solutions to improve cost competition position" and "develop and implement the Terneuzen Industry Park in a way that maximizes value creation". Regarding growth, Dow Terneuzen site wants "to support growth with concepts like maintenance value park, Industry Park (…)". Terneuzen maintenance expresses its mission as "to ensure custom made professional maintenance solutions in the most efficient, effective and safe way." The ultimate goal of our project, after the solutions being implemented by the managers, is to lower cost (business orientation) and to have innovative and effective MRO processes (best in class). Hence our project is aligned with the corporate strategy.

To scope and bound the project, we can say it is bounded to the processes related with MRO. However, the project goes across organizational Dow departments: our project is related with maintenance organization but also purchasing and accounting for example. The project also goes across companies. Dow is the main concerned but Styron as a current customer for the MRO services as well as potential future companies in the maintenance value park are important to take into account. From a geographic perspective, the project is limited to Terneuzen. But it could be very interesting to extend it to other locations for future projects to extend the knowledge and share solutions with all Dow worldwide sites. At Terneuzen site, the MRO management situation has the multi-product, multi-indenture and single-location characteristics. According to the six sigma methodology, the following consecutive steps could be used to guide our project: define measure, analyze, implement, and control. The implement and control steps are not in the project's scope. Those two last steps will

be left to MRO managers after the end of the Master Thesis project. However, we will initiate them. The project output for Dow are recommendations to the Dow Terneuzen MRO organization to be best in class and business oriented. The MRO managers will be convinced by the proposed solutions and will agree on it.

As a summary for the project analysis, the MRO organization wants to sustainable. My project for Dow is to analyze and assess the current MRO processes, to provide guidelines, gap closure actions to improve the MRO process performance such that the MRO management will be best in class and business oriented.

As pointed out by Cavalieri et al. (2008), "a gap still exists between what has been largely investigated and proposed in the scientific literature and the lagging industrial practices". To some aspects, the spare parts management may be considered as an old topic since many models, concepts and rules of thumb are available since 1960s. Despite the large literature available, the managers may not use it in practice. Our goal is to help managers to analyse and improve current industrial practices. Through a case study, we will identify and analyse gaps between current practices and best in class practices. We will investigate the importance and impacts of those gaps and human decisions on the maintenance spare parts management process. This work and the developed insights will be considered as a starting point to redesign the maintenance logistics organization. Relevant analysis and recommendations will allow reducing the gap between theory and practice.

1.2. Research design

We now have defined and analysed the project. We know as well the industrial context in which the problem occurs. In this section, we structure our project: a research design to handle the project with methodology is proposed. Section 1.2.1 states the project's main objective and corresponding main research question. Section 1.2.2 decomposes the main objective of the project into sub objectives structuring the project. From there, sub-research questions are derived and analysed in section 1.2.3: we investigate how the literature answers the questions related to the project and identify the open research opportunity. Those sub- research questions are investigated during the project, they constitute a value added opportunity for the research community. Lastly, section 1.2.4 summarizes key MRO processes and decisions from Driessen et al. (2010) conceptual framework to handle the MRO management problem.

1.2.1. Main research question

Our main research question is the following: ***How to get a sustainable maintenance spare parts management?***

Based on this main research question, our assignment for the Master Thesis project is the following:

Assignment: ***Develop an assessment process to improve the maintenance spare parts management sustainability.***

The considered MRO organization has the following characteristics:

- ***Multi-product with high diversity;***
- ***Multi-indenture structure;***
- ***Single stocking location;***
- ***Several customer companies;***
- ***High risk environment leading to excessive downtime cost if the maintenance is not quickly and successfully conducted because of spare part unavailability.***

The project is considered in a general environment. The developed process and results are usable for different industrial context that have the given characteristics. The assumptions and considered

assumptions fit with Dow Terneuzen industrial practices. Hence the results are directly usable for Dow but also for companies having the considered characteristics. As the results and process are applied to Dow MRO organization, this application can be seen as a case study from the chemistry industry that comes to strengthen the literature research.

1.2.2.Project decomposition & methodology

To decouple and structure our assignment, we make use of the Work Breakdown Structure (WBS) tool to decompose the project into smaller components. The main WBS element is our main research question and smaller elements will be the sub objectives.

Our main objective, which corresponds to our main research question, is to make a MRO management sustainable. The Master Thesis assignment does not include implementation. The scope of the project is to propose an assessment process to improve the MRO management sustainability. To reach this sustainability, two objectives must be reached. The sustainable MRO organization is both business oriented and best in class. Those two project objectives are analysed in section 1.1.2 and shown in Figure 3. Figure 5 decomposes the project further by showing the steps to be business oriented and best in class.

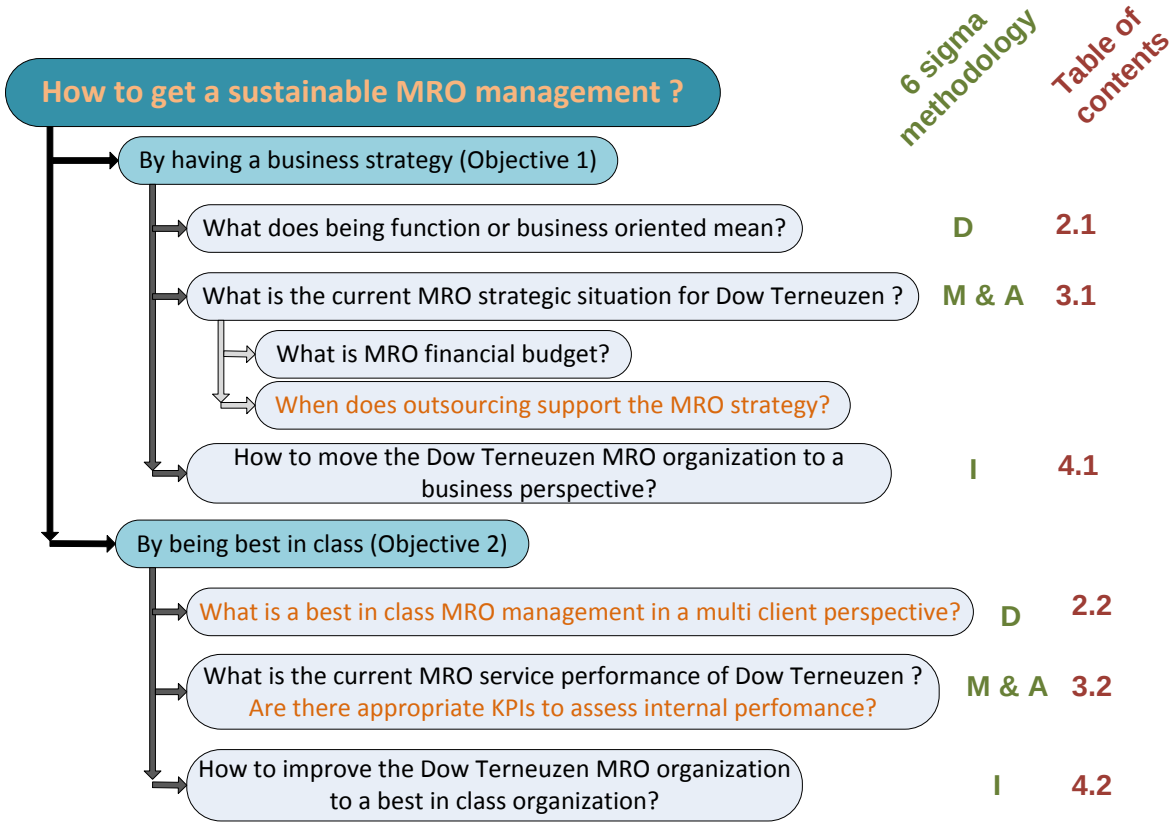

Figure 5 : Project decomposition and methodology

To achieve business strategic orientation, we first need to define and characterise what business oriented MRO organization mean, in comparison with a function oriented MRO organization. Once we have defined the business driven MRO organization, we will measure and analyse the current strategy of the Dow Terneuzen MRO organization. To do so, we will assess the MRO financial budget and examine whether outsourcing might support this business strategy i.e. lowering cost. After

knowing the current MRO strategy, we will propose ways to move the Dow Terneuzen organization in a business perspective.

To achieve best in class performing MRO organization, we follow the same methodology. First step will be to define a best in class multi-user MRO organization. Then, the current MRO service performance will be assessed. To support this assessment phase, internal KPIs will be proposed to allow further measurement and analysis. Once we know the ideal best in class MRO organization and Dow Terneuzen MRO performance, last step will be to propose gap closure actions to move Dow Terneuzen to best in class.

To reach the two project main objectives, the first step of the 6 sigma methodology will be achieved through the project. The all 6 sigma steps are: Define, Measure, Analyze, Improve, Control, Leverage. The Define phase is handle in chapter 2. The Measure and Analyse steps are done through chapter 3. Chapter 4 constitute the Improve phase. Latest steps of the 6 sigma methodology are not in the master thesis scope, however we will propose guidelines for the Control step in section 5.1 and for the Leverage step in section 5.2. Further information on 6 sigma and the project methodology can be found in Appendix A.

1.2.3. Sub research questions

The previous section decomposed the project. Figure 5 summarizes the decomposition, highlights the methodology and shows the relationships with the table of contents to let the reader know where answers to questions are given. Among the project decomposition questions, Figure 5 highlights some of them (orange colour) as being open research questions from the literature. Those three questions are the sub-research question of our project that we need to investigate further to fulfil our main objective and research question. In this section, we identify and discuss the sub research questions: we state how the literature answers those questions and what is the added value of our work for the research community.

Sub research question 1: ***What is a best in class MRO management in a multi-client perspective?***

Since the 1960s, there is huge and specific literature addressing the MRO management problem as spare parts differ from semi-finished inventories. This literature is abundant as practitioners face many challenges. For more details on spare part's management, we refer to Appendix D. From the available literature, we use Driessen et al. (2010) conceptual framework providing rules of thumb to facilitate management decision-making process. Their framework identifies eight MRO related processes: assortment management, demand forecasting, parts return forecasting, supply management, repair shop control, inventory control, spare parts order handling, and deployment. In Appendix D, we go through those eight processes in detail to see what are the issues and decisions on stake and how the literature adresses them. However, one important assumption in most literature is that the MRO organization supplies only to one company - its own company in most cases.

New issues arise when supplying several companies. With regards to inventory control, shared stock allows economies of scale and resources but raises new issues: how to set the new stocks levels? Who is responsible for the parts? Who will pay when a problem occurs? How to face allocation problem if the stock is insufficient to meet the cumulative demand over the companies? Should the MRO organization make use of service differentiation? Scare litterature deals with those topics in a multi company environement. In his Master Thesis work, Karsten (2009) studied the problem of how to distribute the cost between cooperative companies, using cooperative game theoretical models. His

assumption was that the inventory pooling was implemented by allowing lateral transshipments. In Dow MRO organization context, all the stocks are kept in one location so thansshipments between Dow sites are not used. Later, Karsten et al. (2009) examined the conditions under which a stable cost allocation exists. Karsten et al. (2011) extended this work by allowing waiting time: the demand may not be satisfied immediately.

Our contribution to the literature will be double. First, we aim to illustrate Driessen et al.(2010) control framework by defining best in class MRO organization and associated best practices. Secondly, we will adress practical issues raised when the MRO organization has the considered characterisitics and supplies several companies as the situation is at Dow Terneuzen industry park.

Sub research question 2: ***When does outsourcing support the MRO strategy?***

A large literature is available to handle outsourcing issues in a general context (Gilley and Rasheed(2000), Leiblein(2003)). For example, Eshuis et al.(2010) introduced a conceptual framework to support service outsourcing using shared process views and specified which combinations of projection relations are useful for service consumers and service providers. Gilley et al. (2000) studied the extent to which outsourcing of core and peripheral activities influence the firm's financial and non financial performance. Their study also takes into account the moderating effect of the firm strategy (cost leadership strategy, differentiation strategy or innovation strategy) and the environment (dynamic or stable) on the outsourcing-performance relationship.

However, the outsourcing decisions for the specific MRO processes have not been investigated in the literature yet. Some literatures address them for the maintenance in general or to the logistic activities: Damme et al. (1996), Deepen(2007). Among others, Visser (2000) studied for his Master Thesis the parameters influencing the outsourcing decision as well as the prior conditions and key success factors for the outsourcing of the maintenance activities. Some consultancy reports (http://www.portek.com/publications/Maintenance_Outsourcing_New_Trend.pdf) suggest that maintenance outsourcing has become a global trend for the two past decades as it is a way for the manufacturing companies to focus on their core activities. Supporting this view, Accenture High Performance Business research (Tech, 2009) suggested firms can achieve 10-20 percent reductions in operating costs by optimizing and outsourcing spares and inventory management. In this report, they give qualitative insights on how outsourcing allows reducing cost, maintaining high service levels and customer satisfaction, and redistributing and sharing the risks related with spare parts management. Spare parts management is a high complex problem requiring specialists to handle it. Moreover, this inventory management does not provide a competitive advantage to manufacturing companies. Accenture also suggested that, when firms are experiencing challenges and considering outsourcing the spare parts and inventory activities, those firms should lead a strategic assessment of their current situation and position themselves relative to industry and leading practices. Except this report from Accenture, no research article to our knowledge address the outsourcing decisions to the MRO processes. The outsourcing decisions for the MRO related processes are still an open question for the research community.

Our contribution to the literature will be to investigate several MRO related processes, their degree of outsourcing, and the drivers and consequences of the outsourcing decisions. In other words, we investigate the conditions and key success factors in outsourcing MRO processes. We will propose a MRO outsourcing process. Wagner and Lindemann (2008) conducted a case study across engineering

industries to examine those questions for sales spare parts. We will address the same questions for maintenance spare parts.

Sub research question 3: ***Are there appropriate KPIs to assess the MRO internal performance?***

To drive a high performance organization, a MRO business needs to assess their processes. Managers are interested in having ways to measure how well – or how bad – the processes are conducted. They may need some keys performance indicators to analyze the situation and identify management problems before conducting changes within the organization. In their book, Campbell et al. (2006) give some ways to analyze the situation. For example, they present the number of emergency orders sent to the suppliers as a way to measure if the work has been planned properly. They also argue that the number of stock-outs in the stores reveal if the inventory control is well conducted. However, this topic has been too briefly studied and is still an open question for the research community: managers need an extensive palette of performance indicators with associated cut-off values to analyze and judge without ambiguity the current situation. To assess Dow MRO processes, we will make use of Driessen et al. (2010) conceptual framework. Even if the eight identified processes are not proven to be a best practice, we believe this decomposition of the MRO management problem into eight key processes is adequate. We will use it as a management framework to guide our assessment objective of Dow industrial practices. Today, there is no assessment conducted at Dow to assess the MRO organization performance. Only a self assessment has been proposed to the concerned departments to know whether the procedures are correctly followed or not.

Our contribution to the literature in answering this sub research question will be to propose extensive and relevant KPIs to assess the MRO processes. We will do our best to propose KPIs to assess each of the eight sub processes identified in Driessen et al. (2010) control framework for the strategic, tactical and operational decisions.

As a partial conclusion, this section showed the link between our project and the literature. We now know what is the relevant literature we will make use during our project. We also know how our project contributes to the research community by addressing some gaps from the literature. As a reminder, our contribution to the literature will be to investigate the conditions and success factors in outsourcing MRO processes, to illustrate Driessen et al. (2010) with a case study, to address new issues risen in a multi company context and finally to propose KPIs to assess all MRO-related processes.

1.2.4. MRO processes and management framework

The spare parts management process is a highly complex process involving many actors to handle very different types of spare parts. The literature has largely studied the spare parts management problem: models under different assumptions are available as well as rules of thumb, management and decision-making frameworks. More information is available in Appendix C.

To organize our work and review the diversity of issues handled in the literature, we use Driessen et al. (2010) general framework. In this article the authors split the spare parts management process into eight sub processes and discuss the managerial decisions taken at the strategic, tactical and operational levels within each sub-process. The difference between strategic S, tactical T and operational O decisions lie in their frequency: strategic decisions are taken on a yearly basis; tactical ones are taken

on a monthly basis whereas operational decisions occur every day or every week. Figure 6 gives an overview of the eight processes and the main information that flows between them. All feedback loops are not considered. We provide a definition and brief discussion of key decisions. For a more detailed discussion, we refer to Appendix D.

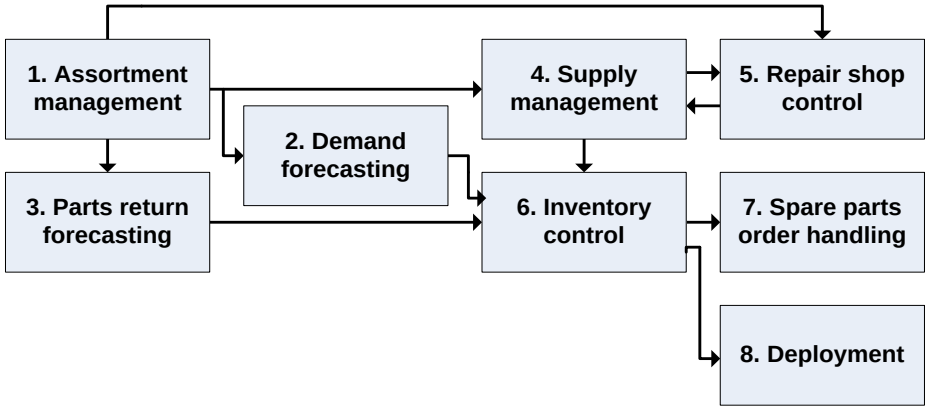

Figure 6 : MRO management framework adapted from Driessen et al. (2010)

- **Assortment management**

This process concerns the decisions to have data (or not) on a given spare parts and to maintain this technical information. This decision is different from the decision to have the spare part in stock. For example, a low moving, non-critical and short supplier lead time spare part may be in the assortment management but not kept in stock by the company. Two sets of decisions with regards to assortment management are to include a given spare part in the assortment (i.e. define the spare parts list) and to gather technical information about the parts including in the assortment.

- **Demand forecasting**

Parts that will be demanded in the near future need to be forecasted. These future demands come both from planned demand (preventive maintenance) and unplanned demand (corrective demand). The forecast is based on historical and/or known future demand. First strategic decision to be taken is to classify parts with respect to demand forecasting. Then, at a tactical level, the demand process must be characterized using the appropriate forecasting method (maintenance planning based, reliability based or time series based - the more common that extra poles historical average demand and its variation)

- **Parts return forecasting**

The return flow concern spare that comes back from the plant to the warehouse without being used. This return flow comes from the difficulty of the repair maintenance to know the spare they need, more parts than needed are issued. The MRO organization needs to take into account those return rates and return time in their planning and control operations. For example, they must take care to not reorder immediately new parts to the suppliers when those parts may return soon from the plant in order to avoid excessive inventory levels. Parts return affects replenishment decisions.

- **Supply management**

Supply management ensures that at least one supplier is available to supply the needed spare part. Type of suppliers are external suppliers, external repair shop, internal repair shop and re-use of parts. The MRO must maintain and control information on supply characteristics for the spare parts defined in the spare part lists: contractual or historical prices, discount quantities, repair or procurement agreed lead time, type of contract, minimum order quantities and multiple quantities are relevant

information. Supplier selection and contract management should be handled as well by the MRO organization.

- **Repair shop control**

Agreements between the repair shop and the MRO are made upon the repair lead time for each spare part and the workload levels per unit of time. Those decisions impact the operational level through the schedule of repair job. Moreover, tactical decisions are taken to determine the global capacity and resources (machines and tools, employees) of the repair shop.

- **Inventory control**

Inventory control decisions concern which spare parts to keep on stock, at which stocking location and in which quantities. Ready-for-use parts are kept in stock to meet service levels. The maintenance logistics organization should only keep in stock parts to cover unplanned demand (corrective maintenance), and planned demand (preventive maintenance) in case the supply lead time exceeds the delivery time of the parts. Other planned demand that is know enough time ahead of time is delivered to order and is not kept in stock at the maintenance logistics organization level. Decisions regarding inventory control are to classify parts and determine stocking strategy, to select replenishment policy and to determine the replenishment parameters (such as order points and order quantities for example).

- **Spare parts order handling**

The global maintenance organization releases work orders for planned and unplanned jobs. The work orders are assigned centrally to the MRO organization that must handle them. According to Driessen et al. (2010), the order handling consists of the following steps: accept, adjust or reject the order, release spare parts on the order, and handle return order of failed repairables. At a strategic level, the maintenance and MRO must agree upon the handling process: order quantities, order priority, order lead time. At an operational level, the MRO organization must manage spare parts orders.

- **Deployment**

Deployment concerns the process of replenishing spare parts inventories using different parameters than those advised by the inventory policies. Empirical evidence from production scheduling suggests that deployment is a spread practice: managers disregard most advises (Fransoo, J.C., & Wiers,V.C.S., 2008). Deployment is even more observed in complex environments (Fransoo, J.C., & Wiers,V.C.S., 2006). This deployment process consists of defining the preconditions order process and managing procurement and repair orders.

2. Definition of a sustainable MRO management

This chapter constitutes the define step of the 6 sigma methodology. To answer our main research question "How to have a sustainable maintenance spare parts management?", we first define and characterise what a sustainable MRO management is. As having a sustainable MRO management is being both business oriented and being best in class, section 2.1 defines the business strategy for a MRO organization and section 2.2 defines the best in class MRO organization and answers our first sub-research question "What is a best in class MRO management in a multi-client perspective?"

2.1. Definition of a business oriented MRO organization

This section defines a strategy for managing MRO. This section answers the following questions: Why do we need a strategy for the MRO organization? What are the possible strategies for the MRO organization? Which one is the best strategy and why? Definition and characterization of function-oriented and business-oriented MRO organization are given.

Why do we need a strategy for the MRO organization?

A MRO organization, like all entities in a company, must have a strategy. This strategy must be aligned with the firm overall strategy and must sustain the long term business. Strategic decisions are taken on the long run and condition tactical and operational decisions taken at a lower level and on a shorter time basis. In a maintenance environment, a MRO organization is responsible for matching supply and demand of the required spare part to conduct the maintenance intervention. To achieve this objective at a high service level the MRO organization may want to assure that the right part is available at the right place, at the right time, in good working condition and at the best possible price. This way to formulate the MRO management problem is very complex and difficult to tackle because we lack to have objective and non ambiguous targets and priorities in between all objectives. Setting a strategy for the MRO organization will facilitate management decision-making for all MRO-related processes.

What are the possible strategies for the MRO organization?

An organization aims at delivering the best service at the lowest cost. For a MRO organization, there are several ways to measure the delivered services. One way to measure the delivered MRO organization service is the downtime at the equipment level. Another way is to measure the availability of spare parts. As shown in Figure 7, the total cost of ownership TCO increases as the MRO wants to lower the downtime or increase the availability level. The MRO must position itself along the blue curve. The TCO integrates the initial price for equipment as well as the maintenance and MRO cost. The challenge for the MRO organization is to lower downtime (or increase availability) and decrease cost i.e. to move this blue curve further to the green circle which represents a virtual target.

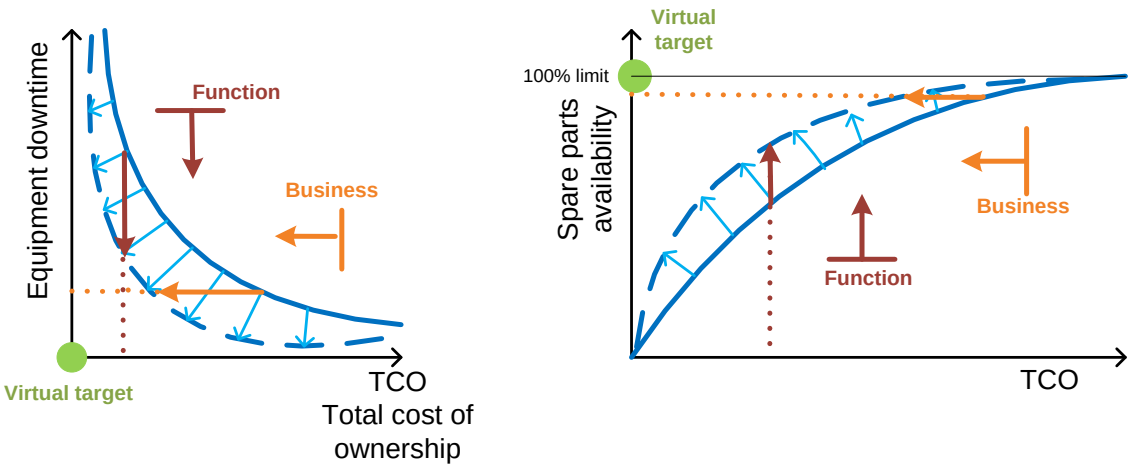

Figure 7 : Downtime, availability, TCO; challenges and strategies for the MRO organization

In the scientific literature, the MRO management problem is stated in two different ways. First way to considerer the MRO objective is to maximize the availability level given a cost constraint. Second way is to minimize the total cycle MRO cost while satisfying a predetermined minimum availability level. Those two different ways to state the MRO management problem will not lead to the same results and reveal two different underlying strategies. The first way fits with a functional strategy whereas the second statement is business oriented strategy. A function service oriented organization strategy is to maximize its delivered service given cost levels. Given budget constraint, the functional organization aims to achieve the highest service. Whereas the business oriented organization has an opposite strategy: it aims at minimizing cost given service levels constraints. This makes a sensitive difference in the way to consider the MRO organization. The function and business strategies are represented in Figure 7. The function oriented MRO organization sets a budget or TCO constraint depicted by the brown dotted line and optimizes the delivered service by reducing downtime or increasing availability. The business oriented MRO organization sets a service constraint depicted by the orange dotted line and aims at decreasing the cost. According to the way the literature formulate the MRO management problem; a MRO organization has the choice between two main strategies i.e. being a function or a business.

Which one is the best strategy and why?

A business oriented strategy is a much more sustainable strategy for the MRO organization in supporting the maintenance activities. We have several arguments to defend this choice.

First of all, we believe that the function oriented MRO organization corresponds to an old fashioned and non sustainable way to consider organizations. A function strategy is adequate for departments that must perform their activities and achieve high service level given pre-fixed budgeting constraints. On the contrary, the business oriented organization will achieve the adequate level of performance required by the other organizations and will achieve it at the lowest cost. Primary objective must be to achieve the desired service and second one to achieve it at the best cost. The other way to prioritize those objectives lack long term sustainability and impede innovation. Applied to the MRO organization, a business oriented strategy means achieving the required and agreed availability of spare parts i.e. the desired level of service, and to do it at the lowest cost. The function strategy is less appropriate for the MRO organization because the delivered service is a target and not a constraint and might not been reached if the budget is not appropriate. When the MRO organization misses to deliver the right service, this could have severe consequences on the all maintenance organization and may lead to excessive costly shutdown.

Secondly, we argue that the business oriented MRO organization is much more credible and sustainable in a competition environment. Customers want a product or a service and they want it at the lowest price. Applied to the Industry Park in Terneuzen, both Dow and Styron require maintenance spare parts and associated services and they want the Dow MRO organization to deliver them the spare parts at the lowest price. There is no obligation for Styron to make use of the Dow MRO organization. Hence the Dow MRO organization must be the best competitor for the MRO activities to achieve sustainability. The Dow MRO organization may grow in the future Maintenance Value Park by supplying surrounding companies.

2.2. Definition of a best in class MRO organization in a multi client perspective

This section defines a best in class MRO organization in a multi client perspective. Answer to our first sub-research question will be given: "What is a best in class MRO management in a multi-client perspective?"

Different alternatives are possible to define a best in class MRO management among the following. The ideal way to define best in class MRO management and leading industrial practices would be to lead an industrial benchmarking across MRO organization from chemical and non-chemical manufacturing industries. An exhaustive industrial benchmarking is not possible in the time frame of the Master thesis project. Other way to define best in class MRO management will be the use of KPIs with clear cut off values. The use of KPIs was not possible as KPIs are not used within industries and not proposed by the literature. To define the best in class MRO organization, we make use of best practices. The use of best practices is relevant to define the best in class MRO organization becomes it provides non ambiguous practices that drives performance. To our knowledge, the literature did not propose best practices to manage MRO. The best practices I propose are based on the conducted literature review on MRO management as well on interviews conducted within Dow Terneuzen and in other companies from Terneuzen surroundings. For brief description of visited companies, interview questions and main output, we refer to Appendix K. For this practical and research knowledge, I indentifie leading practices and translated them into best practices. The value added of our work to the literature and Driessen et al. (2010) article is to propose best practices for each MRO process. As a reminder, the considered assumptions are the following: multi-products with high diversity, multi-indenture structure, single stocking location[2], several customer companies, high risk environment as spare part unavailability might lead to costly plant breakdown. Our discussion is valid in environments having those characteristics. The section objectives are to complete Driessen et al.(2010) MRO management framework with best practices and to address practical issues raised when the MRO organization has the considered characterisitics and supplies several clients as the situation is at Terneuzen industry park. To answer our first sub-research question questions, we first explain why Driessen et al.(2010) framework is adequate to manage MRO. Secondly we define what MRO management pooling mean when the MRO is supplying several clients. Then, we explain why we can and cannot speak about MRO pooling for Dow MRO organization in Terneuzen. Last, and most important, we define and defend best practices for each MRO process and discuss issues raised by MRO pooling.

[2] Within Terneuzen, the MRO items are stocked in several physical locations but are managed as one single system location as they are all local warehouses (no global warehouse is refurnishing local warehouses, the stocked MRO supply chain is a one level supply chain.

Why Driessen et al. (2010) conceptual management framework is adequate?

As explained in Appendix C, a conceptual framework is useful as it provides rules of thumbs facilitating management decision-making process. A framework allows comprehension by showing the connection between the decisions taken in different sub-processes within spare parts management overall processes. A general framework increases efficiency, consistency and sustainability of decisions on how to plan and control the spare parts supply chain. Decision framework proposed by Driessen et al (2010) is the more recent and complete one to our knowledge. We make use of this decision framework as a starting point and assume the proposed decomposition in processes as a best practice. For a brief discussion of eight processes, we refer to section 1.2.4. For more details, we refer to Appendix D. We will provide best practices with each of those processes later on. Input for defining those best practices come from scientific articles, interviews within Dow, and within companies in Terneuzen surrounding. For a description of companies visited, we refer to Appendix K.

What does it mean to pool/to share spare parts management?

Spare parts pooling and sharing are used as synonym terms. Before discussing issues raises by pooling, we need to provide a clear definition of spare parts pooling. The definition and meaning can be broad and depends on the context. We must be clear each time we use this term. Spare parts pooling meaning is broad because:

- Spare parts pooling can be seen **as inventory pooling and/or service pooling**. When inventory pooling is used, we can **pool inventory over clients**, i.e. one MRO location supplying several customers, or we can **pool inventory over MRO sites**, i.e. several MRO stocking location will supply one customer. Definition and characterisation of a MRO client is given later on and illustrated in Figure 8. In case of inventory pooling over MRO sites, all geographical sites will be managed using the idea of a single virtual warehouse. Inventory pooling over MRO sites is done through lateral transhipments. We can notice that, in most cases, when pooling inventory over MRO sites, pooling over clients will also be used. The reverse is not true. When spare parts pooling means service pooling, services such as purchasing, coding, receiving can be pooled. Service pooling requires similar work processes and procedures over clients. In our discussion, we will make use of spare part pooling as both pooling of inventory and pooling of services. However, when meaning inventory pooling, the definition will be limited to inventory pooling over clients.

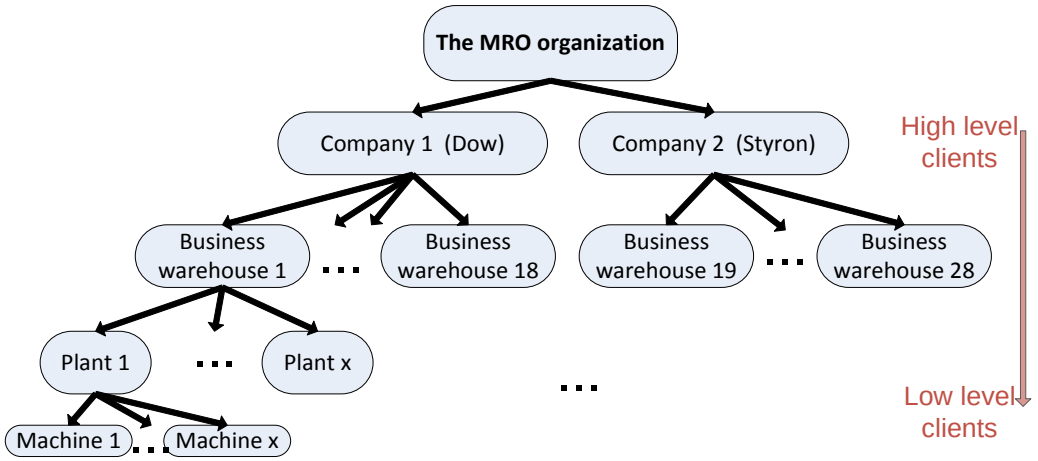

Figure 8 : the MRO organization different level clients

- Spare part pooling can be seen at **different levels i.e. for different MRO clients**. At a high level, a client can be a company. At a medium level, a client can be business warehouse within a company i.e. an indentified and independent group of plants. At a lower level, a client can be an

equipment or a machine within a plant or business warehouse. Indeed a given spare parts like a bearing or a pump can be used by two different companies, two different business warehouses or two different equipments/machines. Relationships in-between those different level clients are shown Figure 8.

Whatever the meaning behind spare part pooling, great savings and risk reducing (i.e. service availability increasing) through spare parts pooling can be achieved. Economies of skills and resources for handling, stocking, etc, are achieved allowing money saving. Spare parts pooling is a best practice in a business perspective as it allows reducing cost while delivering the desired service level.

However, spare parts pooling do not come by its own. It raises several issues and requires an initial important investment to model and implement spare parts pooling in practice. When pooling inventory over clients, issues to be solved are: How to set the stocks levels? How to face allocation problem if the stock is insufficient to meet the cumulative demand over the clients? Should the MRO organization make use of service differentiation? For inventory and service pooling, responsibility and financial issues must also be solved: Who is responsible for the parts? Who will pay when a shutdown occurs due to spare unavailability?

What is the MRO pooling situation for Dow MRO in Terneuzen?

In Terneuzen Industry Park, the situation is the following:

- The MRO organization is Dow responsibility and owning as shown in Figure 1. The MRO organization is part of the Maintenance service and solution entity.
- Spare parts service pooling is done for all MRO clients. The MRO organization supplies the two major manufacturing companies within the Industry Park: Dow and Styron. MRO resources, skills, procedures are the same for Dow and Styron and for the different business warehouses.
- Spare parts inventory pooling is not done in-between companies. Dow and Styron share the MRO services but do not pool their spare part inventories: the MRO warehouse is split, spares on some shelves belongs to Dow, spares on other shelves belongs to Styron. For exceptional events, one company can agree to sell one critical spare to the other company when urgently needed.
- Spare parts inventory pooling is done in-between business warehouses (belonging to the same company), and in-between equipments.

Which are best practices to manage MRO when supplying several clients?

MRO management will hardly depend on the breadth and depth dimensions of the outsourcing strategy. Indeed, which and how MRO processes are outsourced (contracted elements) directly impact how the manufacturing firm manages its MRO organization: invested time and resources, control processes will be adapted accordingly. Key elements must be contracted when the manufacturing firm decides to engage in MRO outsourcing. It is its responsibility to guaranty that the third party company works and respects best practices. This can be done through contract management and control mechanisms. MRO management depends on the outsourcing strategy. However, best practices do not depend on the outsourcing strategy. Each procedure and taken decision to manage MRO should fit with MRO best practice, whatever management is outsourced or not. For every MRO processes, we define best practices to be best in class and discuss issues raises in a multi client perspective. Further details on the best practices are provided in Appendix E.

Assortment management

Assortment management concerns the decision to have (or not) data on a given spare parts and to maintain technical information on it. Assortment management concerns catalogue management.

Coding management is included in catalogue management. We identify two best practices related with assortment management to guarantee completeness and uniqueness of the catalogue description.

Best practice: the catalogue description is complete.

Catalogue completeness facilitates purchasing, inventory management and MRO overall management. Assortment management is the starting point of MRO management and impacts on all other MRO processes. Complete catalogue description is important to have reliable information on the item description, clients needs (response time, criticality level) and supplier characteristics (deliverer time, price).

Best practice: the catalogue uniqueness is guarantied

The catalogue uniqueness is guaranteed when a given spare is uniquely referred i.e. when the catalogue is duplicate free. Duplicate free catalogue allows between inventory and supply management and increases spare availability.

Multi client perspective: uniqueness of the global catalogue description over clients is a necessary condition for pooling inventory over clients. Similarly, uniqueness over sites is necessary for pooling over sites. In our environment where we want to achieve spare part inventory pooling over clients, the catalogue should be unique over companies, i.e. Dow and Styron, and over business warehouses.

Best in class catalogue/assortment management that requires complete and duplicate-free catalogue is a huge effort. Ultimately, catalogue should be managed with cleaned, standardized, complete, consistent and duplicate-free information. An automated catalogue management should handle this complexity while being connected to the used MRO management system such as SAP or other ERP or EAM.

Demand forecasting

Parts that will be demanded in the near future need to be forecasted to support equipment reliability while optimizing inventory management and stock levels. These future demands come both from planned demand (preventive maintenance) and unplanned demand (corrective maintenance). The forecast is based on historical and/or known future demand. We identify two best practices with regards to demand forecasting.

Best practice: planned demand for slow moving and expensive items are forecasted to be bought at suppliers

For preventive maintenance, the demand of spare parts is known ahead of time. For expensive spare that have a supplier delivery time that allows having the spare before the preventive maintenance work, the spare should be bought at the supplier at the right timing and delivered directly to the user instead of being issued from the warehouse for then being replenished.

Best practice: unplanned demand are forecasted using time series based forecasting method.

To set the right stock levels and optimizing inventory management and replenishment, unplanned demand must be characterised using forecasting techniques.

Multi client perspective: when inventory pooling over clients applies, forecasting method should aggregate demand over all clients, at all levels (companies and business warehouses).

Parts return forecasting

Parts return flow comes when the clients return unused spares to the warehouse. Returns can concern spare that were initially issued from stock or spare that were bought at the supplier. Reason for returns is when the client did not know which spare was responsible for a failure and issued or purchased

more than needed. The return rate should be as low as possible. Returns create extra work and affects replenishment decisions. I identify two best practices regarding parts return and return forecasting.

Best practice: returns are tracked to reduce them
Returns should be avoided as they create extra work. Identifying the return root causes and engaging in improvement actions with the clients should help to reduce the return rate.

Best practice: a maximum return time is agreed with the client
To avoid unnecessary replenishment of spares that might return soon to stock, a maximum return time should be agreed between the client and the MRO organization.

Supply management

Two major suppliers are external suppliers or repair shops. Type of supply, i.e. buying a new part or repairing it depends of the repairability level of the part (whether the spare is repairable and how many times it can be repaired). The incentive to repair is higher for expensive than cheap items whereas it will be better to buy new parts for cheap items rather than repairing them. We identify two best practices regarding supply management; one for managing external suppliers, another one for managing repair shops.

Best practice: external suppliers are managed
It may be very beneficial from financial and administration points of view to use a strategic sourcing strategy (i.e. when a few major suppliers provide most of the spare parts supplies) (Campbell, J.D.,& Reyes-Picknell, J.V., 2006). Strategic sourcing allows having fewer transactions and fewer suppliers to manage. Supplier characteristics such as procurement price, lead time etc, must be set and maintain in the supplier description (we refer to previous discussion on assortment management). Contracts with suppliers must be managed.

Best practice: internal and external repair shops are managed
When an item is repaired in-house or in an external repair shop, repair time and location of the spare parts should be tracked. Inventory management needs to have visibility on which spares will be back to stock and when to take into account stocks levels in the repair process while taking replenishment decisions.

Multi client perspective: when the MRO organization supplies several clients, bought MRO quantities to external suppliers will be higher. A multi client perspective is beneficial as purchasing will be able to negotiate better prices and delivery times when bought quantities are higher.

Repair shop control

To some extent, the internal repair shop can be considered as a production unit in a supply chain. Agreements between the repair shop MRO should be made upon the repair lead time for each spare part and the workload levels per unit of time. Those decisions impact the operational level through the schedule of repair job. Moreover, tactical decisions are taken to determine the global capacity and resources (machines and tools, employees) of the repair shop. We identify one best practice related with repair shop control.

Best practice: due date for each repair job are managed and communicated upon.
Whatever repaired in-house or repaired by an external suppliers or repair shop, the expected due date should be known. This repair due date, when the repaired spare is intended to go back to MRO inventory, should be communicated upon to inventory management to avoid useless replenishment.

Multi client perspective: repair resources and control can be shared over clients. Repair processes sharing can occur as pooling of MRO services. Clients sharing repair process must agree on common repair procedures and work processes. They must agree on a fair charging mechanism to allocate repair cost over them. Priority rules for repair jobs in-between clients must also be set for all types of jobs. If no service differentiation is made over clients, a first in first out FIFO rule can be used.

Inventory management

Inventory control decisions concern which spares to keep on stock, at which stocking locations and in which quantity. Our single location assumption simplifies to inventory management problem to what and how much to keep on stock. Inventory must be kept to cover unplanned demand of spare parts, planned demand of cheap items or planned demand of items whose supplier lead times exceed delivery due date of the client. In this perspective, the MRO warehouse should be managed as a closed warehouse. Every movement from or to the warehouse should be controlled and justified. The MRO warehouse should not be managed as a shop. Opposed with a warehouse perspective, a shop keeps high inventories to stimulate and cover client unjustified and uncontrolled demand.

Best practice: MROs are classified using multi-criteria ABC to identify homogeneous groups of parts

Most companies managing MRO have adopted a classification to handle management complexity. Adopted classification differs over companies. Literature does not agree on a MRO classification to be adopted. Based on practical experience and literature knowledge, Appendix G shows the importance of classifying spares, argues why ABC is a useful classification and proposes ABC classification based and criticality and demand criteria. The goal of this classification is to identify stocking policy and strategy for each homogeneous group of parts.

Best practice: from the spare parts classification, adequate replenishment policy and replenishment policy parameters are selected.

Once the ABC classification has been set, inventory strategy must be set for each group of parts.
Figure 9 shows the relationships between Driessen et al. (2010) classification, our ABC multi-criteria classification and inventory control.

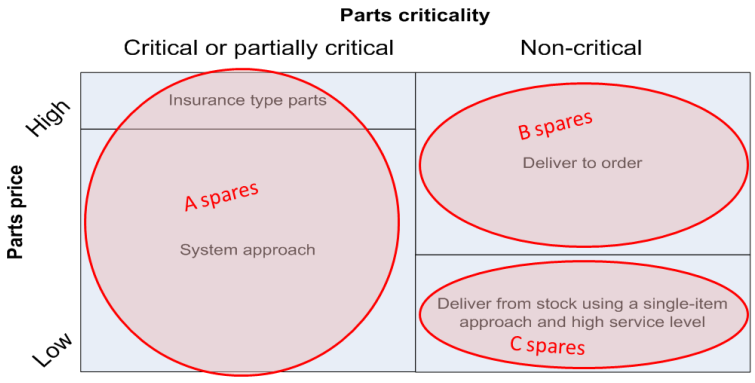

Figure 9 : relationships between Driessen et al. (2010) classification, our ABC multi-criteria classification and inventory control.

A items: critical spares

From Driessen et al. (2010), expensive and critical parts are insurance type parts and are kept on stock. Cheap to medium priced and critical parts will have a system approach strategy.

B items: non critical, slow moving and expensive parts

As B items are non critical, slow moving and expensive parts, stock levels should be controlled and limited. From Driessen et al. (2010), those parts should be delivered to order meaning that no B items are stocked.

C items: non critical, high moving and cheap parts
For C items, setting good replenishment policy and replenishment parameters is key as C items are fast movers.

Further information on inventory management of ABC items is provided in Appendix E.

Multi client perspective: spare parts inventory management is already a complex and difficult task in a single client perspective. We raise inventory management complexity in a multi-client perspective. First necessary, and obvious, condition to pool inventories over client is to have common spares to share. This condition is not ensured in chemical industries. Second condition to pool physical inventories is that each client should have an incentive to pool; this incentive will either be service level increase or cost saving. In this respect, we estimate that pooling of critical spares will be difficult as it can have a negative impact on service level and equipment reliability. For non-critical spares, pooling spares is attractive for expensive spares to save cost as well for cheap items, fast movers items to reduce handling workload. If those two conditions-commonality and incentive- are passed, it can be possible to pool inventory. But before effectively pooling inventory over clients on common shelves, clients must share catalogue and item description. Indeed, one spare must be uniquely identified over clients in order to pool its inventory. Then, clients must agree upon the work processes, procedures, cost allocation rules for managing shared inventories. Clients should assess spare parts criticality level to rate an item as critical or non-critical. Then demand volume must be aggregated by the MRO organization over all clients. Inventory pooling should be taken into account while setting stocking levels and replenishment parameters. The issuing process and allocation rule also needs to be set in this multi client perspective. It might be wise to adopt a first in first out policy when the stock is high with low risk of stock outs and priority rules over clients that takes into service differentiation, based on client's needs, when stock is low with high risk of stock outs. In inventory pooling, the MRO organization holds a centralized decision role by setting inventory policies and replenishment parameters and assigning inventory holding cost incurred via indentified and non ambiguous cost allocation rules over clients. We point out that, for contracts managed MRO (i.e. when the manufacturing firm has outsource inventory management), the third party external company can take the decision to pool inventory over its clients. If the manufacturing company does not want its MRO inventories to be pooled by the third party company, this should be specified in the contract.

Spare parts order handling

Spare parts order handling consists in accepting, adjusting or rejecting a released order for a spare parts; releasing the spare parts and handling return orders.

Best practice: the MRO organization manages in and out inventory movements with a closed warehouse

A closely managed warehouse allows to control in (i.e. return and replenishment) and out (i.e. issues from clients) inventory turns. A closed warehouse helps to manage and track turnover.

Best practice: the MRO organization checks spare parts orders on order lead time and quantities

For unplanned demand, direct issues from the warehouse (or from the supplier if the spare is not on stocked), should be placed. For planned demand, the client should make use of reservation process instead of direct issues to reduce handling and allowing MRO to optimize their inventories. For

example, if a client knows he will need a spare in one month, he should reserve the spare with a need date of one month to the MRO organization. Then, the MRO organization manages the reservation: if the spare is not on stock, it will place an order to the supplier to be just in time delivered and the spare should be directly delivered to the client, bypassing MRO inventory. If the MRO organization has the spare on stock, it will purchases slow movers at the supplier is timing allows, and issue fast movers from the MRO warehouse.

Deployment

Deployment concerns the process of replenishing spare parts inventories. Replenishments can come from the repair process or from procurement orders. Hence, for best practices, we refer to previous discussions.

Our **first research question** was "What is a best in class MRO management in a multi-client perspective?" **To answer this first research question we kept Driessen et al. (2010) decision framework as an adequate management framework to manage MRO in a multi client perspective. For each MRO process, we proposed best practices and discusses issues raised when supplying several clients.** Our investigation does not go in details on all topics. Questions might remain when one want effectively implementing forecasting, simulation and optimization of replenishment policies and parameters, criticality assessment of spare part, inventory pooling. We see and recommend further study on those topics.

Chapter 2 was the Define step in our 6 sigma methodology. We have defined a sustainable MRO management by defining the business strategy and best in class MRO management. Characterization of the function and business MRO strategies were given. We defined a best in class MRO organization by illustrating Driessen et al. (2010) framework with best practices and by discussing issues raised in a multi client perspective. Answer to our first sub-research questions "What is a best in class MRO management in a multi-client perspective?" was given.

3. Measurement and analysis of Dow Terneuzen MRO situation

The previous chapter had defined the MRO management sustainability by defining and characterising what being business oriented and being best in class meant.

This chapter constitutes the measure and analyze steps of the 6 sigma methodology. Chapter 3 measure and analyses the Dow Terneuzen MRO management. To know whether Dow Terneuzen has a sustainable MRO organization, section 3.1 examines the MRO strategy is business driven and section 3.2 examines whether Dow Terneuzen has a best in class MRO management. In this chapter, answer to second sub-research question "When does outsourcing support the MRO strategy?" and third sub-research question "Are there appropriate KPIs to assess the MRO internal performance?" will be given, respectively in sections 3.1.3 and 3.2.

3.1. Current MRO strategic situation of Dow Terneuzen

In this section, we aim at measuring and analyzing the strategy of the Dow Terneuzen MRO management. In section 2.1, we have defined the business MRO strategy and explained why a business strategy support MRO sustainability more that the function oriented strategy. Being business oriented mean to achieve the desired level of performance and service and to achieve it at the lower cost. Section 3.1.1 will measure the delivered service by the Dow Terneuzen MRO organization from the client perspective thanks to SLAs and external KPIs. Section 3.1.2 will evaluation the MRO financial situation. Last, section 3.1.3 will examine whether outsourcing part or all MRO activities might support MRO management in its business strategy and will answer the second sub research question "When does outsourcing support the MRO strategy?"

3.1.1. SLAs and external KPIs

In this section, we assess the Dow MRO organization from the external perspective i.e. from the client. We first identify who are the MRO clients (or stakeholder) and their needs. Then, we propose objective ways to measure the MRO performance thanks to service level agreements (SLAs) and external Key Performance Indicators (KPIs). Last we effectively rate the Dow MRO organization from the client perspective.

From the Terneuzen surrounding companies we visited that manage themselves their MRO (Cargill, Yara, Sabic, and Sitech), none of them have set SLAs for MRO management. Setting SLAs is a huge effort for companies and takes time. When MRO is in-house managed, the company might miss to see the benefit of settings SLAs for the MRO organization. The MRO business might suffer from lack of awareness and might not be seen as important as it is by high level management. However, identifying client's needs in maintenance, setting service measures and target levels is key in optimizing MRO management. Combining service measures in a SLA is a minor step further. When outsourcing MRO management, engaging in Vendor Managed Inventory or Consignment stocks, SLAs and external KPIs must be contracted, as ways to measure, track and control performance. When SLAs and external KPIs are already in-house set when engaging in outsourcing, they facilitate discussion when being used as a core discussion topic in the outsourcing process and contract design. In order to set SLAs and external KPIs for the MRO organization, we must define a few terms:

- **Service level agreement SLA:** the part of a contract between a service provider and a customer that specifies, in measurable terms, what level of service will be provided.
- **Service measure:** a measure used in SLA to express the level of service. We use **external key performance indicator KPI**s and service measures as synonyms.
- **Service level:** the actual value of a certain service measure
- **Target level:** the value of a service measure that is agreed upon in a SLA

What are the clients of the MRO organization and their needs?

The clients of the Dow MRO organization in Terneuzen are:

- the internal repair shops as they also have MRO needs and issue from the MRO warehouse
- the maintenance organization as MRO items are needed resources to conduct the maintenance activities supporting equipment reliability
- All Dow and Styron plants of Terneuzen industry-park site. All those plants are aggregated over business warehouses, 18 for Dow and 10 for Styron. For details, we refer to Figure 8.

We identify several major clients' needs. As we have distinct need, SLA should be a multi-criteria SLA that integrates all services. Key services that should be targeted by the MRO organization to fulfil its client's needs are, in order of importance:

- High **reliability** in spare parts availability: the client must rely on MRO organization that provides them with the spare parts they need.
- Low **response time**: the items should be delivered on time. This means that planned demand (coming from preventive maintenance) should be delivered on time. The desired delivery date for an item is then equal to the start date of the work order. Unplanned demand (coming from proactive maintenance i.e. after a failure occurred) should be delivered in best delays, from the warehouse or from external suppliers or manufacturer.
- Good **quality**: items should be delivered in good condition to the client.
- Low **cost**: the total cost of MRO management should be controlled and fairly charged over the clients, to be as low as possible.

Reason for setting the cost service level with the lowest importance is due to our high risk environment assumption. Shutdown of a plant because of an equipment failure can cost over 1 million Euros per day. As financial impacts of shutdown can be extremely high, the clients must have the MROs when they need them, in operating conditions. They will prefer to pay more for MRO services rather than taking the risk of a shutdown.

The MRO organization is responsible for availability of spares to conduct system maintenance whereas the maintenance organization is responsible for all other resources (technicians, machines, etc). Spares can be available at the client level, in the site MRO warehouse, in a warehouse managed by an external distributor (such as Van der Peijl) or at the original manufacturer. The availability location is MRO decision. To achieve the desired level of performance, the MRO supply chain should be agile and flexible.

How to measure the MRO delivered services from the client perspective? Or how to set SLAs and external KPIs?

Now that we know which are the MRO clients and their needs, we will propose service measure to assess MRO performance. Performance will be measured thanks to external KPIs reflecting reliability, response time, quality and cost services delivered by the MRO organization.

According to Driessen et al. (2010), the MRO organization and its client typically make agreements and specify upper/lower bounds for key performance indicators such as the average work order delay due to unavailability of spare parts, the percentage of work orders without delay (caused by unavailability of spare parts) or the maximum "number of unfinished work orders" due to unavailability of spare parts at any given time. From visited companies, we have not found such agreements nor SLA or external KPIs. Only one company had a survey in place to measure satisfaction of maintenance and finance customers.

There exists alternative ways to measure a given service. For example, reliability of spare parts availability can be measured through availability, aggregate dill rate or total number of stockouts. A way to define availability is a service measure as time based i.e. the percentage of demand that has been satisfied within the agreed lead time. To measure how the clients judge the MRO in its role as a service provider, we propose the following external KPIs (we paid attention to propose meaningful and measurable KPIs):

- **Stock out rate** = average number of stock out/ total number of stocked items. Stock out measures availability of spare parts stocked by the MRO organization. It reflects if inventory control is well conducted. We propose monthly measurement and reporting of this KPI. Stock out rate should be as low as possible.
- **Backorder rate** = total number of backorders/ total number of issues over a period of time. A backorder occurs when the MRO does not deliver the client within the client required need date. The way to measure the number of backorders should aggregate over all backorders and integrate how long it took to fulfil the backorder. This KPI measures how frequent and how late the MRO was in delivering its clients. Quarterly reporting seems adequate. Low backorder rate is the target.
- **Quality rate** = number of rejected orders by the client for justified quality issues/ total number of orders. This KPI measures whether items are delivered to the client with the expected quality. Quality issues can come from problems during transportation or non adequate stocking conditions. To guaranty good quality rate, quality checks should be done when suppliers are delivering to the client or to the MRO warehouse and when items goes out of the warehouse. Quarterly or yearly reporting of this KPI seems adequate. High quality rate is the target.
- **Charged cost levels.** Way to measure this KPI comes from the way the MRO organization is charging its clients. We proposed monthly reporting for this KPI. In a business perspective, the MRO organization targets service levels and deliver those services at the lowest cost. The lower the MRO cost, the lower the cost charged to the MRO clients. The charged cost should be computed such that they cover at least the real cost. The difference will be used by the MRO organization for investing in long term perspectives.

When setting SLA in-between the MRO organization and its client, the SLA should aggregate external KPIs that measure reliability, response time, quality and cost performance. In a business strategy orientation (i.e. when the MRO organization aims at minimizing cost given service level constraint), the MRO organization must set target levels for external KPIs measuring reliability, response time and quality performance. Different service target can be set for different kinds of parts. Non-critical spares that do not cause immediate shutdown of the plant will have lower service targets than critical spares. Once service targets are set, the MRO organization aims at reaching those targets at the lowest cost.

What is the Dow MRO organization service performance from the client perspective?

Today, the Dow MRO organization in Terneuzen is only using the number of backorders as a KPI to track its performance from the client perspective. Most of MRO clients does not plan their MRO need and place work order with MRO to be delivered on a next day basis. All MROs being stocked are then rapidly delivered to the client that might keep MRO stocks lying long time before effectively being used for a maintenance or repair activity. As most demand for MRO is currently unplanned (direct issue process rather than reservation), a backorder occurs when the MRO does not have the item on stock when the client needed and issued it. The number of backorder KPI currently used is defined that way. The backorder rate we propose measures how often and how long the MRO organization was late in delivering, it integrates both planned and unplanned demand.

The number of MRO backorders is rather low within Terneuzen. We conclude that the MRO organization is well performing regarding reliability of spare parts availability and response time. This high service level might be reached thanks to high inventory levels. In average, the MRO organization faces 2 or 3 quality problems i.e. when the MRO item is not delivered to the client in good conditions. We rate the MRO organization as good to very good regarding reliability, response time and quality performance. Financial performance will be assessed in section 3.1.2.

A useful tool to assess the Dow MRO organization from the client perspective in more details could be the SCOR model. SCOR strives for Supply Chain Operation reference. SCOR is a model, product of the Supply Chain Council SCC organization. SCOR provides a unique framework that links business process, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities. The model proposes metrics to measure the supply chain reliability, responsiveness, agility, cost, and asset management. The Dow Chemical Company is already a SCC member and could make use of the SCOR model. For further details on SCOR and SCC, we refer to the website www.supply-chain.org.

3.1.2.Evaluation of the MRO financial budget

This section investigates the cost structure of the MRO activities and how those costs are recharged to other Dow departments and priced to Styron, the external client. We remind that the MRO organisation within Terneuzen is managed within Dow and provides its services to both Dow and Styron companies, the two tenants of Terneuzen industry-park. Most MRO services are provided to Dow but since the MRO organisation is also provided its services outside the company, it is vital to fairly price the MRO costs for the provided service to those external clients. As the MRO organisation will move in coming years to the maintenance ValuePark, competition with other MRO services provider is real and will increase, as well as growth opportunities. The competitive environment forces the MRO environment to assess it cost structure and to fairly price it to achieve long term sustainability. Financial considerations are also main variable in a business strategy, i.e. when the MRO organization aims at minimizing its cost while delivering the agreed service levels. To evaluate the Terneuzen MRO financial budget, we first consider the cost structure organization before considering real MRO Total Cost of Ownership (TCO). Last, we discuss what a fair and sustainable recharge model (for Dow clients)/pricing mechanism (for Styron clients) is.

What is the Dow Terneuzen MRO organization financial budget?

Within Terneuzen, the MRO organization is only responsible for inventory management. Related activities such as spare parts order handling for stock items, deployment (i.e. replenishment and receiving) and returns of unused MROs are also handled by its responsibility. The MRO organization within Dow Terneuzen is limited to a few people: some inventory coordinators, one discipline activity specialist and overhead maintenance management leaders. All logistics activities have been outsourced to Ceva logistics that takes care of receiving from supplier and transportation of MROs for the issue, return and repair processes. About 15 people are working for Ceva logistics for Dow activities in Sluiskil and Terneuzen sites. The MRO organization scope within Dow is limited to inventory management and logistic activities. All other processes related with MRO such as repair shop control, assortment management, supply management are other departments' responsibilities.

Hence, the current cost of the MRO organization has the following two main components, for 2011:

- The inventory management cost represents 1 million €/year for salaries and site infrastructure cost. This cost includes both inventory control and central store cost centers. The inventory management costs are recharged to the client through issuing tickets (fixed cost for Styron,

real cost based on budget and estimate of number of tickets within Dow). One ticket represents one demand with a list of needed MRO items.

- The logistics cost: for Ceva logistics contract

But this cost structure that reflects the ways the MRO activities are separated and spread over departments, does not reveal the total costs related with MRO activities. Every year, 17 million € of new spares are bought to replenish the MRO warehouse. Another 1 million € must be added for consignment stocks. We do not know in value, how many MROs were bought at the suppliers and directly delivered to the final user, bypassing inventory. 55 million € items that are kept on stock in Terneuzen and Sluiskil shelves. We do not know the MRO costs associated with supply management, catalogue management and repair activities. Dow Terneuzen does not have visibility on the MRO TCO. The yearly MRO TCO might exceed 20 million €/year.

What is the real MRO TCO?

While doing interviews within Terneuzen surroundings, we had the opportunity to view how Brammer and Accenture consider the MRO TCO. According to Accenture, 37% of the MRO TCO is non-price related. According to Accenture and Brammer information, Figure 10 gives an estimate of the MRO TCO components. Knowing the MRO TCO is key for MRO management and should be known and assessed within Dow to strive reduction of variable cost and control of fixed cost to achieve long term sustainability in a business perspective. Not knowing the MRO TCO might lead to wrong management decision or wrong pricing mechanism to non Dow clients and wrong recharge mechanism to Dow clients.

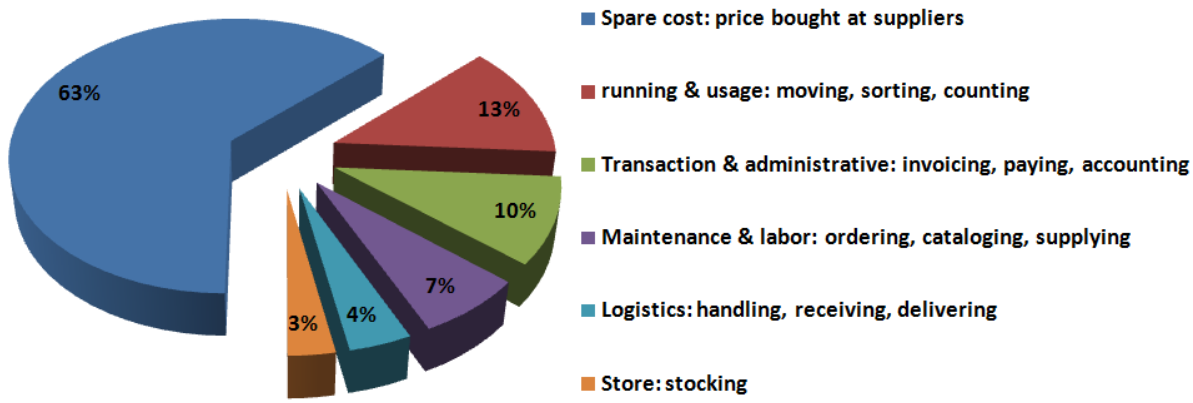

Figure 10 : MRO TCO components

What is a fair and sustainable recharge model/pricing mechanism?

Once the MRO TCO is known, the question is to know how to recharge those cost to Dow MRO users and have a faire pricing mechanism for the non-Dow MRO users. Today non-Dow user is Styron. As the repair shops are planned to be outsourced to a third party company, a future MRO user might be this repair third party company. Currently, the internal repair shops represents one third of issues from MRO stock.

The Sustainable Economic Cost SEC calculation method is a newly developed Dow method to calculate Dow total cost to provide a service to third parties on a long term basis. The SEC calculation integrated all internal Dow cost. The internal costs considered by the method are the operating, reinvestment, administrative costs and cost of capital. The SEC method is appropriate when the service is delivered to non-Dow user. The difference between the SEC and the price between Dow and the non-Dow user makes the margin, either positive or negative. The SEC is important to know while negotiating with the third party company. The Dow SEC method has started to be implemented

and might be used in the future by the MRO organization. Today the Dow Terneuzen MRO organization is recharging its inventory and central store management (2 cost centers) through issuing tickets. The ticket price for Styron is fixed and contracted for year. The ticket price for Dow is variable every year. Tickets prices are based on the MRO budget and estimation of the number of tickets. Within Dow, this ticket price is the key to recharge MRO cost to other Dow cost centers.
The Dow Terneuzen MRO organisation must know his in and out financial flow: gross cost (TCO) and recoveries can be represented in a value mapping.
The recharge model within Terneuzen for MRO inventory and store management (2 cost centers) with issuing tickets is not a Dow global recharge model for MRO activities. For example, Dow Germany has adopted another model to recharge its cost through several keys. Unit fees are charged based on the number of inventory units, capacity storing area (for indoor, outdoor, racks and pallet shelves), as well as material movement and receiving. The disadvantage of the Germany recharge model is its complexity but it gives incentives for MRO optimization to control inventory levels, storing space and logistics movements.
There is value for Dow Terneuzen to reconsider its MRO recharge model. The adopted recharge model might differ from the one adopted in Germany. I think that the chosen recharged model should even go further than the Germany to give financial incentive to the MRO user to behave according to best practices. For example, the MRO should give positive incentive to the user for making use of the reservation process. Returns or urgent issues should be charged to the clients as they create extra MRO work. To rethink the Dow Terneuzen recharge model, one should make use of the previously discussed element: TCO, SEC, value mapping, Dow Germany recharge model. The work by Kivinen et al. (2003) that presented an activity-based costing spreadsheet tool for analysing the logistics tools might also be useful.

We do not go further in financial assessment due to the master thesis time constraint and to the required effort to go deeper in those aspects.

3.1.3. The outsourcing decision

To support its MRO strategy and having the right MRO service at the best cost, a manufacturing company must take the decision to manage MRO in-house or to outsource it. This section addresses the following sub-research question: “When does outsourcing support the MRO strategy?”

When examining the outsourcing decisions, the ultimate goal is to strive for long-run sustainable and competitive advantage. We argue there is two different ways to assess whether going for outsourcing or not. Below we propose two different criteria.
Criterion 1: Service performance criterion. For a given MRO budget constraint, if the third party company is able to achieve higher level of performance than the outsourcer company then the outsourcing decision is a worthwhile investment, otherwise it is not.
Criterion 2: Cost criterion. For a given and constrained level of performance, if the third party company is able to reach the desired performance at a total cost lower than the outsourcer company then the outsourcing decision is a worthwhile investment, otherwise it is not.
Both criteria require an appropriate scanning of the market suppliers. The selected market suppliers must be audited on both performance and price criteria. If the service performance criterion is used, then the best supplier is the one that achieve highest level of performance given the budget constraint. If the cost criterion is used, then the best supplier is the one that achieve the desired level of performance at the lowest price.

How the strategy does impacts the outsourcing decision?

Then the question that follows is: How to choose in between the two available criteria for outsourcing? We argue that the criterion selection depends of the organization strategy. If the organization has a function strategy, i.e. if it strives for the highest performance level given budget constraint, the service performance criteria is the adequate one. The function oriented organization will engage in outsourcing if it can achieve a better service given a predetermined budget constraint. On the contrary, we argue that the organization that has a business strategy, i.e. which strives for the lowest cost given service level constraint, will use the cost criteria when considering the outsourcing decision.

How the management wishes impact the outsourcing process? What is the situation for Dow MRO Terneuzen?

Dow MRO wants to have a business strategy. Then the cost criteria must be considered before outsourcing any MRO processes. Dow MRO must question itself. First of all they must set service level targets and assess their own organization to know whether they achieve the desired level of performance. If the desired levels of performance are already achieved, then the cost criterion for outsourcing is straightforward to use: for the same level of performance, the outsourcing is interesting if the third party cost is lower than the in-house cost. Then the MRO must know what the in-house cost is by assessing their budget cost and must know the third party cost by making a bid on the market. But if the current performance level is lower than the target levels, then the MRO organization needs to fulfil the gaps. In this situation, the organization needs to choose if they want to improve the service before outsourcing or let the improvement action to the outsourcing company. The cost criterion is less straightforward to use. If the MRO organization decides to improve before considering the outsourcing decision, then outsourcing is worthwhile if the price proposed by the outsourcing company is lower than the estimate future cost for performing the activities in-house. The estimate future cost includes the current cost and the costs for improvement. If the MRO organization wants to let the improvement actions to the outsourcing company then the cost criteria is used for the current situation and improvements must be agreed and contracted between the outsourcer and outsourcing companies. The decision tree depicted in Figure 11 summarizes the discussed steps. The decision tree also shows the symmetric path that a function oriented organization must follow.

Whatever the decision path, the MRO business oriented organization needs to set service targets, to assess the current level of performance, and to investigate the in-house cost as well as outsourcing price and performance proposed by third party companies.

Appendix I provides more detailed information on the outsourcing decision: definition of outsourcing is provided, advantages and disadvantages of outsourcing the MRO activities are described, which MRO processes can be outsources together are proposed, key elements to be contracted in the outsourcing process are described, drivers and success factors of the outsourcing process are given.

Our **second research question** was “When does outsourcing support the MRO strategy?” **To answer this second research question we proposed a decision tree outsourcing process that identifies when outsourcing the MRO activities helps the MRO strategy.** Both function and business strategies have been considered. **When being business oriented, the outsourcing decision is meaningful when the third party is able to deliver the same level of performance for a lower cost.**

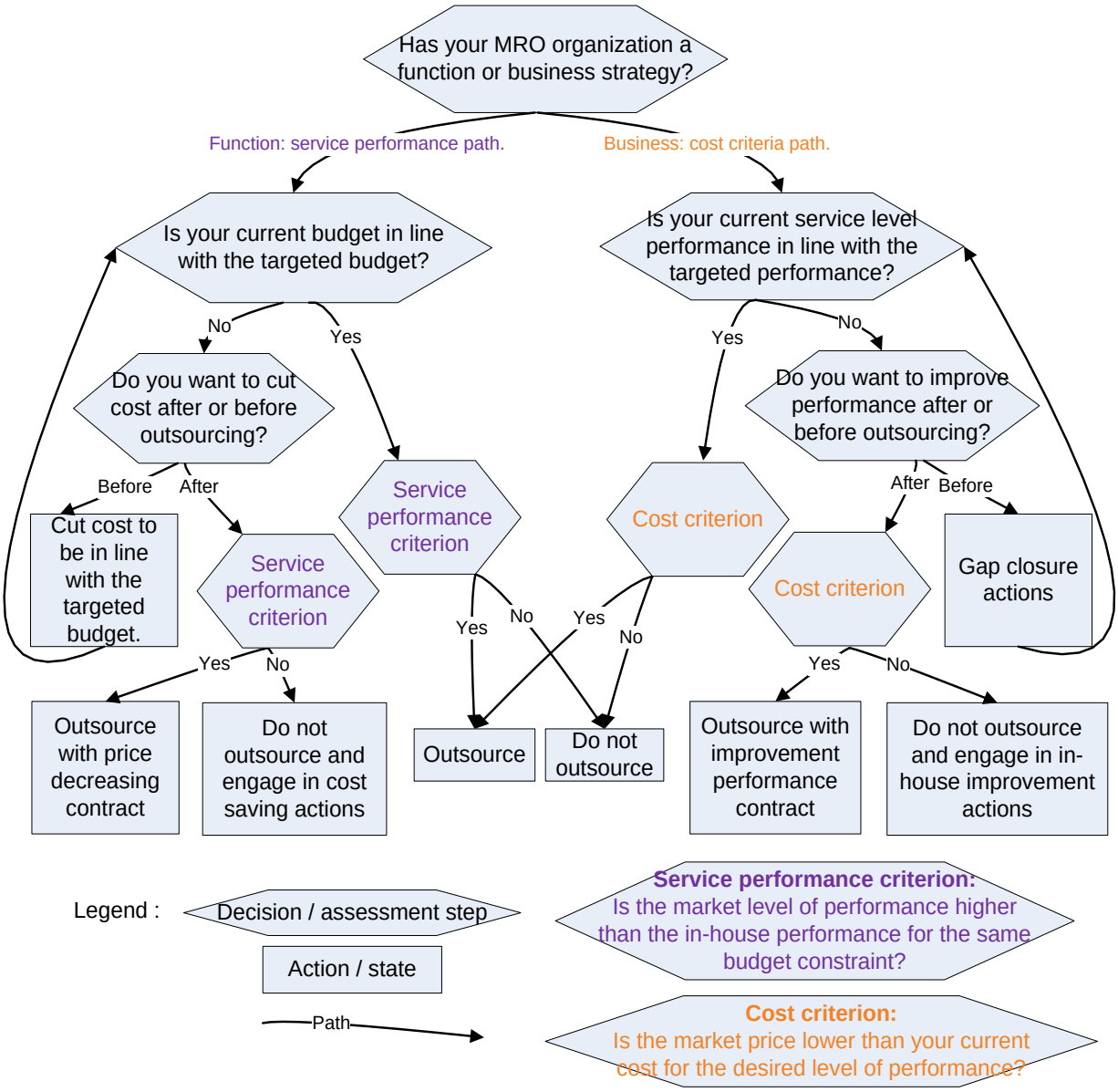

Figure 11 : The outsourcing decisions tree integrating the outsourcer strategy, situation and management desires

3.2. Current MRO service performance of Dow Terneuzen

After assessing the business orientation of the Dow Terneuzen MRO management, this section measures and analyzes whether Dow Terneuzen is a best in class. To assess internal performance, we make use of best practices we have defined and described in section 2.2. We propose ways to go further in the assessment by proposing internal KPIs to track internal performance and management of resources. After assessing the MRO organization external performance from the client perspective, this section assesses the internal performance. We will give answer to our third and last sub-research question: "Are there appropriate KPIs to assess the MRO internal performance?"

To assess the Dow MRO internal performance, we make use of Driessen et al (2010) conceptual framework that decomposes the MRO management problem in eight processes. Figure 12 shows the relationship between Driessen et al. (2010) processes and Dow Global Maintenance Work Process GMWP. For further information on Dow GMWP, we refer to Appendix L. For each process, we

describe the work process and practices within Dow, judge its performance based on the best practices we identified and described in section 2.2, and propose internal key performance indicators KPIs to allow the MRO organization to assess itself more deeply. An internal KPI is an objective and useful way to express the efficiency of the use of internal resources. A KPI also allows leveraging the opportunity over different sites, allows tracking change in performance over time. Internal KPIs must be used for internal assessment and management leading to improvement actions. Good use of internal resources and improvements actions should ultimately improve the delivered service for the client that will be measured through external KPIs. For each KPI that we propose, appendix F provides more information on the KPI meaning, way to compute it, direction for high performance and frequency of measurement.

Driessen et al. (2010) decision framework	Dow Global Maintenance Work Process GMWP
1. Assortment management	Global MRO coding process 4.4. Spare part determination
2. Demand forecasting	Not done, could be done within MSMS, the inventory management system
3. Parts return forecasting	Not done: repairable MROs are not identified, no forecast of return rate or return time in 5.3.4. Return to stock
4. Supply management	External suppliers: Purchasing organization Repair shops: 5.3. Issue & return process
5. Repair shop control	Maintenance organization
6. Inventory control	4.1.1. Set up MRO & PPM programs 4.3.2. Evaluate spare parts requirement 4.4.8. Perform risk assessment review and determine MRO strategy to be followed 5.1. Manage inventory by addition request 5.2. Manage existing inventory 5.4.Stock take
7. Spare parts order handling	5.3. Issue & return process 5.3.1. Store issue require
8. Deployment	5.5. Inventory receipts

Figure 12 : Relationship in-between Driessen et al. (2010) processes and Dow GMWP

Assortment management

Within Terneuzen, at the business warehouse level, a PPM coordinator and reliability engineer are responsible for setting and maintaining spare part lists for their own business. All spare parts being in the catalogue do not need to be stocked in the local warehouse. Code requests and material code management are done through SAP diamond system tool. Catalogue management is done at the global level. When a new code is created, information is documented on the item description, if the spare requires specific quality control or a repair code. Once supplier information with price and delivery time are filled in, reliability engineers will set order point and order quantity for replenishing inventories. Documentors fill in technical information in the database based on reliability engineers input information. Documentors also link the spare part with the equipments having the spare installed: this is the fits in. This fits in is a one level bill of material. 4.4. “Spare part determination” in GMWP specifies work process for managing spare parts lists. 4.4.8 “Perform Risk Assessment Review and Determine MRO Strategy to be Followed” adds valuable insights on the need to conduct a risk assessment at the spare part level to determine the need for a spare and timing required having it on location. But work process 4.4.8 is not executed in practice.

Best practice: the catalogue description is complete.

We score the performance as **low** regarding catalogue management and completeness. Reliable and complete data are a problem of upmost importance. To rely on complete catalogue information, the global, supplier and local descriptions should be different role responsibilities. Coders should take care of the global descriptions with information such as unique original code, item description, and repair code if the item is repairable. Supplier description with at least price and delivery time should be managed by procurement or purchasing people. The local description with needed delivery time, fits in, criticality, specific stocking condition or quality checks should be reliability engineers input to provide local need and usage information. Information for inventory management should not be in the catalogue description. The decision to have the spare on stock in the local warehouse and replenishment parameters such as order points and order quantities for stocked items should be left to the MRO organization for optimizing inventory management. Inventory decisions should be based on usage information and on information from the catalogue such as supplier lead time, item price, local criticality assessment and required client lead time.

Best practice: the catalogue uniqueness is guarantied

We score the performance as **average** at site level, and poor at the globe level. This Dow video on master data management http://www.photodex.com/share/donnyham/27p89mg4 shows the coding situation within Dow over the globe and explains savings that could be achieved if Dow succeeds to get rid of duplicated. Over the globe, Dow systems are managing 3 million codes with an estimated 50% duplicates. Best in class is less than 10% duplicates. Dow is managing MROs through 7 different systems or images, in 9 different languages. Globally 800.000 items are stored in over 500 warehouses. This global stock is valued at $575 million. Estimates savings of a global management coding is $12 million/year and saving of 4 billion in wasted resources and time every year. This problem of duplicates within Dow is still an actual problem. The master data management video is from February 2011. With SAP Diamond Systems, Dow Chemical expects to reduce its number of codes from 3 to 2 millions. Duplicates are a problem over Dow sites but also over MRO clients for a single Dow site such as Terneuzen: a spare used by several Dow business warehouses should be uniquely catalogued to avoid extra work and improve purchasing, maintenance and inventory management activities. In Terneuzen, Dow is managing 300.000 MRO codes among which 45.000 ones are kept on stock for a value of 55 million Euros.

We propose the following KPIs to measure and track the completeness and uniqueness performances for catalogue management:

- **Percentage of items with incomplete descriptions.**
- **Total number of original codes.**

Demand forecasting

Within Terneuzen, for almost all spare part orders, the MRO client issues spares from the warehouse as soon as it has indentified the need. After being issued, the spare might stay weeks, or even months at the client location before being effectively used, or returned if unused. The urgency and priority of the maintenance work orders are not embedded in the spare parts ordering process. Most spare parts orders are placed with today's date as the need date. Then, the MRO organization receives and handles all spare parts orders with the same and urgent priority.

Best practice: planned demand for slow moving and expensive items are forecasted to be bought at suppliers

This best practice is **not followed** currently in Terneuzen. The current practices allow the MRO client to issue all their spare part order directly from the warehouse. Our best practices stipulates that

savings could be achieved by buying slow moving and expensive spare directly to supplier and by-passing inventory to fulfil the client need rather than issuing from stock. This is possible if demand is known enough ahead of time and if supplier lead time is reliable. Bypassing inventory is a best practice for slow moving and expensive spare parts because one-to-one replenishment is appropriate. Handling is reduced because the spare goes directly from supplier to the client instead of being issued from stock and then being replenished. Bypassing inventory for planned demand also let inventory available if unplanned demand for the same part occur from another client. The best practice is not valid any more for fast movers as we miss batching opportunities.

Best practice: unplanned demand are forecasted using time series based forecasting method.
This is **no demand forecasts** done for MRO demand in Terneuzen so this best practice is not adopted. Forecasting should be done to estimate future unknown demand to optimize stock levels and replenishments. Traditional techniques should fit for fast movers whereas specific techniques might be needed for slow movers. Replenishment parameters should be set based on forecasting information, supplier lead time and quantity per issue.

We propose two ways to measure how well the clients are anticipating their spare parts need and whether they are reserving the spare for this planned demand as they should do. Those measures could be KPIs to measure the maintenance organization performance. The MRO organization does not have the position to impact them but should use them as valuable input for internal management:

- **Average client response time per maintenance work order priority**
- **Reservation rate for planned demand**

To measure internal MRO performance and whether best practices are used, we propose the two following internal KPIs:

- **Bypassing rate for planned demand of expensive slow movers**
- **Forecast errors for fast/slow movers.**

Parts return forecasting

The Terneuzen MRO organization is suffering from high return rate (about 33%) and late returns. This is a problem as returns creates extra handling work and impede inventory optimization. Getting rid of all returns would allow reducing by 50% over issuing and returning handling work.

Best practice: returns are tracked to reduce them
The performance regarding this best practice is currently low. Tracking which spares are returned often, which client is returning will allow engaging in actions to decrease this return flow. To track the returns, information should be extracted from the MRO system. Feedback reporting can be created for each MRO business warehouse client to make them aware of the return issue.

Best practice: a maximum return time is agreed with the client
There is currently no agreed return time between the MRO organization and the MRO client. A maximum return time will facilitate inventory replenishment as spares will not been replenished before the return time expires. On the long run, this return time might also force the client to better identify its MRO need which will lead to a lower return rate. Setting a maximum return time within Terneuzen is not yet possible as the client is not being delivered the spare when he will effectively use it. The maximum return time best practice is only possible once the client is reserving MRO with the correct need date. This maximum return time is more valuable for slow moving items.

We propose an indicator to judge how well the MRO client is taking care of return and MRO inventory. This indicator is not a KPI for the MRO organization but should be seen as valuable input information for the MRO return process:

- **Average levels and value of stocks kept by MRO clients**.

KPIs to judge the MRO organization regarding return management are the following:

- **Return rate**
- **Average return time**

Supply management

Within Terneuzen, MRO supply management is spread over the purchasing department for external supplier management and over the maintenance organization for external and internal repair shops management. We previously identified two best practices regarding supply management for external suppliers and repair shops types of supplies.

Best practice: external suppliers are managed

Management of external MRO suppliers is **good** within Terneuzen, but delivery lead times are not respected. Within Dow, the external suppliers delivering MRO items are managed by the purchasing organization and not by the MRO organization. For the stocked MRO items in Terneuzen, many different suppliers are providing spare parts. Work processes, tools are defined at the purchasing organization level to perform strategic sourcing and to evaluate supplier performance. Strategic sourcing allows better supply management: items are delivered by a limited number of suppliers. For MRO items, suppliers such as Van der Peijl or Brammer distributing companies allow strategic sourcing, reducing supplying effort with all original manufacturers. For external supply management, delivery lead time is a key information for MRO management to deliver the MRO clients at the right time or to replenish the MRO stocks as soon as possible. The delivery lead time is even more important than the unit price as late delivery might lead to breakdown and harm the business much more than a costly spare. The purchasing organization should take into account this MRO specificity for strategic sourcing, contract design and supply management. The respect of the delivery lead time should be high priority element for MRO suppliers. However, MRO suppliers are often delivering late and the supplier lead time used in the MRO management system does not reflect reality. Having unreliable supplier lead times (i.e. vendor delivery times) is a problem for the MRO organization when taking the decision to have the spare on stock or not. Unreliable lead time also harms the MRO order reservation process.

Best practice: internal and external repair shops are managed

We rate the internal and external repair shops management performance as **average**. The repair process is the following within Terneuzen i-park. When an equipment, such as a pump break downs in one plant, the equipment is repaired if the estimated cost to repair is less than half the price to buy a new pump to the external suppliers. This 50% threshold is the rule to determine whether to repair a spare or to buy a new one. This rule could be completed by a minimum value rule as it brings no value to repair a cheap and broken spare. The cost to inspect the spare, the cost to repair and logistics repair cost will always exceeds the value of cheap items. 500 Euros can be an appropriate cut off minimum value. The best option is to purchase new spares for cheap items.

Once the equipment has passed the repair test and will be repaired, two scenarios can occur. If similar equipment is available from MRO warehouse (e.g. pumps), the equipment is issued from stock and is directly bring to the plant for replacement. The broken equipment will be repaired with low priority urgency as the plant is not waiting for the equipment anymore. Once the equipment is repaired in internal or external repair shops, the equipment goes back in MRO stock. Expected return time to stock is not well monitored. Tracking return time to stock is however important to avoid unneeded

stock replenishment. For example, when revision report is agreed upon with an external repair shop, emphasis is on price on scope of work, timing does not receive the attention it should.
Second scenario for the broken equipment is when no similar equipment is available from MRO stock. Then, a repair order is placed with (high) priority level (driving the latest starting date) and need date set by the plant gatekeeper and the repaired equipment goes back to the plant. Only this second scenario is depicted in Figure 2. This second scenario does not involve the equipment stock. For the two scenarios, the equipment can either been repaired in an internal repair shop if resources are available or to an external repair shop. When repair in house, the time to repair varies with repair technicians and spares availability. For in house repair, needed spares are issued from MRO warehouse. The 4 in house repair shops currently represent the biggest client for the MRO organization. For internal repairs, spares are issued from stock without delay and bring to the repair client, even when the repair need date does not justify to do so. As the other MRO clients, the repair shop client (or workshop) is issuing right away from stock instead of reserving needed spares with the real spare need date.
To conclude, performance is poor regarding timing management of spares issues for the internal repair activities and for managing return time of spares or equipment being repaired in an external repair shop. When problem due to timing mismatch, no root cause analysis neither improvement actions are conducted to improve for next time.

To manage external supplier, internal and external repairs shops and track performance, we propose the following KPIs:

- **Delivery in full time (DIFO) rate** for strategic suppliers
- **Completeness delivering rate**
- **Average quantity per order line for replenishment orders for ABCs**
- **Emergency orders to external suppliers**
- **Emergency orders to external repair shop**
- **Number of external suppliers.**

Repair shop control

For description of repair shop control for Terneuzen activities we refer to the previous discussion in the best practice “internal and external repair shops are managed”.

Best practice: due date for each repair job are managed and communicated upon.
For both internal and external repair shops, timing and due date are not well managed. For discussion and discussion, we refer the previous section.

Inventory management

Before assessing the Dow Terneuzen MRO organization regarding MRO classification and replenishment policy, we first need to understand which kind of spare are kept on stock and need to be managed. There is no criticality assessment at the spare part level so the MRO organization is not able to focus and give high priority to critical items. Information is available on demand and on the item price. Appendix H provides information based on Terneuzen inventory information: fast movers are also cheap items, expensive items are also slow moving items, a few items are responsible for major part of inventory turnover.
Best practice: MROs are classified using multi-criteria ABC to identify homogeneous groups of parts
The current performance regarding this best practice is **poor**. The only adopted classification within Dow is a classification based on the item supplier price: if the supplier price of an item is exceeding

3.500 €, the item is classified as Inventory, otherwise it is classified as Expense. Once an item is repaired, it is always classified at Expense. This Inventory vs. Expense classification is used for accounting purposes and does not drive inventory management. A classification for inventory management purposes is needed. Our best practice proposes multi-criteria ABC classification for managing MROs. The ABC classification we propose is described in appendix G in which A items are critical spares, B are non critical, slow movers and high valued items, and C are non critical, high movers and low valued items. This ABC classification is similar to the one currently implemented within MSMS, the Dow MRO management system, except A and C types are exchanged. The current ABC classification within MSMS is neither update neither used in practice. To achieve the multi-criteria ABC classification best practice, we propose a process in three steps for Dow:

- Step 1: Identify A items i.e. critical
- Step 2: Among remaining items (i.e. non-critical ones), distinguish between B and C items
- Step 3: Keep your classification updated overtime to take into account client needs changes in MRO inventory management.

The three steps are described further in Appendix G. Figure 13 summarizes key results on ABC classification.

	A: critical	**B: non critical, low moving, high value**	**C: non critical, high moving, low value**
Proportion of codes	20%	40%	40%
Classification criteria	Cf steps 1	Cf steps 1+2	Cf steps 1+2
Targeted availability service level	+++ e.g. 99.5%	+ e.g. 90%	++ e.g. 95%
Control level	High	Medium	Low
Stocking strategy	Managed by Dow	Consignment?	VMI?
Inventory, replenishment strategy	Manually managed On site stock. Critical warehouse?	Automatic	Automatic
Cycle counting	High frequency	Medium frequency	Low frequency
QA/QC strategy	Strict	Flexible	None
Sharing in-between plants? With other companies?	Difficult to implement	Valuable	Non valuable

Figure 13 : ABC classification

Best practice: from the spare parts classification, adequate replenishment policy and replenishment policy parameters are selected.

In total, the Terneuzen MRO organization is managing about 47.000 unique codes that are stocked. Among those 47.000 codes, about 2.000 are on consignment. Dow is paying for those consignment inventories only when issuing from the stock. Having high consignment stocks is not as costly as other stocks to Dow. But setting adequate replenishment policy and replenishment parameters for the other 45.000 codes are key to optimize inventory management. We refer to appendix G and to Figure 9 for discussion on ways to set adequate replenishment policy and replenishment parameters for A, B and C item types. Within Dow Terneuzen, the 47.00 codes being stocked are managed through a (R,s,Q) replenishment policy. (R,s,Q) policy means periodic review with fixed re-order point and fixed order quantity. Other possible replenishment policies are reminded in Appendix E. Once a day, MSMS system selects items whose real stock is below re-order point s (referred as order point OP

within Dow) and recommends to buy the order quantity Q (referred as OQ within Dow). Order points and order quantities are set by the reliability engineers. Inventory coordinators might suggest changes to reliability engineers if they detect change in usage or if they face problems. In practice, order point and order quantity are not focus of reliability engineers that rely on existing parameters or set by there predecessors. This is no systematic review on order point and order quantity. Changes in parameters occur when problems occur and changes will tend to increase inventory. The need is vital to have a critical review and assessment on order points and order quantities to optimize stocks levels. Forecasting output, supplier lead time, issued quantities, client response time is needed information to set right order points and order quantities. Analytics tools such as the one from Oniqua (cf. Appendix B) might help Dow in this task. Other similar tools are available on the market such as the one from Accenture: Accenture Parts Optimization.
Once new optimal order points and order quantities are computed and compared with current parameters, two scenarios can occur for a given spare. If the spare has been under stocked in the past, you must make a purchase order to raise your stock until the new computed stock level. If the spare has been over stocked in the past, you must get rid of excessive slow moving inventories, i.e. some B items: to either through investment recovery actions for expensive items, either by throwing away cheap items. For fast moving excessive inventories, i.e. some C items it is still wise to keep inventories as the excessive inventory will rapidly decrease and reach the desired optimal level.

We propose the following KPIs to measure inventory management performance:

- **Percentage of MRO codes having warehouse information**
- **Inventory levels for ABCs**
- **Inventory value for ABCs**
- **Replacement Asset Based (RAB)**
- **Turnover for ABCs over a period of time**
- **Volume and value of issues from the warehouse for ABCs**
- **Availability of stocks**
- **Stock accuracy for ABCs**
- **Obsolescence rate over a period of time**
- **Investment recovery**

Spare parts order handling

Spare parts order handling consists of accepting, adjusting or rejecting a released order for a spare parts; releasing the spare parts and handling return orders. Within Dow Terneuzen, Ceva logistics is handling the logistics transport for the issuing and return processes.

Best practice: the MRO organization manages in and out inventory movements with a closed warehouse

The Dow Terneuzen MRO organization is **well** performing regarding this best practice as MRO inventories are managed in a closed warehouse. A closely managed warehouse allows to control in (i.e. return and replenishment) and out (i.e. issues from clients) inventory turns as all inventory movements should be justified. A closely managed warehouse also helps to control access to guaranty respect of work process and registration of inventory movements in the system. A MRO warehouse cannot be managed like a shop.

Best practice: the MRO organization checks spare parts orders on order lead time and quantities

The Dow Terneuzen MRO organization is **low** performing regarding this best practice. When a spare part issue order is placed to the MRO organization, there is not check on lead time neither on ordered

quantity. As there is no agreed response time, the MRO clients are directly issuing spare rather than placing a reservation with the real need date. All spares not urgently needed should be reserved rather than issued. In practice, the reservation process is the exception, less than 5% of total issues have been reserved whereas 20 to 30% of total maintenance work orders are urgent work orders. The MRO client is, in most cases, issuing before he will effectively use the spare. This leads to outstanding MRO stocks at the client site. Those uncontrolled stocked at the client location affects the MRO return process. The MRO organization does not know when unused spares will be returned by the client and what might be returned. High return rate (about 33% within Terneuzen) and non agreed return time affects badly MRO inventory management and optimization.

Deployment

Deployment concerns the process of replenishing spare parts inventories using different parameters than those advised by the inventories policies. Replenishments can come from the repair process or from procurement orders. Every time an automatic replenishment recommendation made by the MSMS MRO management system based on the given order point and quantity is not accepted or changed, a feedback loop is needed to improve the order point and order quantity replenishment parameters or work process.

Our **third research question** was "Are there appropriate KPIs to assess the MRO internal performance?" **To answer this third research question we proposed and argued on internal KPIs that allows assessing internal performance for the different MRO processes identified in Driessen et al. (2010) decision framework.** We did not set target level for the KPI we proposed because no target is available from the literature neither comparison from others industrial practices. Setting cut-off target value is a not a straightforward as target performance level depends of the environment characteristics and client's needs. However target level will be very useful for contract management in case of outsourcing. When no target levels are set, we recommend to strive for a consistent annual bottom line improvement, measured in % of improvements.

Chapter 3 was the Measure and Analyze steps in our 6 sigma methodology. We have assessed the Dow Terneuzen MRO strategy and internal performance. The Dow Terneuzen MRO organization is not yet business oriented as no SLA and external KPIs are agreed with the clients, they miss visibility on the MRO TCO and the recharge model does not appear sustainable. Regarding internal performance and alignment with best practices, the assessment of Dow Terneuzen MRO performance is mixed: some best practices are respected such as the use of a closed warehouse for example but some best practices are not yet implemented. Chapter 3 had answered second and third sub research questions: "When does outsourcing support the MRO strategy?" and "Are there appropriate KPIs to assess the MRO internal performance?". Chapter 4 will propose gap closure actions and ways to move the Dow Terneuzen MRO organization to a business strategy and best in class performance, to achieve long term sustainability.

4. Improvement of MRO management in Dow Terneuzen

In chapter 2, the sustainable MRO management has been defined by defining and characterising the business oriented MRO organization and best in class management with best practices. In chapter 3, the MRO management in Dow Terneuzen has been assessed: MRO management is far from a business oriented strategy and some practices are not aligned with best practices.

In this chapter, we propose recommendations to close the gap between current practices and the ideal sustainable MRO organization by moving Dow Terneuzen MRO management in a business perspective and to best in class. This chapter constitutes the improve steps of the 6 sigma methodology. Having a sustainable MRO management requires to be both business oriented and being best in class, section 4.1 proposes ways to bring Dow Terneuzen in a business perspective and 4.2 proposes gap closure actions to be best in class.

Before formulating and defending the recommendations, I want to highlight that a lot of good practices are already adopted within Dow and Terneuzen. The list of formulated recommendations might appear long, but this is due to the broad investigation we conducted to cover all MRO related processes. Some recommendations are more difficult to implement than others. The benefits of all recommendations are not comparable, some are more valuable than others, and they do not impact the same processes. Some recommendations will be valuable or feasible when pre-recommendations are firstly acted upon. Driessen et al. (2011) conceptual framework with relationships in between MRO processes, reminded in Figure 6, can help to prioritize recommendations and under relationships in between them. Figure 14 and Figure 15 summarize the formulated recommendations, the domino relationship in-between them and their potential impact and benefit. At the very end of this section, we will highlight a few recommendations that we consider as first priority for Dow Terneuzen to consider. The formulated recommendations are not to blame any role within Dow. They should be considered as an opportunity to improve by sitting together, understanding the problem lying behind and what the recommendation can bring, and discussing the recommendations' feasibility and implementation.

4.1. Moving Dow Terneuzen MRO management to a business orientation

MRO **business awareness** is identified as the key improvement driver to have a business oriented MRO management. MRO management is a complex, specific and critical business and as such, MRO management should receive the attention it deserves from high level management. Business awareness is an external driver as MRO business awareness goes beyond MRO management boundaries to other management functions, across maintenance and purchasing. While setting MRO strategy, there is a real need to understand why and how a balance must be found between inventory cost and risk for managing MROs. This balance is reminded in Figure 4. This figure clearly and easily shows why finding the right level of MRO stock results from a balance between inventory cost (that increases what stock levels increase) and unavailability cost (that increases when stock levels decrease). So, for some spares, it might be optimal to accept little and non costly shutdown rather than stocking expensive spares. A model might help to find the appropriate balance. The model must be elaborated enough to fit with Dow Terneuzen industry-park environment i.e. diversity in stockout and inventory cost. Stockout cost measures the shutdown/breakdown cost due to spare unavailability. This useful information is however difficult to estimate. To balance risk and inventory cost, reliability engineers should balance their two goals which are high Asses Mechanical Reliability AMR and low % MRO/RAB. However, in practice, reliability engineers, tend to focus on high AMR goal, leading to excessive MRO stocks and non optimal solution while summing over inventory and unavailability costs. We believe Dow Terneuzen is carrying excessive MRO stocks because they have left MRO

inventory decisions' responsibility to reliability engineers that are driven by shutdown fear and prefer to overstock, whatever it costs. This balance between unavailability cost and inventory cost illustrates why MRO need to receive attention it deserves from high level management. Many MRO issues need high level management support to be changed and improved such as obsolescence, return, reservation, or supply management. Improvements in those areas are not possible without high level management involvement. Group team with participants which does not belong to the current MRO organization might help to discuss MRO issues and find solutions. MRO items purpose is to support the maintenance activities in getting the needed spares to avoid costly equipment shutdown but MRO should not be a 'window for throwing money out', driven by shutdown fear and emotions. Great savings are possible within MRO area. To achieve them, efforts are needed, as well as support from high level management. Potential money savings in MRO management is important.

To move the Dow Terneuzen MRO management to a business strategy, we formulate several recommendations. Figure 14 shows the different recommendation to be business oriented and potential impact and benefit.

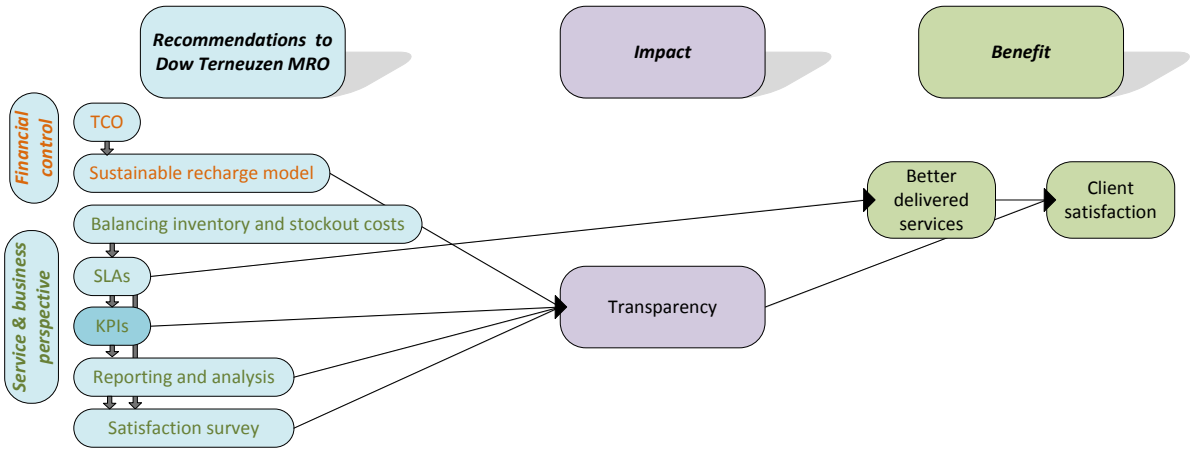

Figure 14 : Recommendations to Dow Terneuzen MRO to have a business strategy

We group the recommendations into two main improvement areas:

- **Financial control**
  - ***TCO***

    With business strategy, the MRO organization aims at minimizing the cost. Then we recommend to the MRO organization to know the total cost of ownership TCO for the MRO activities. Today, the costs associated with the MRO activities are related with inventory management operational cost. In reality, the costs associated with the MRO activities are much broader: logistics cost, spare price, supply management, catalogue management etc. The TCO integrates all cost associated with an activity. The MRO TCO components are described in Figure 10. This notion helps to have visibility on all occurred cost to control them in order to minimize them, while satisfying the client needs. The TCO should serve as the basis cost to redesign the recharge model for Dow clients and the pricing mechanism for non-Dow clients. The TCO can also be valuable for the Dow SEC (sustainable economic cost) calculation model. In short, I believe that the TCO concept is a key concept for the Dow MRO organization that wants to have a business strategy and aims at long term sustainability in the competitive Terneuzen industry-park and maintenance value park environment. The MRO manager should be responsible for the financial aspects of the MRO

business and should strive for low TCO. Risk of not knowing and controlling MRO TCO is not sustainable recharge model or pricing mechanism or wrong management decisisons.

- ***Sustainable recharge model***

  Once the MRO TCO and SEC are known, next step is to relocate those costs to the different clients. The recharge model for Dow clients and the pricing mechanism for the non-Dow clients should be aligned with the service level agreements. A good recharge model represents the MRO workload and encourages the clients to behave according to best practices. Today, the Dow MRO organization is recharging its costs through an issuing ticket price, estimated for Dow clients and fixed for Styron clients. This recharge model is simple and non ambiguous but does not represent the MRO workload and does not incite the client to make use of the reservation process or to return unused spares to stock.

➢ **Service & business perspective**

- ***Balancing inventory & stockout cost***

  Before setting service level agreements with the client, the MRO organization and the clients should find a balance between inventory and stockout cost. This balance is represented in Figure 4. The agreement should allow optimizing the total cost over the inventory and the stockout cost. The spare part function is to support asset mechanical reliability but should not be stocked if its long term inventory cost goes over the long term downtime cost. Today, the Terneuzen site might carry excessive stocks as the inventory decision levels are the reliability engineers' responsibility. The reliability engineers tend to keep stock to prevent from any risk. It is difficult not to let the inventory management being driven by shutdown fear but after a certain inventory level and cost, it is time to question whether it is the long term optimal solution. In section 3.1.2, we have discussed MRO TCO components and highlighted the lack of visibility on TCO. The shutdown of Terneuzen most critical plant is evaluated around 1 million €/day whereas the MRO stock is valued at 55 million €. This balance recommendation is highly dependent on the business awareness improvement driver discussed at the beginning of this section.

- ***SLAs***

  The MRO organization and its clients should agree on the service level to be delivered thanks to a SLA. The SLA should set availability, response time, and service quality and cost agreements. SLAs are discussed further in section 3.1.1.

- ***KPIs***

  Both internal and external KPIs are useful and serve their own purposes. External KPIs measure the MRO performance from the client perspective. External KPIs are useful for designing SLAs. Internal KPIs measure the MRO internal performance. Section 3.1.1 proposes external KPIs for the availability, response time, quality and cost performances. In section 3.2, I proposed several internal KPIs to assess internal performance of all MRO related processes.

- ***Reporting & analysis***

  To track its performance, the MRO organization should report and analyse its external and internal KPIs. External KPIs management supports client management. Internal KPIs management supports efficient use of internal resources and processes to ultimately improve service or lower cost.

- ***Satisfaction survey***

  Some satisfaction survey lead by the MRO organization should be conducted to the different MRO clients. Knowledge of the client satisfaction levels and expectations helps to have an aligned MRO organization that meets client needs. The strength, weakness, opportunity and treat SWOT analysis can be used for the satisfaction survey. SLAs should be input information for the satisfaction survey.

I also formulate one further recommendation that might be considered in a second phase to be business oriented. The previous recommendations can be considered right away after the end of this project. The coming recommendation are not to be considered before the first recommendations are successfully implemented.

- **Outsourcing?**

  I do not recommend to Dow Terneuzen to completely outsource inventory management but I believe that the MRO organisation should be broader. Today the Dow Terneuzen MRO organization responsibility is rather limited because inventory level decisions are taken by the clients who are the owner of the stocked items, supply management is done by purchasing department, coding is done at the global level. Currently the Dow MRO organization coordinates the MRO inventory and logistics activities. Without broader scope and responsibilities, the MRO organization cannot implement long term and deep changes. I do not recommend full outsourcing inventory management. Consignment or vendor managed inventory can be valuable for certain types of parts, but full inventory outsourcing is not possible in a short term basis. First of all, full MRO inventory outsourcing requires market knowledge to know whether a third party company is able to deliver the desired service at a lower cost (as explained in Figure 11 in the business strategy path). But most importantly, the current Terneuzen MRO organization misses visibility on its TCO and on its delivered service (availability of spares, response time, and quality) because there are not SLA or KPIs. Deep assessment is needed because examining seriously the inventory outsourcing decisions. Last problem in completely outsourcing inventory management is that the inventory ownership is in the MRO client scope instead of being the MRO organisation scope. A full MRO inventory management outsourcing would require to move this ownership from the plant to a third party company. The current Dow Terneuzen MRO value is about 55 million €. This transfer of ownership from the plant to a third party company is too high to be overcome in a short time basis. A first step can be to move the inventory responsibility and ownership to the in-house Dow MRO organization. This transfer of ownership requires pre-work: knowledge on the spare part criticality level, knowledge on the consumption and client response time, and all elements that should be agreed upon between the MRO organization and its clients in a SLA. In this perspective, the MRO organization would be critical business, delivering crucial services and value to its clients to support its maintenance activities. With SLA and inventory ownership within the MRO organization scope, the client might not see any more what is on stock.

  The Dow Terneuzen repair shops (i.e. workshop) are going to be outsourced in the near future: the designed outsourcing contract should integrate SLAs that specify the relationship between the repair shops and the MRO inventory management to answer the two following questions: will the future repair third party company make use of MRO stocked items (because the repair shops currently represent one third of issues from MRO stock)? How the repaired spares that come back to stock will be managed (time agreement)?

4.2. Moving Dow Terneuzen MRO to a best in class organization

MRO **knowledge** is identified as the key improvement driver to be a best in class MRO organization. As MRO management is a complex and specific business, MRO management required appropriate knowledge. Adequate knowledge means adequate people, tools and processes. This knowledge driver is an internal driver as the right knowledge should be in place within MRO to achieve high performing MRO management. We place this knowledge driver as less important than the business awareness driver as first priority is that high level management understands how important, complex and specific the MRO business is. Once MRO management has the attention it deserves, the right changes can be conducted with the appropriate knowledge level.

Regarding MRO **tool**, MSMS (the current MRO management system within Dow Terneuzen) appears to be an unfriendly environment. For example, taking a simple decision requires to navigate and extract relevant information through several screens which requires a lot of effort and is time consuming. Some default value are non sense such as 0 as the vendor delivery time or today's date as the need date when a spare part request is done. Moreover, information provided by the system is not visible as no curve or chart or any visual information tracking changes over time is depicted. The MSMS system will be changed for SAP in coming years, the change has already started in other Dow sites. Complementary tools can come to strengthen SAP or other ERP system for MRO inventory management, such as Oniqua Analytics Solutions or Accenture Parts Optimization. Those analytics tools can work where other tools (Titan, Spar) failed as they required filling too much input information. The power of mathematics (forecasting) and automatic should not be neglected in MRO tools.

Regarding MRO **processes**, we see possible improvements regarding the return process (by setting a maximum agreed return time for slow movers), the reservation process, and by having a fast moving program in place. Those improvements will be described in more details in coming section.

Regarding knowledge of MRO **people**, I have seen a lot of good and meaningful ideas or tools but that partially failed to be implemented or executed. Inventory coordinators might not behave as inventory specialists. Training could also be in place regarding MRO inventory management when new people fill the inventory coordinator role.

We find support for our improvement from Vos et al. (Managing MRO-Growing towards sucessful performance based logisitcs logisitics contracting: a supplier's handbook to mature into performance based logisitcs contracts for maintaining military assets, 2011): "It is of the upmost importance that engineers and technicians are knowledgeable on technology, planners in planning, and forecasters in forecasting. (…) On top of a skilled workforce, all employees must have full understanding of their impact, as part of a supply chain, on the outcome and profitability. (…) Providing performance based logistics training to all maintainers, maintenance managers and engineers involved in the MRO processes, is therefore essential. It ensures that everyone speaks the same language, aims at the same goals and shares the same starting points. All people have to be performance based logistics minded, which typically not only requires a certain level of knowledge, but also a cultural change within the organisation" (p. 96)

To move the Dow Terneuzen MRO organization to a best in class performing organization, we formulate several recommendations. Figure 15 shows the different recommendation to be best in class and potential impact and benefit.

We group the recommendations into two main improvement areas:

- **Stocking strategy & inventory optimization**
  - ***Criticality analysis & ranking at spare parts level***

    As all MRO items do not have the same downtime consequence (stockout cost if the spare is unavailable) and probability to fail, it is valuable to identify which are the most critical spares from the ones that are less critical. Once the critical MROs are identified, the MRO organization can focus its effort and analysis one those critical items to ensure high service and availability to the user. In appendix G we propose our own way to determine critical spares based on equipment criticality ranking, user and supplier lead time. Further criticality considerations are presented in Appendix D.

- ***Multi-criteria ABC classification***

  As the considered MRO are very diverse (criticality, price, demand rate, user and supplier lead time, shape, weight, etc) a multi criteria ABC classification helps to identify homogeneous groups of part. ABC classification facilitates inventory and supply management where each ABC group is managed why its own strategy according to its characteristics. In appendix G we argue for a ABC classification based on criticality and demand rate (or price). Criticality assessment at the spare part level is then needed for the ABC classification we propose. Results and ABC strategy are summarized in Figure 13. A MRO spare is characterized by the group it belongs to. Updates in group over time should be controlled and justified, as we proposed. The current C group within MSMS (the Dow Terneuzen MRO management system) does not contain critical items but low and not moving items.

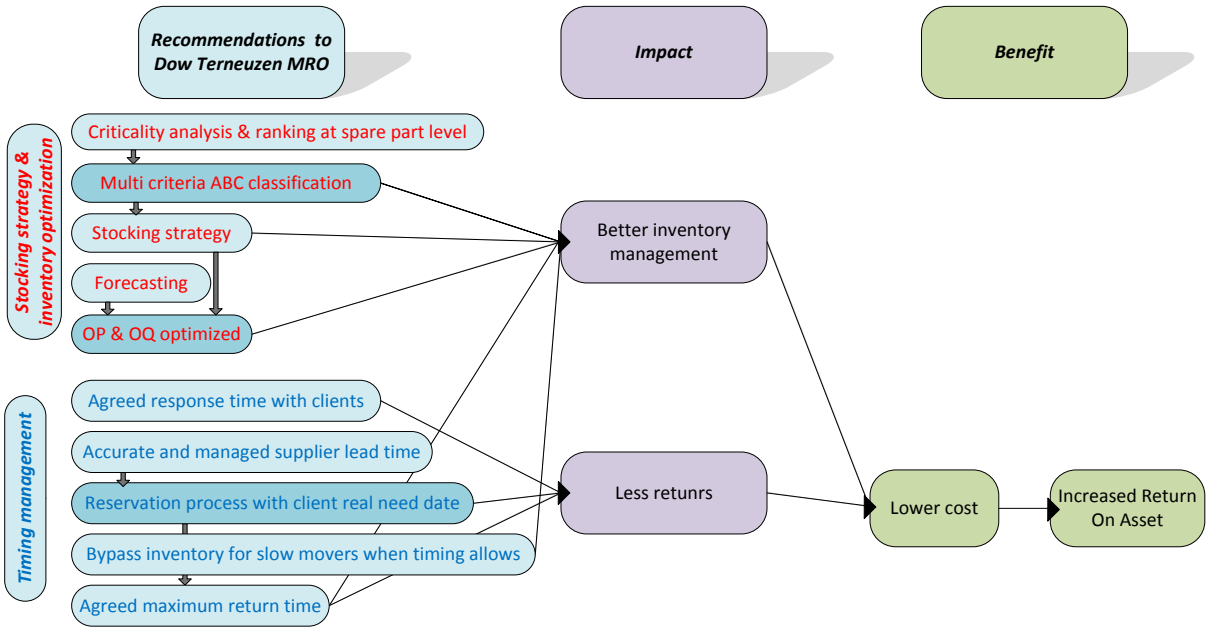

Figure 15 : Recommendations to Dow Terneuzen MRO to be best in class

- ***Stocking strategy***

  The MRO organization should have visibility and control of both stocked and non-stocked MROs to optimize the full MRO process. It should be the MRO responsibility to decide whether to keep a spare on stock in its own warehouse or to keep it at the supplier site, based on the supplier lead time, user lead time and service availability target. The current Terneuzen MRO organization is only concerned by the stocked items. For the MRO item that is kept on stock in the MRO warehouse, the MRO organization also needs to determine whether the stocked items should be managed by Dow or a third party with consignment or vendor managed inventory stocks. The ABC classification is useful input information to take this decision. In short, the stocking strategy concerns two decisions: what to keep on stock close to the client and how to keep it on stock (Dow-managed, consignment, VMI).

- ***Forecast***

  Demand for stocked and non-stocked items, for both planned and unplanned demand should be forecasted. For fast moving items, traditional forecasting techniques are appropriate but specific methods should be used for slow moving items as demand is characterized by many 0 values. Review on historical consumption and characterisation of the demand process with average and deviation will help management proactiveness. Forecasting benefit is discussed in sections 0 and 0.

For example, obsolete or potential obsolete can be found among non moving items. The few top moving items can be managed accordingly: replenishment by batches, specific supply management, stock close to the final user etc. As show in Figure 27, a few items are responsible for large proportion of warehouse turnover. As explained, this is current no forecasting within Dow Terneuzen for the issuing and return processes. For the issuing process; demand forecast for stocked items and unplanned demand is based on historical consumption and allows optimizing stock levels (OP and OQ).

- ***OP & OQ optimized***

  The stock replenishment parameters, order point OP and order quantity OQ within Dow, should be optimized: neither too low to deliver the right service and ensuring spare availability, neither too high to control stock and cost levels. Replenishment could be automatic for some items with reliable replenishment parameters. Optimizing OP & OQ levels is a difficult task as many input information are needed: demand characterised by forecasting, client lead time, service level, criticality levels, number of users, inventory cost and constraint, vendor price, supplier delivery lead time, lot size etc. Setting optimal OP & OQ requires knowledge, specific models with expertise, and time to be done correctly. I believe that an inventory management optimization tool is adequate and will help in this task. Oniqua and Accenture companies propose such tools. Suggestion made by those tools can later be accepted, modified or refused by manual control. Manual optimization is effort and time consuming. Currently, reliability engineers are responsible for OP & OQ. But, in practice, they have little incentive to optimize OP & OQ as it should be. Their incentive is not to take risk and to carry excessive stocks to ensure asset mechanical reliability. In the ideal word, OP & OQ should be inventory management responsibility, i.e. within MRO, and not the plant responsibility. If so, the plant, i.e. the client, needs to provide information to the MRO organization on the spare criticality level and their response time. The need for service level agreement is stronger when OP & OQ responsibility are in the MRO organization scope.

➢ **Timing management**

- ***Agreed response time with clients***

  The MRO clients, i.e. the plants and the repair shops, should agree with MRO on their response time. The agreed response time reflects the spare criticality. The client might require a 30 min delivery time for high critical spare because when a spare or equipment fails the spare is urgently needed. For less critical spares, the client might manage one to a few days before having the spare delivered, because a replacement solution can be found for example. Non critical spares might have a response time from weeks to months. Today this is no agreed response time between the MRO organization and its client and the clients is issuing as soon as they identify a spare need even is the need is not urgent. With agreed response time with its clients, the MRO organization could better remove items from the inventory list, based on the supplier delivery lead time. For example all items which have an agreed response time of one day and can be delivered from external supplier within one day should be removed from MRO warehouse.

- ***Accurate and managed supplier lead time***

  The supplier lead time, referred as vendor delivery time within Dow, should be managed and accurate. The information within the inventory management system should be reliable and reflect reality. For parts under contract management, the agreed response time should be tracked. If the supplier is not respecting the agreed response time, the information within the system should reveal real lead time from historical transaction rather than the contracted lead time. For parts which are not under contract management, an estimation from the supplier or historical delivery lead time should be used to fill in the information management system. Timing management is a key element for MRO management, and even more important for critical items. Today, the system

vendor delivery time is not reliable and does not reflect effective delivery time within Dow Terneuzen. Non accurate supplier lead time is part of a broader data quality management problem.

- ***Reservation process with client real need date***

  The reservation process should be the most often used solution rather than the exception. Within Dow, 70 to 80% are low priority maintenance work orders and less than 5% of spares are concerned by the reservation process. 95% of spares are being issuing from stocked with today's date as the need date. The reservation process should be the preferred solution for different reasons. The client should enter an appropriate need date that reflects its need based on the maintenance work order priority and scheduling. First of all the reservation process improves the MRO service: when the spare in on stock, the service remains the same and the spare is delivered just in time, according to the real client need date; and when the spare is not on stock it let time to get the needed spare delivered from the supplier or to find an alternative solution. Alternative solution for critical spare can be emergency delivering from another Dow site for example. When using the reservation process, the supplier lead time should be reliable enough for unstocked items to be delivered just in time; and for stock items to allow replenishing the stock on time when the virtual stock goes below the order point. The virtual stock is the difference between the real stock and the quantity that has been reserved. Second reason for making use of the reservation process is that it drastically reduces the MRO stock at the client location. Lastly, the reservation process will have positive impact on the return rate as the client better identify its real need and reserve accordingly. Requiring making use of the reservation process is a constraint for the client but the client must think about benefit on long term basis. To initiate this best practice, financial incentive can be considered. For Dow Terneuzen this would mean different ticket prices when reserving or not. What MRO can also propose to its client that compensates the reservation process is to create a fast delivering process (30 min for instance) for urgent matters.

- ***Bypass inventory for slow movers when timing allows***

  When the client needs a slow moving spare that is available from stock, the spare should be directly delivered from the supplier to the client - if client and supplier lead time allow doing so - instead of being issued from stock for then being replenished. This recommendations concerns slow moving spare which are one-to-one replenished. This by passing recommendation is not valid any more for fast movers that are replenished in batches. The benefit of this recommendation is that it reduces handling work, saving on logistics cost and it saves the stocked inventory if an unplanned urgent demand occur from another client, increasing delivered service. Bypassing inventory is possible if the client is making use of the reservation[3] process.

- ***Agreed maximum return time***

  There should be an agreed maximum return time between the MRO organization and the MRO user for at least two reasons. First reason is to avoid unnecessary inventory replenishment. Second reason is that it might have positive impact on the return rate by forcing the user to better indentify its needs. This agreed return time is computed from the delivering date. Before implementing the return time, the reservation process should be in place so that the spare is delivered when the client really needs it. Without the reservation process, the spare is often delivered far before the real need date and the return time has no chance to be respected. A return time from a few days to one week seems appropriate. This return time recommendations does not create extra handling: when bringing new spares to the user, the truck can bring back unused spares to MRO stock, once a day for example. The agreed maximum return lead time best practice is provided in section 2.2.

[3] Within Dow, a reservation will be satisfied by issuing the needed spare from stock. We use reservation in a broader sense: a reservation can be satisfied by either MRO stock or by a direct purchase order to a supplier.

I also formulate further recommendations that might be considered in a second phase. The previous recommendations can be considered right away after the end of this project. The coming recommendations are not to be considered before the first recommendations are successfully implemented.

- **Inventory management system?**
  The currently used MRO inventory management system MSMS is unfriendly. There is no visual information i.e. no graphs tracking performance (e.g. stock levels, costs charged to clients) over time. Taking a replenishment decision requires navigating over screens to know the relevant information. The MSMS user might need extra work, macro and excel spreadsheet to efficiently collect the needed information. Some values per default are not relevant: for example the value per default for the issuing date is today's date whereas most of MRO demands are not urgent; the default vendor delivery time is 0 which does not represent reality. The MSMS unfriendly system will be changed for SAP in coming years.
- **Centralised control?**
  For most expensive and slow moving items, it can be valuable to manage them centrally, at the world or continent level. Dow Chemical is a worldwide organization, stocking MRO items at each local manufacturing site. Centralized inventory management instead of decentralized management will help to lower total inventories for the expensive and slow moving items that are common to several sites. Centralized inventory management can be achieved by a virtual inventory, i.e. all sites can see the other sites stock levels, or by global and local warehouses. Global and local warehouses require emergency shipment procedure from a global to local warehouses and lateral transhipments between geographical close from each other local warehouses. The report by Accenture (Survival of the fittest: adaptable supply chains for assest-intensive commodity producers, 2011) gives insights on centralized control.
- **Inventory pooling?**
  Inventory pooling can be considered for slow moving parts that are common and equally critical for several clients. Inventory pooling issues are discussed in section 2.2. Karsten et al.(2012) show how spare part pooling between two players having the same stockout cost is beneficial on the long term. According to Karsten et al. (2012), savings are valuable for expensive and slow moving items. Inventory pooling is not an urgent recommendation as it appears that MRO items in the chemical industry are rather client specific. Priority for the MRO organisation is on inventory optimization.

In chapter 4, we formulated many recommendations for improving the Dow Terneuzen MRO activities to business oriented an best in class. We made the distinction between the recommendations that can be considered and implemented right after the end of this master thesis project from the ones that should be considered later. Among the recommendations to be considered at first, the most important, feasible and valuable ones are:

- Multi criteria ABC classification
- OP & OQ reviewed and optimized
- Reservation process
- KPIs, external and internal

I highlight that all the recommendations are not in the current Dow Terneuzen MRO organisation scope as its scope and responsibility does not goes over all MRO processes. To implement the formulated recommendations, a project team should be created with the concerned and knowledgeable people (from maintenance, MRO, purchasing, information management, coding etc) that can conduct the change. Together, they should build up an implementation plan that contains the project planning, resources, risk analysis, work performance analysis and management of change.

5. Follow up for Dow Terneuzen

The implementation phase is left to Dow after the end of this master thesis project. Hence, the improve, control and leverage steps of the 6 sigma methodology are full Dow managers responsibility.

To strengthen the recommendations, a data analysis should be conducted. A data analysis with measurable figures and quantified benefits would provide more information on the effort, risk and benefit associated with the formulated recommendations. This report proposes directions for improvement and argues for it. A deeper investigation will help high level management to support MRO improvements. For example, deeper investigation is needed to optimize OP and OQ with help of forecasting techniques.

Change management is key in this implementation phase. Change can concern people, process or tools. To successfully manage a change, the strategy should be aimed at making people understand the need for a change, making them feel they are part of it, and aligning their behaviour with the goal. Resistance for change will then be overcome. To stimulate the need for the change, risk and data analysis should be conducted upfront. An implementation plan proposition with decomposed steps, timeframe and deadlines allows projecting itself for the change. People need to know why it is needed to change, how the change will be conducted, the required effort, and what it will ultimately bring them and their organization.

5.1. Controlling the solution effectiveness

We propose criteria to measure the solution effectiveness. For every recommendation, a control plan should be build up with a process map to identify new processes, measurements, contingency plans to know what to do if things go wrong, and identified responsibilities. The modification and consequences of a recommendation need to be tracked. External and internal KPIs are the right measurement tool to track performance change in service levels. Service measures should be recorded before and after the modification and compared to the desired output or target level. The effect of a modification is specific to a recommendation depending on the process and services it impacts. Each recommendation effect can be controlled and tracked by a few and appropriate KPIs.

5.2. Leveraging the opportunity

On a long time horizon, the successfully implemented recommendations should be leveraged across Dow sites to share knowledge, saving and improvements. The processes are the same all over the Dow worldwide sites. Standardized and shared KPIs over sites helps to identify poor performing sites to help them to improve. Differences in measured service performance can be a starting discussion point for sharing solutions and ideas over sites.

On a short time horizon, other Dow sites can benefit from the work done in this master thesis project conducted for Terneuzen: best practices, KPIs, analysis are valid for all MRO organizations that have the considered characteristics i.e. multi-product with high diversity, multi-indenture structure, single stocking location, several customer companies, high risk environment. Minor changes might be needed if all assumptions are not valid. Recommendations are valid for organizations having the same performance than Terneuzen and facing the same management problems. The master thesis work is shared and presented to other Dow sites through the Dow global MRO network.

On a short time horizon, my work can also benefit other companies managing MRO. My public report is shared with main MRO leaders we interviewed in Terneuzen surroundings to define the best in class MRO organization and best practices. Many companies face the same problems regarding MRO management.

6. Conclusion

This chapter concludes and highlights key findings of this master thesis work. Section 6.1 provides the answer to our main research questions. Section 6.1 highlights the contribution of our work for the MRO management literature. Section 6.3 identifies some work limitations. Section 6.4 proposes further scientific research area for MRO management. Last, section 6.5 is an overall conclusion with main results.

6.1. Answer to main research question

Our main research question was "*How to get a sustainable maintenance spare parts management?".* To answer it, we have designed and assessment process to improve a MRO management sustainability. To get a sustainable MRO management, both business strategy and best in class performance are needed. MRO management is business oriented when the goal is to delivered the client needed service at the lower cost: service level are agreed in a SLA thanks to external KPIs, the MRO organization aims at lowering its TCO, the recharge model is sustainable and pricing mechanism for non Dow clients is adequate. MRO management is best in class when best practices are adopted. Internal KPIs assess the internal performance further. Results and analysis are valid in environments having the following characteristics: multi-product with high diversity, Multi-indenture structure, single stocking location, several customer companies and high risk environment leading to excessive downtime cost if the maintenance is not quickly and successfully conducted because of spare part unavailability.

6.2. Contribution of our study

Our work, by answering main and sub research questions, contributes to the literature related with MRO management. Our contributions to the literature are the following:

- I defined **function and business MRO strategies** and characterised those strategies by showing the consequences on the service and cost levels.
- I designed a global **outsourcing process** for the MRO activities that takes into account the chosen strategy, service and cost performance and management desires. Advantages, disadvantages, drivers and consequences of the outsourcing decisions are discussed. I also analyzed which MRO processes can be outsourced and what are the elements that should be contracted with the third party company, according to the depth dimension of the outsourcing strategy.
- I completed Driessen et al. (2010) decision framework by introducing new issues that must be handled when the MRO organization is delivering its services to distinct clients. The service and inventory pooling issues are discussed in this **multi-client perspective**.
- I complete Driessen et al. (2010) decision framework by defining **best in class MRO** organization with associated **best practices.**
- I illustrated Driessen et al. (2010) decision framework with an **industry case** which is Dow Chemical at Terneuzen site.
- To assess a MRO organization and measure its performance level, I proposed concrete **KPIs**: **external** ones to measure the performance from the client perspective, **internal** ones to measure the use of resources for all MRO related processes. External KPIs track availability, response time, quality and cost performance. They should be agreed upon between the MRO organization and its client in a **SLA**.
- I achieved the project main objective by answering the main research question: I proposed **a process to assess a MRO organization to improve its sustainability by being best in class and business oriented.**

6.3. Limitations

Our work has several limitations.

First limitation is due to our assumptions. The analyzed Dow Terneuzen MRO organization is characterized by the environment characteristics that are multi-product with high diversity, multi-indenture structure, single stocking location, several customer companies, and high risk environment. Definition of function and business MRO strategies, design of a MRO outsourcing process and definition of a best in class MRO organization with best practices are valid in all environments that meet our assumptions. The assessment and measurement done in chapter 3 and improvement guidelines provided in chapter 4 are specific to Dow Terneuzen.

Second limitation of our work is that our definition of best in class MRO organization and associated best practices is based on interviews conducted within Dow Terneuzen and in Terneuzen surrounding companies (Sabic, Yara, Cargill, Sitech etc). This analysis can be strengthened by a benchmarking study conducted in worldwide chemical and non chemical companies. A benchmarking study will reveal which are the industry peculiarities specific to the chemical area. A global benchmarking would also allow comparing and rating Dow Chemical with the achieved performance in other companies. Some key measures such as replacement asset base RAB, turnover, stock levels, stockout rate, response time and other measures from KPIs allow this comparison and assessment.

Last limitation, and probably most important one for Dow, is that our project is conducted at a strategic level. The scope of our project is limited to high level issues. Moreover, the study has a broad scope as we considered all processes related with MRO management: catalogue management, supply management, inventory management, forecasting, return and repair management etc. I see room to improve the strategic analysis by an analysis conducted at an operational level. For example, inventory management could be assessed further by investigating the operating work process for logistics, information and financial flows. The recommendation to review and optimize the inventory stock and replenishment levels (order points and order quantities) will be better supported by a data analysis, including forecasting methods. As our project does not considered operational details, we miss visibility on the cost and long term benefit of the formulated recommendations.

6.4. Further research area

However, there is still room for further scientific research work in MRO management area. Despite the large amount of literature available on spare parts management, some areas have not been studied - or at least not sufficiently. Directly related with our study, the identified further research areas are the following:

- MRO leaders need criteria to judge which spares are the candidates for **consignment and vendor managed inventory stocks.** As summarized in Figure 13 on ABC classification, my though on the ideal situation is to have non critical, expensive and slow moving items on consignment (because the user will pay only when using the spare and the spare will be available when needed) and to let non critical, cheap and high moving items being vendor managed inventory (because the inventory optimization, supply management and logistics workload is important for those parts). But this proposition might not be realistic, depending of the market position and profitability for the third party logistics.
- **MRO benchmarking study** in chemical and other manufacturing non chemical industries would help to compare industries and improve them in MRO management.
- To our knowledge, there is not study showing **differences and similarities between maintenance spare parts management and after sales part management**. Maintenance spare parts aims at supporting the maintenance activities and are bought at external suppliers whereas after market spares are in-house manufactured and sold to the clients. The purposes of maintenance and after market spares are completely different but are their management completely different? Both

demands are characterized by sporadic and difficult to forecast demand, and inventories need to be managed accordingly. Is a MRO organization characterized by a business strategy and competitive environment so far from the after sales spare part market?

Less directly related with our project, the open MRO research topics are the following:

- A topic that requires further research is the use of the **Internet communication**. Since many years, more and more business transactions are conducted over the Internet. The term E-business refers to those activities. The term E-maintenance – referring the E-business conducted in maintenance activities – has recently started to be used in the literature. E-maintenance need further research on how it can effectively supports day-to-day activities related with spare parts management. According to Kennedy et al. (2002), the internet has the potential to change the relationship between the maintenance logistic organizations and the spare parts suppliers by increasing communication. Increased communication means greater frequency of communication as well as faster communication. Campbell et al. (2006, p. 149) argue in the same direction on the potential benefits of Internet : "E-business allows the customer to identify, order, specify shipping, and pay for items online on the supplier's website. Efficient systems working in tandem with e-business substantially reduce the transaction costs associated with these purchases". Even if E-maintenance may seem challenging to set, savings and reward are very large – even more for worldwide global companies. The paper by Levrat et al.(2008) presents a framework for E-maintenance and can be considered as a starting point for further work.
- For other **technical** future research, we refer to the paper by Driessen et al. (2010) in which they identify some open research topics in each of the eight processes described through Appendix D.

6.5. Overall conclusion with main results

This report proposed a process to assess a MRO organization to improve its sustainability by being business oriented and best in class. This master thesis project was build up with and for MRO leaders from Dow Chemical in Terneuzen industrial site. MRO management is a multi-disciplinary activity that requires broad and specific knowledge in information management, supply management, planning, forecasting, inventory management, logistics, etc. Our results on MRO strategic issues are valid in all industrial context having the same characteristics than Terneuzen site and can be valuable for other MRO organization within Dow and outside Dow Chemical: the defined function and business MRO strategies, the proposed outsourcing process, the designed best in class MRO organization with industrial best practices, the issues raised when the MRO is delivering its service to several clients and the proposed external and internal KPIs.

Our project benefits both the industry and the research field. It first benefits Dow Chemical in Terneuzen as the MRO management has been assessed and concrete recommendations were formulated for Terneuzen site. Some analysis and recommendations can be leveraged to other Dow Chemical sites. Our work can also benefit to other companies. This public report is shared with MRO leaders we interviewed during the project. Our main contribution to the existing literature on MRO management is the process to assess a MRO organization to improve its sustainability by being business oriented and best in class. To reach this goal, we also contributed further to the research in the following topics: function and business MRO strategy, MRO outsourcing process, best practices, external and internal KPIs are major contributions.

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Appendix

A. Detailed project methodology

This appendix gives more information regarding the project methodology by explaining Van Strien regulative cycle and 6 sigma methodology. It comes to strengthen section 1.2.

Van Strien has settled a regulative cycle in order to handle problem solving projects. His regulative cycle starts with the organizational problem and involves 5 mains steps has shown in the picture below.

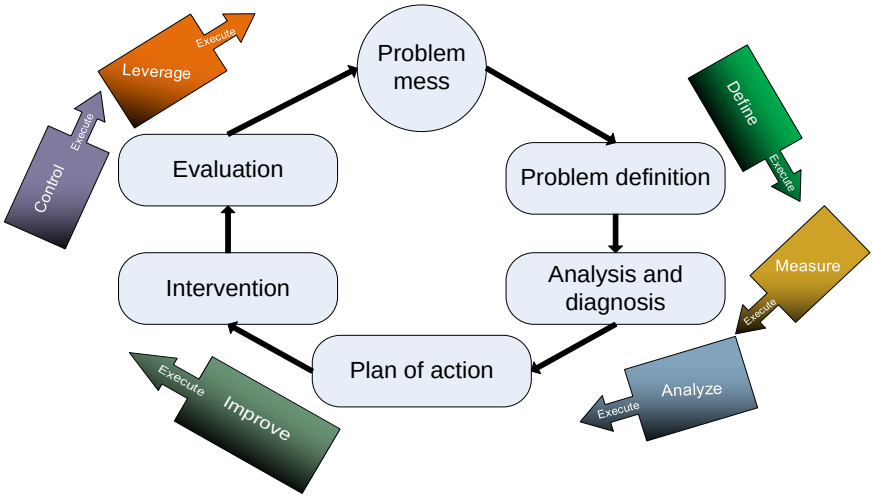

Figure 16 : Van Strien regulative cycle and 6 sigma methodology

In the problem definition step, the industrial problem and context is explained and a research plan is designed. The analysis and diagnosis step is the analytical part of the project in which the MRO organization will be assessed. During the plan of action step, the design of the solution is done. In this design phase we come up with gap closure suggestion to improve the performance. During the intervention step the designed solution is implemented. Once the changes are implemented, the process of learning occurs. In the last step of the regulative cycle, an evaluation expresses how the practices have integrated the changes and if the expected improvements have been achieved. After an appropriate time delay, when the achieved improvements are lower than the expected ones, the regulative cycle starts one more time. My work, due to time constraints, is limited from the problem definition to the plan of action i.e. design phase.

To some extent, van Strien regulative cycle and the 6 sigma (DMAICL: define, measure, analyze, improve, control and leverage) methodologies are similar. The 6 sigma methodology fits with our final improvement objective. The 6 sigma definitions of the DMAICL steps are the following:

- Define: to clearly understand the opportunity, define agreement on work to be done, and understand how the effort services the business objectives.
- Measure: to characterize and measure the current performance of the critical process.
- Analyze: to identify and validate the true Root Causes of the defects causing the current process performance.
- Improve: to develop and implement solutions for the validated Root Causes and demonstrate improved process performance.
- Control: to ensure that improved process performance is maintained over the long term, key learnings are documented and shared, and results are validated.
- Leverage: share and implement the results over sites.

B. A dynamic national and worldwide environment for MRO

Dynamic Dutch organizations

- **Dutch INstitute for Advanced LOGistics DINALOG**

Dinalog is a Dutch technological top institute that stimulates R&D for logistics and supply chain management by connecting industries and universities. Dinalog ambition is to increase the Dutch gross domestic product related with logistics activities and supply chain control from €3 billions in 2007 to over €10 billion in 2020. By 2020, the Netherlands wants to be a European market leader in controlling the flows of goods passing through one or more European countries. This flow might be MRO good flow.

- **Service Logistics Forum SLF**

The Service Logistics Forum is the place where responsible managers on Service Logistics area meet to developments in the field of service and parts to discuss with each other. In 1993, the Service Logistics Forum was founded by the logistics consultancy Districon as a network for developing and exchanging Service Logistics knowledge. Meanwhile the Service Logistics Forum has become the Service Logistics knowledge platform in Netherlands.

- **Innovation Center for Service Logistics ICSL**

Linked with Dinalog and Service Logistics Forum, ICSL (to be pronounced as 'I see Service Logistics') mission it to stimulate, initiate and implement service logistics innovations, to disseminate the related know-how and to boost the service logistics business development. The start of ICSL is planned in 2012.

- **Dutch Institute for World Class Maintenance DI-WCM**

The DI-WCM stimulates Dutch R&D in the maintenance field by creating academic and business cross industrial partnership. The institute aims to develop, parts and implementing advanced knowledge in the field of maintenance of goods and equipment which have a long life (10 years and more). They are working with Dow through the Maintenance Terneuzen Value Park project. We refer to Section 0.6 for further details on the Maintenance Value Park.

A dynamic worldwide market place

- **IHS Intermat solutions**

IHS is one of the leading global providers of critical technical information, decision-support tools and related services to customers in a number of industries Intermat is an IHS solution focused specifically on helping Global 2000 organizations optimize and manage their industrial MRO parts information. IHS Intermat cleanses, standardizes and enriches material descriptions using industry proven templates and tools to have complete, correct and consistent material description. IHS Intermat also provides software and services to optimize MRO inventory and supply chains.

- **xIO tool from xtivity developer**

xIO is a web based inventory optimization solution working in conjunction with any ERP or EAM software. Based upon client's business rules, xIO recalculates ordering values, increases material availability and fill rates, reduces inventory and drives cash flow savings and provides lead time analysis. The order point and order quantity are determined every month for every item line. xIO tool has been developed by xtivity which aims at assisting asses incentive industries and simplifying decisions related to MRO materials.

- **MRO connection**

MRO connection was developed and is sponsored by a group of partner organizations (PCA, xctivity, Net Results group and HIS) dedicated to providing organizations information and integrated solutions to analyze, standardize, optimize and sustain the MRO Supply Chain. IHS provides data cleanse, standardize descriptions, identify duplicates and manage MRO catalogue. PCA analyze best practices to optimize physical space, identifies storeroom procedures and practices and link planning and scheduling. Net Results group indentifies obsolete and non-functional, identifies intra-company use, creates disposal strategy and executes. Xctivity revises order point, order quantity and lead times, cancel unnecessary purchase order and identifies potential stock outs.

- **Oniqua's analytics optimization**

Oniqua Autralian Company has developed Oniqua Analytics Solutions software that leverages optimization algorithms and analytical techniques to dynamically optimize MRO decisions to reduce cost and risk. Oniqua Analytics Solutions has similarities with xIO, it works by extracting data from SAP and makes monthly recommendations for order points and order quantity.

- **Accenture**

Accenture, a global management consulting, technology services and outsourcing company, is an active player in the MRO field. Accenture has written several papers on MRO: (Predicive Maintenance Repair & Overhaul, 2005), (Survival of the fittest: adaptable supply chains for assest-intensive commodity producers, 2011), (Price optimization for high performance: How Accenture Parts Optimization Services can boost performance and brand image, 2011), (Leveraging Captive Spare Parts to Boost Operating Profit, 2010). Accenture has developed the Accenture Parts Optimization tool to help clients to manage their MRO spare-parts with end-to-end solutions by addressing all stages of MRO life-cycle: design, data, sourcing, inventory, and usage.

C. Relevant and general information from the literature regarding MRO and maintenance issues

This Appendix summarizes some results from the literature. This Appendix is divided in three parts. In a first part, we explain why a specific literature addresses the specific MRO management problem. A second part explains why the existing literature fails to answer our main research question. Last part provides more general information regarding maintenance concepts.

Why a specific literature addresses the maintenance spare parts management problem?

Specific literature addressing maintenance spare part management as spare part inventories differ from semi-finished inventories through several aspects. First difference pointed out by Kennedy et al. (2002) between spare parts inventories and semi-finished inventories concerns the function of the inventory: semi-finished inventories exist in order to smooth production flow whereas the function of spare parts is "to assist maintenance staff in keeping equipment in operating condition" (Kennedy, W.J., Patterson, J.W., & Fredendall, L.D., 2002, p. 201). Spare parts are used in the maintenance environment. The British Standards Institutions defines maintenance as "the combination of all the technical and associated administrative actions intended to retain an item in, or to restore it to, a state in which it can perform its required function". Secondly, maintenance spare parts inventories are different from other semi-finished inventories because they have the following unique characteristics: the need for a spare part is defined by the maintenance policies. Corrective and preventive maintenance policies both affect the stocks levels and inventory policy.

Two review papers have been written on spare parts management. The first one by Guide et al.(1997) discusses the existing literature, examines the various models proposed and the major assumptions made in those models, and classifies them according their solution and methodology (single versus multi echelon and exact versus approximate solution). This first review focused on inventory control processes. The second review by Kennedy at al. (2002) discusses management issues, age-based replacement, multi-echelon problem, problems involving obsolescence, repairable spare parts.

However, none of those reviews give a conceptual framework. A framework is useful because it provides rules of thumbs facilitating management decision-making process. It also gives a general comprehension by showing the connection between the decisions taken in different sub-processes within spare parts management overall process. A general framework is needed to increase the efficiency, consistency and sustainability of decisions on how to plan and control the spare parts supply chain. In this respect, Cavalieri et al. (2008) provides a first framework for spare parts control. He presents a five steps decision-making process (part coding, part classification, part demand forecast, stock management policy, policy test and validation) to allow managers to control their maintenance spare parts. Driessen et al. (2010) provide a broader perspective by incorporating a repair shop and its control. We will use this latest framework to guide our work. Driessen at al. (2010) identify eight key MRO processes : assortment management, demand forecasting, parts return forecasting, supply management, repair shop control, inventory management, spare parts order handling, and deployment. Section 1.2.4 provides definitions and key notions of those eight processes. For further information, we refer to Appendix D.

Why the existing literature does not answer our main research question?

The assignment is conducted at a strategic and high level decision making. As pointed out by Wagner et al. (2008) most literature focus on planning and operational aspect (e.g. determination of optimum spare parts inventory levels and replenishment policies). In order to manage their spare parts business effectively, a manufacturing company must consider qualitative, organisational and strategic aspects

before dealing with detailed and quantitative aspects by organizing tactical and operational level decision functions. In their article, Wagner et al. (2008), they assess problems that companies face in their spare parts business and make recommendations for successful management. Wagner et al. (2008) work has been recently extended by Hertz et al. (2011) in a paper in which they review the strategic planning problems arising from designing an after-sales field service network. However, those two studies only consider sales spare parts whereas we want to consider maintenance spare parts i.e. MRO. Maintenance spare parts significantly differ from sales spare parts as their goal is to support the maintenance activities to face failure whereas sales spare parts is considered as a after sales service and aims to increase revenues and profits of the manufacturing company. Our assignment goal is similar with those article goals but we cannot directly use their research as we do not consider the same kind of spare parts.
Moreover, we cannot use results from the literature addressing supply chain management problems because maintenance spare parts management is highly specific in comparison with semi-finished inventories: sporadic demand hard to forecast, low demand, high price, high risk with high downtime cost.

The maintenance environment of MRO management

Within industries that use and maintain their own capital assets, a maintenance organization is responsible for maintaining the capital assets. Main resources of this maintenance organization are spare parts and service engineers. In the maintenance organization, the MRO is responsible or spre parts resources. To maintain the capital assets, the maintenance organization aims at maximizing the equipment availability while minimizing the total costs. In his work van Houtum (2010) defines equiment availability as the fraction time that equipment is up and running during the normal operational hours. Equipment availability is given by the following formula:

$$\boldsymbol{Availability} = \mathbf{1} - \frac{\boldsymbol{DT}}{\boldsymbol{number\ of\ operational\ hours\ per\ year}} \quad (1)$$

where DT is the total number of hours per year that the equipment is down during the operational hours. This formula shows that maximizing the equipment availability is equivalent to minimizing downtime. Downtime, starting when an unplanned failure occurs, is usually divided into a maintenance delay caused by unavailability of the required spare part and the repair time (including diagnosis). Then as shown by van Houtum (2010), the formula for downtime is the following:

$$\boldsymbol{DT} = \boldsymbol{FA} * (\boldsymbol{MD} + \boldsymbol{RT}) \quad (2)$$

Where FA is the number of unplanned failure per year, MD is average corrective maintenance delay and RT is the repair time.

Maintenance concepts involve a trade-off between preventive and corrective maintenance and influences the number of failure FA and maintenance delay MD. Maintenance is either planned or unplanned and is conducted within the constraints of the maintenance strategy. Equipment reliability depends of the trade-off between preventive and corrective maintenance. Reliability and availability are two distinct notions. The literature distinguishes three types of maintenance:

- Preventive maintenance: strategy failures are avoided by monitoring equipment and scheduling planned maintenance actions. This type of maintenance is also called proactive maintenance. As preventive maintenance is planned some time in advance, the corresponding needed spare parts can by ordered accordingly. So preventive maintenance, does not directly affect spare parts management. However, it affects it indirectly through FA, the number of unplanned failure per year. The more preventive maintenance is conducted, the less unplanned failures occur per year.

Preventive and corrective maintenances are coupled through FA. A low level of preventive maintenance will tend to increase the stock levels of spare parts in order to have short downtime when an unplanned failure occurs.

- Corrective maintenance: unplanned maintenance actions are taken after a failure has occurred. This type of maintenance is also called reactive maintenance.
- Modification maintenance: actions are conducted to improve overall equipment performance. This type of maintenance is also called aggressive maintenance. Modification maintenance is often related with specific projects. Since this maintenance does not directly concern the daily decisions of the maintenance organization neither the maintenance logistics organization, it will be let out of scope.

To conduct the maintenance, the maintenance organization creates work orders. For each work order, tasks to be performed are specified with needed resources (tools, equipment, technicians, spare parts). The MRO is responsible for the availability of spare parts. In their book, Campbell et al. (2006) show how the global maintenance organization and the MRO organization are linked when managing spare parts through work orders.

D. MRO processes from Driessen et al (2010) framework

This appendix provides further details on the discussion started section 1.2.4 on MRO processes management. To organize our discussion and review the diversity of issues handled in the literature, we use Driessen et al. (2010) general framework. In this article the authors split the spare parts management process into eight sub processes and discuss the managerial decisions taken at the strategic, tactical and operational levels within each sub-process. The difference between strategic S, tactical T and operational O decisions consist in their frequency: strategic decisions are taken on a yearly basis; tactical ones are taken on a monthly basis whereas operational decisions occur every day or every week. The figure below gives an overview of the eight processes and the main information that flows between them. All feedback loops are not considered.

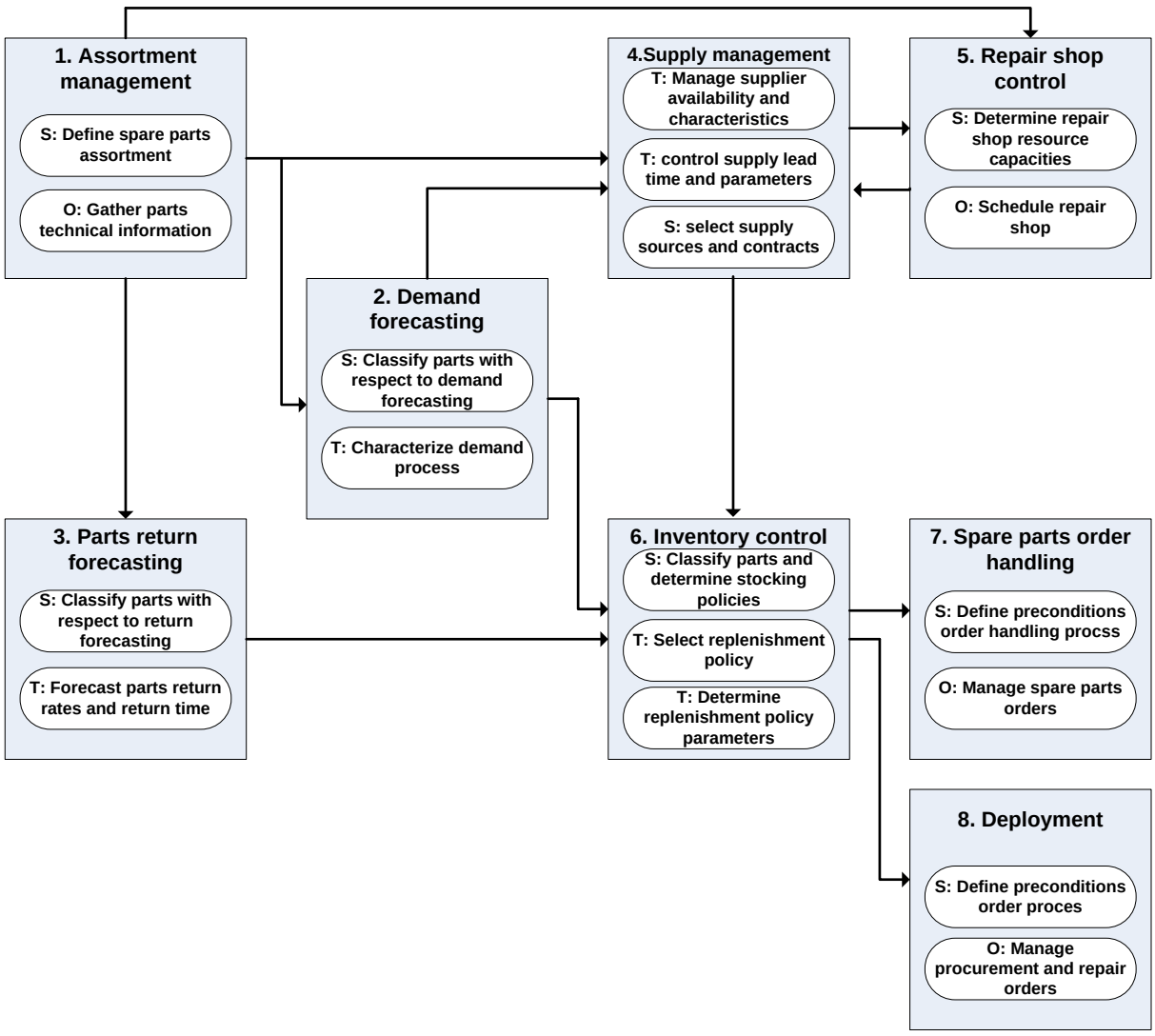

Figure 17 : Overview of spare parts processes and decisions taken to manage them. Adapted from Driessen at al. (2010)

Assortment management

Assortment management concerns the decisions to have (or not) data on a given spare parts and to maintain this technical information. This decision is different from the decision to have the spare part in stock. For example, a low moving, non-critical and short supplier lead time spare part may be in the

assortment management but not kept in stock by the company. Two sets of decisions with regards to assortment management are to include a given spare part in the assortment (i.e. define spare parts assortment) and to gather technical information about the parts including in the assortment.

Define spare parts assortment (Strategic level S)

On the one hand, a part that has high downtime cost (i.e. parts that have high probability to be needed and are critical for the plant) will be included in the assortment. On the other hand, including a spare part in the assortment requires time and operational cost, which are unnecessary if the part is not used. A trade-off is naturally found by practitioners. There is no literature available on this decision that has a technical character more than a logistical aspect. Instead rules of thumb on cost, failure rates and criticality are used. For example, Stamatis (1995) proposes way to determine the criticality level of a part.

Gather parts technical information (0)

Once a part is included in the assortment, technical information must be gathered and maintained. Information may concern criticality, redundancy, commonality, specificity, substitution, shelf life, position in the configuration (or indenture level), repairability, type of supplier contract and expected supplier price.

Demand forecasting

Parts that will be demanded in the near future need to be forecasted. These future demands come both from planned demand (preventive maintenance) and unplanned demand (corrective demand). The forecast is based on historical and/or known future demand.

Classify parts with respect to demand forecasting (S)

According to Driessen et al. (2010) two types of parts need to be considered. The forecast method for the first one does not use the future demand whereas the forecast method for the second one does. The decision to take into account future demand is based on the price of the part and on the ratio between planned and unplanned demand. Indeed, for parts that are cheap or have a small ratio of planned demand, using future information is rather expensive and has low benefits on the forecast. For unplanned demand, mean inter-arrival rate and variability demand size are key factors in choosing the appropriate forecast method. In the literature the mean inter-arrival is referred as the mean time between failures MTBF. FA represents the same thing in equation 2.

Characterize demand process (T)

The demand process is important to characterize because it has a direct effect on the stock levels but also on the repair capacity and supply management. When characterizing the demand, we aim at knowing the distribution of the demand per part and per period. The demand processes of planned and unplanned demand are characterized separately. The demand for planned maintenance is easy to characterize since the demand during the delivery lead time is deterministic. For unplanned maintenance, different types of forecasting methods are applicable. Information on substantiality (also known as cannibalism), commonality and redundancy may be used in those techniques. Driessen et al. (2010) differentiate three types of forecasting methods:

- Maintenance planning based forecasting method: forecasts are based on maintenance planning information. “Demand of spare part at any time is a function of equipment maintenance operations and dependent on some explanatory variables” Hua et al. (2007).
- Reliability based forecasting method: requirements are determined using failure rates and operating changing conditions. Reliable references are Nelson (1982), Nelson (1990) and Ebeling (1997). A recent study by Heng et al. (2009) integrates the use of sensors;

Time series based forecasting method: extrapolation techniques are used using historical data and statistical methods in techniques like moving average, smoothing methods, Croston's method and bootstrapping. This time series based forecasting method is the traditional technique in demand forecasting. Literature on forecasting in inventory control in general is important: Silver et al. (1998) and Hopp and Spearman (2001) are reference books in inventory control and discuss those forecasting methods. Croston (1972) started a new stream of literature to forecast demand for spare parts and increased forecast accuracy by forecasting inter-arrival time and order quantities separately. Teunter and Duncan (2009) continued his work and provided further references. Willemain et al. (2004) adapted bootstrapping technique to specifically forecast spare part demand. The demand for spare parts is characterized by many zero values. To describe the demand pattern, Ghobbar and Friend classified it using two measures: the average time between two consecutive orders (ADI coefficient) and the variation of the demand (CV coefficient). Figure 18 makes the distinction between erratic, lumpy and smooth demand depending on the ADI and CV measures.

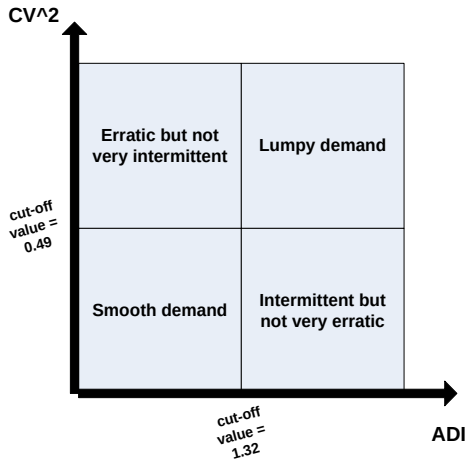

Figure 18 : Classification of demand pattern. Adapted from Ghobbar and Friend (2002).

Parts return forecasting

By having a close look in

Figure *17*, we can notice that a double direction arrow appears between the ready-for-use stock RFU and the maintenance depot. The arrow leaving the RFU indicates flow of spare parts to be delivered to the plant. However, in some cases, it is not known which spare parts is responsible for the machine failure and the plant may order more parts than needed. Once the plant has found which part is responsible for the failure, they will return the unused parts to the RFU stock within an agreed return time. This parts return flow is the one depicted by the arrow that leads to the RFU stock. As explained by Driessen et al.(2010) the maintenance logistics organization needs to take into account those return rates and return time in their planning and control operations. For example, they must take care to not reorder immediately new parts to the suppliers when those parts may return soon from the plant in order to avoid excessive inventory levels. In this example we see that parts return affect replenishment decisions.

Classify parts with respect to returns forecasting (S)

Distinction must be made between consumables and repairable items since they do not follow the same path in the spare parts supply chain.

Forecast part return rates and return time (T)

As the return of consumables and repairable parts to the ready-for-use stock affects the maintenance operations and decisions, the return rates need to be forecasted. The return times affect the replenishment decisions and so need to be agreed with the maintenance organization, or at least forecasted. Different forecasting techniques may be useful. For a brief discussion about those techniques, we refer to the forecasting section.

Supply management

Supply management ensures that at least one supplier is available to supply the ready-for-use parts. Parts must be available at any moment. Supply characteristics such are procurement lead time, type of contracts and price structure are defined between the supplier and the organization. Purchasing literature, for example the book by Van Weele (2010), addresses important topics on how setting and maintaining relationship with external suppliers and external repair shops. It may be very beneficial from financial and administration points of view to use a strategic sourcing strategy (i.e. when a few major suppliers provide most of the spare parts supplies) (Campbell, J.D.,& Reyes-Picknell, J.V., 2006). Indeed, strategic sourcing allows having fewer transactions and fewer suppliers to manage.

Manage supplier availability and characteristics (T)

According to Driessen at al. (2010), there exist several types of supply: external supplier, internal repair shop, external repair shop, and re-use of parts. For each supply type, it is possible to have multiple suppliers as well.

Managers from the maintenance logistics organization must take care about several aspects. First of all, when no supply source for a given part is available, they must find an alternative source e.g. a new supplier or repair shop or a substitute part. When the only supplier of a part is known to disappear, they must place a final order to cover the remaining demand. Models to determine the final quantity to order are available for decision support: Van Kooten and Tan (2009) discuss the case when a repairable item from the own repair shop will become unavailable whereas Teunter and Fortuin (1999) provide a model for consumables. Secondly, the maintenance logistics organization must manage the current contracts with external suppliers. This requires updating and adapting them some time before the contract expiration date. Finally, managers must maintain information on supply characteristics: contractual or historical prices, discount quantities, repair or procurement agreed lead time, type of contract, minimum order quantities and multiple quantities are relevant information.

Control supply lead times and supply parameters (T)

Whether the parts come from a repair shop or an external supplier, the repair lead time and procurement lead times, respectively, must be planned. The repair lead times consists of picking, transports, storage, hand-in and repair times whereas procurement lead time consists of picking, transports, storage, hand-in and supplier lead times. For each type of supply lead time, we can rely on planned lead times: repair lead times are agreed with the repair shop which has the required capacity to meet the repair lead time; procurement lead times are contractual lead times with the external supplier.

Select supply source and contracts (S)

The maintenance logistics organization sets up contract with one or multiple supply sources. Their selection and decisions are based on repair or procurement costs, costs of the contract, costs of the repair shop capability and resources, and inventory holding costs.

An important decision in selecting the supply source is the decision to designate a part as consumable or repairable. Alferdsson (1997) states “The task of determining whether an item should be treated as

consumable or repairable item is called *level-of-repair-analysis (LORA)".* Basten et al. (2009a)(2009b) (2010) address those questions on how to conduct LORA.

Repair shop control

To some extent, the internal repair shop can be considered as a production unit in a supply chain. Agreements between the repair shop and the remaining maintenance logistics organization are made upon the repair lead time for each spare part and the workload levels per unit of time. Those decisions impact the operational level through the schedule of repair job. Moreover, tactical decisions are taken to determine the global capacity and resources (machines and tools, employees) of the repair shop.

Determine repair shop resource capacities (S)

According to Driessen et al. (2010) when a job enters the repair shop, the time spent in the repair shop consists mostly of waiting times for resources. Needed resources can be specialists or tools. The resource capacity must be sufficient in order to deliver the repaired spare part within the agreed lead time. Decisions resources must be taken on the amount of employees and specialists, the number of shifts, the number of parts to stock, the number of tools and machines of various kinds to acquire. Dimensions of those resources are based upon the estimated repair workload and variability following from the demand forecasting and parts return forecasting.

Schedule repair jobs (O)

As the repair operations must be done within the agreed lead times, scheduling repair jobs is necessary to meet the due dates. The objective of scheduling is to minimize the repair job tardiness subject to the resource constraints. Batching is allowed to reduce set-up times and costs. Pinedo (2009) proposes many models for the daily scheduling of jobs. Also Caggiano et al.(2006) integrate inventory levels to allocate the repair jobs. Priority schedules and flexible capacity are discussed by Guide Jr et al. (2000).

Inventory control

Inventory control decisions concern which spare parts to keep to stock, at which stocking location and in which quantities. Ready-for-use parts are kept in stock to meet service levels. The maintenance logistics organization should only keep in stock parts to cover unplanned demand (corrective maintenance), and planned demand (preventive maintenance) in case the supply lead time exceeds the delivery time of the parts. Other planned demand that is know enough time ahead of time is delivered to order and is not kept in stock at the maintenance logistics organization level.

Classify parts and determine stocking strategy (S)

The parts kept in stock are characterized by a high number of parts and a high diversity (slow moving vs. high moving, expensive vs. Cheap, consumables vs. Repairable, differences in failures rates and repair time illustrate how diverse the stock to control is). To handle with this diversity, different and adequate strategies and replenishment policies must be used for each homogeneous group of parts. The first step to control inventory is then to classify parts into differentiable groups.

The literature does not agree on the classification criteria to be adopted. Driessen at al. (2010), proposes a classification based on the level of criticality and the price of the parts. Figure 19 shows this classification of parts and the corresponding stocking strategy for each group.

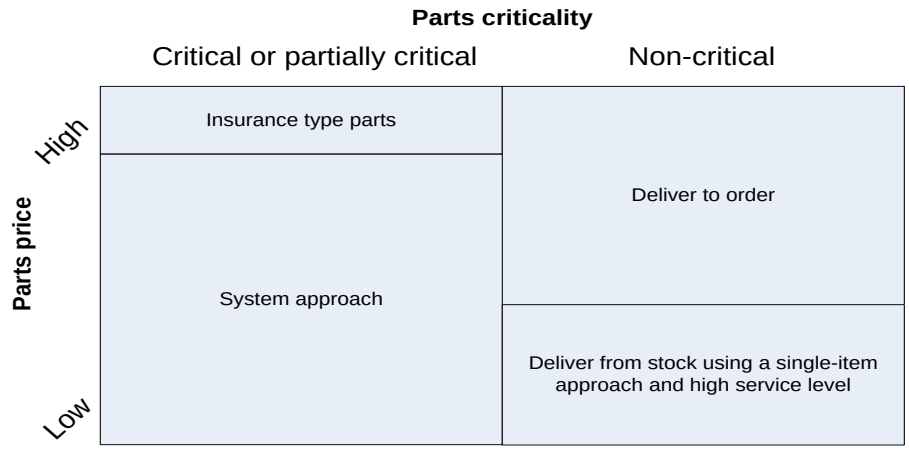

Figure 19 : Classification of parts with respect to inventory control. Adapted from Driessen at al. **(2010)**.

Cavalieri et al. (2008) propose another classification and identify four groups of parts:

- consumables and auxiliary materials characterized by a steady and continuous consumption and having many suppliers;
- generic spare parts;
- specific spare parts;
- strategic spare parts: they are specific spare parts characterized by high supply delivery time, relevant costs and sporadic demand.

In all classifications, criticality is a key aspect when deciding to keep in stock or not. Dekker at al. (1998) defined criticality as the level of importance of a piece of equipment for sustaining production in a safe and efficient way. Two types of methods are available to classify parts based on a criticality analysis. Methods are summed up in Figure 20.

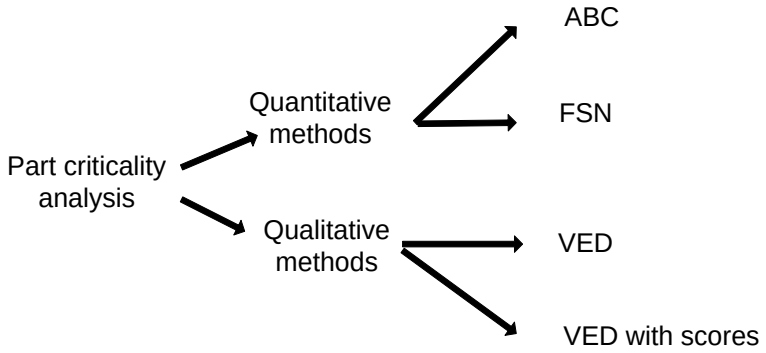

Figure 20 : Methods for spare parts criticality analysis. Adapted from Cavalieri et al. (2008)

The first sets of methods are quantitative. Most quantitative methods are based on an ABC approach. For example, Schultz (2004) uses the MTTF (mean time to failure) and MDT (mean down time) variables to build up ABC analysis and identify levels of criticality. Dhillon (2002) used other variables with the annual demand and the annual purchasing cost of the spare parts. Another

quantitative method focusing on the moving rates of the parts is proposed by Mukhopadhyay et al. (2003): fast-moving parts, slow-moving parts and non-moving parts (FSN).

The second methods are qualitative methods that assign criticality levels based on rough judgment or on scoring methods. A well know method is the VED classification system (Mukhopadhyay, S.K., Pathak, K.,& Guddu, K., 2003) : based on consultation experts, parts are classified as vital (V), essential (E) or desirable (D). Because subjective judgment may render the task quite difficult, Gajpal et al. (1994) propose to combine VED analysis with analytic hierarchic process AHC. In their VED-AHC analysis they identify the three following drivers that influence the criticality of a spare part:

- Type of spare required:
    - standard part available from the shelf;
    - standard part whose availability is not certain;
    - non-standard part to be fabricated according to specifications.
- Procurement lead time :
    - less than 3 months;
    - varying from 3 to 6 months;
    - more than 6 months.
- Availability of the production facility:
    - alternative production facility available;
    - alternative production facility available if suitable modifications are made in the equipment or process;
    - no alternative production facility available.

Select replenishment policy (T)

Once the classification and stocking strategy are determined, the maintenance logistics organization must select replenishment policy of spare parts at all stocking points. The replenishment decisions concern the frequency of orders and order quantities. The environment (multi-echelon vs. Single echelon, multi vs. Single location) and the classification of parts impact on the replenishment policy.

In a divergent multi-echelon environment with a central warehouse and local stocking points, Driessen et al. (2010) argue that the central warehouse replenishes at a fixed frequency for batching reasons. This results in a (R,S)-policy at the local stocking locations. A description of replenishment policies and relevant parameters is given Appendix A. Emergency shipment between the central warehouse and local stocking points and lateral transshipments can be used to deliver critical parts. Spare parts for which a framework contract has not been set up, their stock levels will be reviewed on a daily basis, resulting in an (R,s,S) or (R,s,Q) policy.

Cavalieri et al. (2008) propose another point of view using the demand characteristic (stochastic vs. Deterministic), the level of repairability (repairable vs. Consumables) and centralisation (centralised vs. Decentralised logistical support) to select the proper replenishment policy and stock sizing. Among others, they make use of the work by Jardine and Tsang (2006).

Determine replenishment policy parameters (T)

The replenishment policy parameters differ according to the spare parts classification.

Given the classification from Figure 19, Driessen at al. (2010) argue that non-critical and expensive parts have an order-up-to-level S equal to zero. For other parts, a system approach is used to meet the desired service level.

Models assuming continuous or periodic review are available. The chosen model should take into account the following environment characteristics in order to given a practical solution : multiple-echelon, multiple-items, multi-indenture structure, emergency shipments from central depot, lateral transshipments, multiple service level criteria and budget constraints (Driessen, M.A., Arts, J.J., Houtum, G.J.van, Rustenburg, W.D., & Huisman, B., 2010). Input of the model are information on demand and parts returns forecastings, supply structure management (supply lead times, parts prices, minimum order quantities etc.) and information on the current inventory positions and replenishment policies. This is a high complexity problem.

In their paper, Guide and Srivastava (1997) present an overview of models available in the literature. Those models make different assumptions, consider one or multi-echelon structure and propose an exact or approximate solutions. Kennedy at al. (2002) paper also has a review discussion on those issues. In the multi-echelon context, many inventory theory models are METRIC-based. METRIC (Multi Echelon Technique for Recoverable Item Control) is a model for setting inventory levels and allocating units to achieve the desired level of service, measured by expected backorders at the base level (Sherbrooke, C.C, 1968). Extensions of this METRIC model such as MOD-METRIC (Muckstadt, J.A., 1973) and VARI-METRIC (Sherbrooke, C.C., 1986) allow batch repair, multiple levels of indenture and lateral shipments. For the most important models, we refer to the recent books by Sherbooke (2004) and Muckstadt (2005) .

An adaptation of the Economic Order Quantity (EOQ) model is proposed by Mann (1966). This method is easy to understand and calculate, but it does not take into account either fluctuating demand rates or uncertainty of the ordering cost (Kennedy, W.J., Patterson, J.W., & Fredendall, L.D., 2002).

To conclude this part about the inventory control process, we quickly discuss the advantage of simulation. Once the replenishment policy and parameters have been selected, tests should be performed before implementing the results in order to validate the decisions. Different case studies examine the influence of the control variables and different parameters on the policy. Simulation can be also used to find a solution rather than testing the selected policy. For example, Marseguerra at al. (2005) proposed simulation to decide the optimal number of spare parts required by a multi-component system using Monte Carlo random generation of failure. For a general overview of simulation techniques we refer to Law and Kelton book (1991). Dubi (1999) discuss the application of simulation to spare parts management.

Spare parts order handling

The global maintenance organization releases work orders for planned and unplanned jobs. The work orders are assigned centrally to the maintenance logistics organization that must handle them. According to Driessen et al. (2010), the order handling consists of the following steps: accept, adjust or reject the order, release spare parts on the order, and handle return order of failed repairables.

Determine preconditions order handling process (S)

The global maintenance organization and maintenance logistics organization make agreements on order quantities, order priority and order lead times. When receiving an order, the logistics organization can check it to adjust (in time and/or quantity) unrealistic or unusual orders. After adjustment of an order, the maintenance organization may need to reschedule certain maintenance tasks accordingly.

When an order for a part is placed for the first time, the maintenance logistics organization should consult the maintenance organization on the reasons for requesting this part in order to increase the forecast of future demand for this new part.

When the order is accepted, the part may not be on stock. In this case, a decision must be taken between using emergency shipment from the central warehouse of emergency transshipment from another local stocking point. Alfredsson and Verrijdt (1999) discuss this issue.

It may happen that the maintenance logistics organization faces an allocation problem if the demands from several work orders exceed the available parts. As there is no optimal solution to this problem (Akçay, Y., & Xu, S.H., 2004), the allocation rules should be discussed with the maintenance organization. Lu et al. (2010) propose limited results on this problem and suggest that it can be beneficial to hold back inventory.

The requested spare parts are released by the maintenance logistics organization at the delivery date minus the transportation time. Once the spare part is released, an order is placed for the return process.

Manage spare parts orders (O)
When the maintenance logistics organization receive a spare parts order, the order is either automatically accepted or not. The spare parts order is closed when all parts request are fulfilled and all return and failed parts are handed in by the maintenance organization.

Deployement

Deployment concerns the process of replenishing spare parts inventories using different parameters than those advised by the inventory policies. Empirical evidence from production scheduling suggests that deployment is a spread practice: managers disregard most advises (Fransoo, J.C., & Wiers,V.C.S., 2008). Deployment is even more observed in complex environments (Fransoo, J.C., & Wiers,V.C.S., 2006). This deployment process consists of defining the preconditions order process and managing procurement and repair orders.

Define preconditions order process (S)
In section Inventory control, the replenishment policy parameters (when to replenish and in which quantities) have been determined. However, on a daily basis deployment may vary from those parameters for different reason: new information is available, exceptional repair or procurement order has arisen for instance. Deployment functions as an exceptional management and deployment rules and preconditions should be specified. When deployment occurs, a feedback loop need to start in order to reconsider the forecast demand for instance.

Manage procurement and repair orders (O)
According to Driessen et al. (2010), the process of managing procurement and repair deployment orders consists of the following steps: procure or repair parts with the right quantity and priority, check the quality of the received spare parts and, monitor supply lead times.

E. Descriptions of best practices

Assortment management

Assortment management concerns the decision to have (or not) data on a given spare parts and to maintain technical information on it. Assortment management concerns catalogue management. Coding management is included in catalogue management. We identify two best practices related with assortment management to guaranty completeness and uniqueness of the catalogue description.

Best practice: the catalogue description is complete.

Catalogue completeness must facilitate purchasing, inventory management and MRO overall management. Assortment management is the starting point of MRO management and impacts on all other MRO processes. An item description will consist of the three following descriptions:

- **A global description.** This global description is the one characterising a spare and should be unique for a spare over sites and over supplies. The global description should contain the following information: item code, life cycle, generic stocking conditions, generic quality check, level of repairability, and an item description. This item description should be standardized and will depend of the item type or class. Indeed, we do not describe a pump with the same characteristics than a bearing. Information in the item description can be size, weight, volume, diameter, power, etc. In the chemical environment, we handle an extremely high number of spare parts; hence we will not include redundancy, commonality, specificity nor substitution information. Those latest information will be knowledge of repair technician people. Two identical global descriptions should refer to the same spare part.
- **A local description.** This local description should be site or client specific and related to usage. Information in this local description should be criticality, classification, position in the indenture level (i.e. fits in lists or bill of material), maximum admitted delivery time, specific stocking conditions, specific quality checks, replacement number - this number will be one in most cases but it can be strictly greater than one when changing one broken spare requires changing all similar spares for symmetric reasons.
- **A supplier description.** This supplier description will contain all information related with a supplier for a given spare. If a spare (uniquely identified in the global description thanks to the item code) can be provided by several suppliers, it should be specified a preferred supplier. The supplier description should contain information such as: supplier or manufacturer code, unit price, delivery time, minimum ordering quantity, lot size, discount quantities, forecasted manufacturer availability.

An item and a global description should have a one to one relationship. The uniqueness should be guaranty thanks to the item code in the global description. One global description can have several local descriptions when the same spare is used at several locations (sites, business warehouses or equipments). One global description will have zero to several supplier description. In most cases, one global description will have only one supplier description. The no supplier description corresponds to the situation when the spare is not manufactured any more. If a global description is coupled with more than one supplier descriptions, a preferred supplier must be specified. Relationships in-between description is symbolized figure 21.

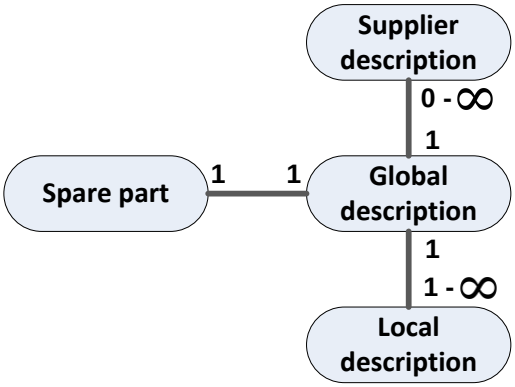

Figure 21 : relationships in-between a spare global, local and supplier description

Best practice: the catalogue uniqueness is guarantied

Having one global description for one spare part globally is challenging. This uniqueness in the catalogue is a difficult task due to the difficulty to describe a spare in a standardized way. Even difficult, uniqueness of the global description over sites and over suppliers should be a goal. Duplicates of codes i.e. two or more codes for the same part has several negative effects on the maintenance, inventory and purchasing bottom lines by:

- Increasing inventory levels which increases inventory cost and decreases inventory turnover.
- Decreasing the equipment reliability. For example, when the system detects one time five different failures instead of five times the same failure because of duplicates, we miss the opportunity to improve for next time and equipment reliability will be lower.
- Increasing purchasing orders and lowering purchasing contract management. Without duplicates, purchasing is more able to go for batches replenishment instead of one-to-one replenishments. Moreover, purchasing, at a global level, can have an advantaged pricing and global contracts with low level of duplicates.

IHS Intermat solution is a tool developed by IHS on ways to clear data and eliminate duplicates. For more details we refer to Appendix B or to the website http://www.ihs.com/products/mro/index.aspx. http://a1024.g.akamai.net/f/1024/13859/1d/ihsgroup.download.akamai.com/13859/engineering/intermat/intermat-demo.htm video presents the tool. Other tools might be available on the market.

Best in class catalogue/assortment management that requires complete and duplicate-free catalogue is a huge effort. Ultimately, catalogue should be managed with cleaned, standardized, complete, consistent and duplicate-free information. An automation catalogue management should handle this complexity while being connected to the used MRO management system such as SAP or other ERP or EAM.

Demand forecasting

Parts that will be demanded in the near future need to be forecasted to support equipment reliability while optimizing inventory management and stock levels. These future demands come both from planned demand (preventive maintenance) and unplanned demand (corrective maintenance). The forecast is based on historical and/or known future demand. We identify two best practices with regards to demand forecasting.

Best practice: planned demand for slow moving and expensive items are forecasted to be bought at suppliers

For preventive maintenance, the demand of spare parts is known ahead of time. For expensive spare that have a supplier delivery time that allows having the spare before the preventive maintenance work, the spare should be bought at the supplier at the right timing and delivered directly to the user

instead of being issued from the warehouse. For cheap items, using information for future demand is rather expensive and has low benefit on the forecast. For those cheap items, we will prefer to have higher stock that will cover demand for planned and unplanned demand. For replenishing stocks for those cheap items, we will prefer replenishment in batches rather than one-to-one replenishment.

Best practice: unplanned demand are forecasted using time series based forecasting method.
MROs must be stocked to cover unplanned demand. Stock is also used to cover planned demand of cheap items or planned demand of items that have an excessively long supplier delivery time. However, major stocks should aim at covering unplanned demand. To set the right stock levels and optimizing inventory management and replenishment, unplanned demand must be characterised using forecasting techniques. In time series based forecasting method, extrapolation techniques using historical data and statistical methods are used. Enough information and history should be available to allow forecasting. For cheap and fast moving items, traditional methods can be used. We refer to Silver et al. (1998) and Hopp and Spearman (2001) for references book on traditional forecasting methods. For slow moving items, forecasting techniques need to be adapted as the demand for spare part is characterized by many zero values. We refer to Willemain et al. (2004).

Parts return forecasting

Parts return flow comes when the clients return unused spares to the warehouse. Returns can concern spare that were initially issued from stock or spare that were bought at the supplier. Reason for returns is when the client did not know which spare was responsible for a failure and issued or purchased more than needed. The return rate should be as low as possible. Returns create extra work and affects replenishment decisions. I identify two best practices regarding parts return and return forecasting.

Best practice: returns are tracked to reduce them
Returns should be avoided as they create extra work. Hence, it could greatly help to reduce the return by tracking which spares are concerned by returns. Which are the spare the more often returned? In proportion of issued? Which clients return the most? Identifying the return root causes and engaging in improvement actions with the clients should help to reduce the return rate. Best in class will be return rate lower than 10%.

Best practice: a maximum return time is agreed with the client
To avoid unnecessary replenishment of spares that might return soon to stock, a maximum return time should be agreed between the client and the MRO organization. Then, the MRO organization will replenish once this maximum return time has expired. This maximum return time should be as low as possible to avoid inventory stock outs. One to a few days might be an appropriate maximum return time. This agreed maximum return time concerns the spare that were issued from stock, based on the issuing date.

Supply management

Two major suppliers are external suppliers or repair shops. Type of supply, i.e. buying a new part or repairing it depends of the repairability level of the part (whether the spare is repairable and how many times it can be repaired). The incentive to repair is higher for expensive than cheap items whereas it will be better to buy new parts for cheap items rather than repairing them. We identify two best practices regarding supply management; one for managing external suppliers, another one for managing repair shops.

Best practice: external suppliers are managed

External supplier's management is the responsibility of the purchasing organization. It may be very beneficial from financial and administration points of view to use a strategic sourcing strategy (i.e. when a few major suppliers provide most of the spare parts supplies) (Campbell, J.D.,& Reyes-Picknell, J.V., 2006). Indeed, strategic sourcing allows having fewer transactions and fewer suppliers to manage. Supplier characteristics such as procurement price, lead time etc, must be set and maintain in the supplier description (we refer to previous discussion on assortment management). Contracts with suppliers must be managed. Type of supplier allowing strategic sourcing for Dow are suppliers such as Van der Peijl or Brammer that deliver a high number of generic parts. For more details on those suppliers, we refer to Appendix K.

Best practice: internal and external repair shops are managed

When an item is repaired in-house or in an external repair shop, repair time and location of the spare parts should be tracked. Inventory management should be aware of which spares will be back to stock and when. Indeed, inventory management needs to have visibility on this to take into account stocks levels in the repair process while taking replenishment decisions.

Repair shop control

To some extent, the internal repair shop can be considered as a production unit in a supply chain. Agreements between the repair shop MRO should be made upon the repair lead time for each spare part and the workload levels per unit of time. Those decisions impact the operational level through the schedule of repair job. Moreover, tactical decisions are taken to determine the global capacity and resources (machines and tools, employees) of the repair shop. We identify one best practice related with repair shop control.

Best practice: due date for each repair job are managed and communicated upon.

Setting the due date for a repair job is done for each new repair job as the time to repair will depend of the type of failure. Whatever repaired in-house or repaired by an external suppliers or repair shop, the expected due date should be known. This due date integrates the time to repair that depends of the type of failure as well as the repair job priority and current workload or repair shops. The repair job priority will depends whether the repaired item will then be directly used by a client or go to the stock warehouse. This repair due date, when the repaired spare is intended to go back to MRO inventory, should be communicated upon to inventory management to avoid useless replenishment.

Inventory management

Inventory control decisions concern which spares to keep on stock, at which stocking locations and in which quantity. Our single location assumption simplifies to inventory management problem to what and how much to keep on stock. Inventory must be kept to cover unplanned demand of spare parts, planned demand of cheap items or planned demand of items whose supplier lead times exceed delivery due date of the client. In this perspective, the MRO warehouse should be managed as a closed warehouse. Every movement from or to the warehouse should be controlled and justified. The MRO warehouse should not be managed as a shop. Opposed with a warehouse perspective, a shop keeps high inventories to stimulate and cover client unjustified and uncontrolled demand.

Best practice: MROs are classified using multi-criteria ABC to identify homogeneous group of part

Most of companies managing MRO have adopted a classification to handle management complexity. Adopted classification differs over companies. Literature does not agree on a MRO classification to be adopted. Based on practical experience and literature knowledge, Appendix F shows the

importance of classifying spare, argues why ABC is a useful classification and proposes ABC classification based and criticality and demand criteria. The goal of this classification is to identify stocking policy and strategy for each homogeneous group of parts.

Best practice: from the spare parts classification, adequate replenishment policy and replenishment policy parameters are selected.

For this best practice, we will discuss inventory strategy for our ABC multi-criteria classification. For other classification, discussion needs to be adapted. Figure 9 shows the relationships between Driessen et al. (2010) classification, our ABC multi-criteria classification and inventory control.

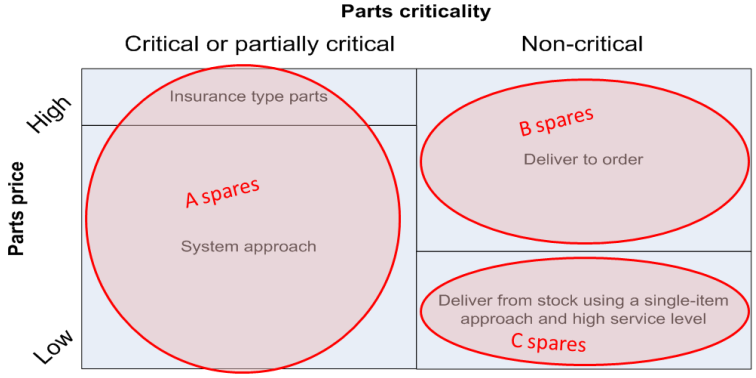

Figure 22 : relationships between Driessen et al. (2010) classification, our ABC multi-criteria classification and inventory control.

A items: critical spares

From Driessen et al. (2010), expensive and critical parts are insurance type parts and are kept on stock. Cheap to medium priced and critical parts will have a system approach strategy. This means that the replenishment policy parameters should satisfy an equipment service level rather than a service level of one part. Levels for critical spares should take into account the number and importance of equipment having this critical spare installed, based on the fits-in lists.

B items: non critical, slow moving and expensive parts

As B items are non critical, slow moving and expensive parts, stock levels should be controlled and limited. From Driessen et al. (2010), those parts should be delivered to order meaning that no B items are stocked. If the MRO organization does not succeed to get rid of B items stocks, stocks should be low, covering unplanned demand. Planned demand should bypass inventory step and should be delivered directly from the supplier or manufacturer to the client. For B items replenishment, one-to-one replenishment policy: batching does not make sense as B are slow moving items. It can be valuable from a financial perspective to manage B items with consignment contracts. This way, the MRO organization does not carry the stocking cost of those expensive parts on its balance sheet and the financial transaction occurs only when the B item is used.

C items: non critical, high moving and cheap parts

For C items, setting good replenishment policy and replenishment parameters is key as C items are fast movers. Possible replenishment policies are reminded Appendix E. Once the replenishment policy is selected, once must set replenishment parameters such are order point and order quantities or min and max levels for each item. To set those parameters, the demand average and variation should be taken into account. As consumption is high, forecasting is possible and replenishment parameters can be automatically computed. Computed replenishment parameters should allow meeting service

level. As C items are high movers, it is wise to make use of batching replenishment. Stocks for C items should cover both unplanned and planned demand. From Driessen et al. (2010), C items should be delivered from stock using a single item approach and high service level. For type C parts, it might be valuable to reduce handling and transportation work, to make use of vendor managed inventory VMI contracts.

For parts under contract management, in most cases, supplier will accept to deliver only once during a fixed period. This results in a (R, S) policy for parts under contract management. Different inventory management policies are described in Appendix J. For in-house managed parts, the stock levels should be reviewed daily, resulting in an (R, s, S) or (R, s, Q) policy for these parts with a review period R equals one day. Ordering quantity is limited by supplier characteristics: minimum ordering quantity, lot size etc. Emergency procedure with catastrophe scenarios should also be in place for urgent unpredictable issues.

Tools are available on the market to recommend optimal replenishment policy parameters. Oniqua Analytics Solutions computes optimal order points and ordering quantities, assuming (s, Q) policy optimal for all types of part. Oniqua is presented in Appendix B. Whatever the used systems and tools, a model should be used to select replenishment policy and replenishment parameters. This model should fit with the environment characteristics and assumptions: single-echelon, multi-items, high diversity, multi-indenture structure, emergency shipment solution if catastrophe scenario, no lateral transhipment, multiple service level criteria, high risk environment, and multi-client perspective. Simulation could help assessing and choosing replenishment policy and parameters.

Spare parts order handling

Spare parts order handling consists of accepting, adjusting or rejecting a released order for a spare parts; releasing the spare parts and handling return orders.

Best practice: the MRO organization manages in and out inventory movements with a closed warehouse

A closely managed warehouse allows to control in (i.e. return and replenishment) and out (i.e. issues from clients) inventory turns. A closed warehouse helps to manage and track turnover. A closed warehouse also increases inventory accuracy: the gap between registered and real quantities should be as little as possible. Stock accuracy should be as high as possible. Cycle counting is a way to detect stock inaccuracy and improve accuracy after correcting, adjusting the information in the MRO management system.

Best practice: the MRO organization checks spare parts orders on order lead time and quantities

For unplanned demand, direct issues from the warehouse (or from the supplier if the spare is not on stocked), should be placed. For planned demand, the client should make use of reservation process instead of direct issues to reduce handling and allowing MRO to optimize their inventories. For example, if a client knows he will need a spare in one month, he should reserve the spare with a need date of one month to the MRO organization. Then, the MRO organization manages the reservation: if the spare is not on stock, it will place an order to the supplier to be just in time delivered and the spare should be directly delivered to the client, bypassing MRO inventory. If the MRO organization has the spare on stock, two scenarios can occur. First scenario is when the needed spare is a slow moving item. Then the MRO organization should purchase a new spare to be delivered right to the MRO client instead of issuing from stock, if supplier and client lead time allows doing so. From a slow

moving item, the stock level should be low and every issue from stock should generate a new purchase order. Preferring buying the slow moving item to the supplier and bypassing MRO inventory rather than issuing from stock and then replenish the stock has two advantages: first it reduces handling and logistic work saving money and secondly it saves MRO stock increasing availability service. Second scenario when the needed spare if on stock is when the needed spare is a high moving spares. Then preferred solution will be to issue from stock instead of purchasing a new spare as fast movers stocks should be high and replenishment should be done in batches. In this latest scenario, the reservation status should be updated to a strict reservation based on the supplier lead time. For instance if the supplier lead time is one week, the reservation status must move to strict reservation to impede other clients to issue the same spare. Otherwise, we take the risk not to deliver the client that used the reservation process as the supplier lead time is too short to be delivered new spares. A condition to use the reservation process for planned demand of spare parts is that the MRO organization can rely on accurate and respected supplier lead time.

Deployment

Deployment concerns the process of replenishing spare parts inventories. Replenishments can come from the repair process or from procurement orders. Hence, for best practices, we refer to previous discussions.

F. Description of internal KPIs

- **Percentage of items with incomplete descriptions.** Examples of important incomplete information are the lack of fits in, supplier lead time and price or client needed response time. Programs should be in place to check whether catalogue information reflect reality facts: supplier delivery lead time, client response time should be checked. Incomplete and unreliable information might come from unchanged default values (e.g. zero as the default value for supplier delivery time). Low percentage of items with incomplete descriptions is targeted and can be quarterly measured.
- **Total number of original codes.** The less original codes, the less duplicates. This KPI can be yearly tracked.
- **Average client response time per maintenance work order priority** = spare part need date – today's date, averaged over orders per maintenance work order priority. This indicates whether the need date for a spare part order is in line with the maintenance work order priority and need date. The client response time should be lower for high priority maintenance work orders. Per maintenance work order priority, the MRO organization expects client response time as high as possible. Long client response time allows the MRO organization to level and anticipate its handling work and to buy MROs directly at the supplier when valuable. This indicator can be monthly measured.
- **Reservation rate for planned demand:** number of reservation/ number of issues for non-urgent maintenance work order. For all non-urgent maintenance work orders, the client should reserve spare parts rather than directly issuing. High reservation rate for planned demand is targeted. Reservation rate can be tracked on a monthly basis.
- **Bypassing rate for planned demand of expensive slow movers** = Number of issues bypassing inventory for planned demand of expensive slow movers (whereas stock was available) /total number of issues for demand of expensive slow movers. This KPI reflects whether the MRO organization is purchasing and bypassing inventory when they had stock available. High bypassing rate is targeted. This KPI can be monthly measured.
- **Forecast errors for fast/slow movers.** Forecast error reflects whether the forecast reflect real demand. The error should be as low as possible. The chosen forecasting technique should minimize the forecast error. Errors can be separately computed for fast and slow movers as forecast will be worse for slow movers. Forecast error can be monthly recorded.
- **Average levels and value of stocks kept by MRO clients**. The most spares are kept on stock at the client site before being used or returned, the worst performing the MRO organization will be regarding return management. Low levels and value of stocks at the client sites should be targeted. Average levels and values can be yearly tracked.
- **Return rate** = number of items returned/ numbers of items issued or purchased. This KPI reflects is the client well identified its MRO need before placing a MRO order. Low return rate is targeted. We propose quarterly measure for the return rate KPI.
- **Average return time** = return date – delivery date, averaged over returns. This KPI reflects if the MRO client is returning on time. Low return time is targeted and should be in line with the maximum agreed return time. This KPI can be quarterly recorded.
- **Delivery in full time (DIFO) rate** for strategic suppliers = 1 – (replenishment orders in overdue/ total replenishment orders) – (purchase orders in overdue/ total purchase orders). This KPI is the most important for external suppliers' management as MRO management should be able to rely on accurate and respected vendor delivery lead time. In case of partial deliveries, the delivery should be considered in overdue when the latest delivered item is delivered after the requested and agreed need delivery date. The best performance for delivery in full time from MRO supplier

for Terneuzen is at best 90%. There is a real need to review whether strategic suppliers are delivering on time and respecting the contracted delivering lead time for parts under contract management. High DIFO is targeted. As lead time tracking is key for MRO management, we propose monthly reporting for this KPI.

- **Completeness delivering rate** = number of complete deliveries from external suppliers/ total number of order. This KPI reflects whether suppliers are delivering completely or partially. Partial deliveries are undesirable as they create extra work. High completeness delivering rate is targeted. This KPI can be quarterly measured.
- **Average quantity per order line for replenishment orders for ABCs** = total bought quantities for replenishing stocks/ total number of replenishment order lines. This KPI reflects whether batching or one-to-one policy is used for replenishment. Average replenishment quantity per order line should be low for A (critical) and B (slow moving) items, and high for C items (fast moving). Quarterly measured average replenishment quantity is appropriate.
- **Emergency orders to external suppliers** = number of emergency orders / total number of orders send to external suppliers. This KPI reflects whether the MRO organization is requiring faster deliveries than what is agreed in contracts with supplier to deliver its client. Once the MRO client has specified its required response time and once vendor delivery time are managed and contracted accordingly, the number of emergency orders to suppliers should be limited. Low number of emergency orders is targeted and can be quarterly measured.
- **Emergency orders to external repair shop =** Number of emergency orders/ total number of orders sent to external repair shops. This KPI is similar with the previous KPI. The timing of external repair jobs must be managed, anticipated and communicated upon.
- **Number of external suppliers.** The lower the total number of external supplier for stocked and non stocked MRO items, the better the supply management regarding relationship, contract design, economies of scale. This KPI reflects whether strategic sourcing is in place. Strategic sourcing means that a high proportion of MRO codes can be delivered by a limited number of suppliers. Low total number of external suppliers is targeted. This KPI can be yearly measured.
- **Percentage of MRO codes having warehouse information =** number of codes having warehouse information/ total number of original codes**.** Whenever possible, a code should not be kept on stock at the local warehouse but should be available at the supplier site to lower inventories. Having spares on stock that to not need to be stocked is a loss of money. Low percentage of MRO codes having warehouse information is targeted and can be yearly measured.
- **Inventory levels for ABCs.** Inventory levels should be measured separately for A, B and C items as changes in A, B and C items inventory levels may not have the same causes. All inventory levels should be as low as possible for A and B items. For C items (i.e. high moving and low value), a balanced and optimal solution must be found between inventory cost and replenishment cost. The lowest inventory that strictly satisfies the client need might not be the best financial solution when summing inventory and replenishment cost. It will be cheaper to hold higher stock in average and to benefit from savings in batching. This KPI can be recorded on a quarterly basis.
- **Inventory value for ABCs.** This KPI completes the inventory level KPI. It can be quarterly measured
- **Replacement Asset Based RAB** = Average inventory level/value of running installed equipment**.** Replacement Asset Base is a common metric to measure the original value of an asset times a cost multiplier to bring it up to current year value. RAB is an approximation of the cost of replacing an asset. RAB of Dow maintenance activities in 2011 was about 2.5%. MRO RAB was slightly less than 1% which in a current value compared to visited MRO organization. RAB value depends of the industry sector. Yearly measured RAB seems appropriate. Low RAB is targeted.

- **Turnover for ABCs over a period of time**= Outgoing (or ingoing) quantities from stock over the period of time/ Average stock levels. For example if 2 items are kept on stock on average and if 4 items are going out of stock per year, turnover rate of this item is 0.5 year. The turnover can be seen as the average expected shelves stay of an item. Over time, outgoing and ingoing quantities from stock should compensate, hence either ingoing or outgoing quantities can be used in the turnover formula. Low turnover for A and B items are targeted: it is undesirable to have a lot of A items (i.e. critical) moving out of stock. B items as slow moving items should have a low turnover. C items as fast moving items will have high turnover. Turnover can be quarterly tracked.
- **Volume and value of issues from the warehouse for ABCs.** This KPI helps to keep track on what the MRO client are issuing from stock. Low volume, high value should be targeted for B items. High volume, low value is expected for C items. This KPI shows the demand for stocked MRO. Monthly reporting of volume and value of issues from stock is possible. This information is already reported every month from data extraction from the MRO management system. The remaining work is to aggregate information over A, B an C item types and track evolution over months, through visual plots for example.
- **Availability of stocks** = 100% - stockout rate. The formula we proposed in section 3.1.1 reveals how often and how long stockout occurs. Our definition of a stockout is from inventory management perspective. The inventory stockout may not lead to a maintenance problem if no order occur during the stockout time. High availability of stocks is targeted. Availability can be quarterly measured.
- **Stock accuracy for ABCs**= (positive adjustments + negative adjustments)/ checks. Stock accuracy can be measured in volume or in value. Stock accuracy shows how well the recorded stock levels and values represents what is really laying on the shelves. High stock accuracy is the target for all types of spares. High stock accuracy can be achieved through regular cycle counting and improvement actions, a closed managed warehouse and a strict movement recording process. We propose to record different stock accuracy targets for ABC items. A items as critical spares should receive more attention than other spares with highly frequent and exhaustive cycle counting and excellent stock accuracy. Cycle counting can be average frequent for B items and low frequent or randomly for C items with less strict accuracy targets. Yearly record of stock accuracy can be created.
- **Obsolescence rate over a period of time** = total number of MRO items becoming obsolete over a period of time/ total number of MRO items. An item becomes obsolete when the equipment(s) using the item is not used any more in the plant. Obsolete items might also come from projects ending. Within Terneuzen, potential obsolete are items that have not been issued since 6 years. Low obsolescence rate is targeted and can be yearly tracked.
- **Investment recovery.** Valuable obsolete and easy to sell back items should be sold back on the market for investment recovery purposes. The more money from investment recovery action, the best it is for the MRO organization. This KPI can be yearly measured.

G. Multi criteria ABC classification

Why to classify spare parts?

Spare part classification is vital to handle reality complexity by handling several less complex problems instead of the all management problem. Classification also allows to identify homogeneous groups of parts and identify strategies for each group. The MRO organization does not think and manage in the same way a expensive spare used once every five years and a cheap spare used several times a day. Classification decreases the complexity and allows simulation and automatic tools for facilitating and optimizing the inventory management problem. As argued by Huiskonen (2001) "we still have to choose control parameters, allocate control resources, make purchasing decisions, and think about different policies for different types of items. For this purpose, item classification is as important as ever." (p126). Figure 23 proposes control parameters to identify homogeneous groups of parts in a classification and shows impacts on logistics elements. An adequate spare part classification must identify homogeneous groups of parts. Each identified group will have its own characteristics (price, demand rate, criticality). The objective of a classification is to facilitate management: each category receives the attention it deserves and has its own strategy. The item category drives maintenance, inventory, purchasing activities etc.

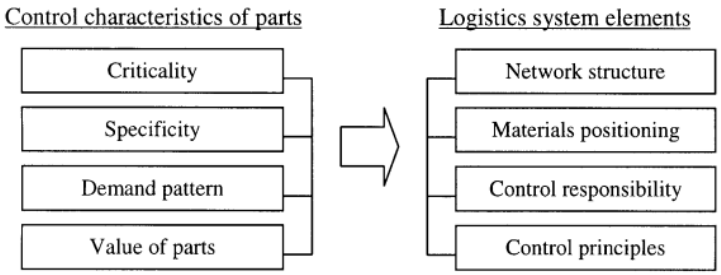

Figure 23 : relevant control characteristics and logistics system element from Huiskonen (2001)

Why ABC classification is adequate and helps MRO management?

The Pareto principle is the best way to achieve superior results with a minimum of investment of time by plant personnel as it allows to prioritize effort. By focusing on 20% of MROs, MRO organization will achieve 80% of results. Those high priority items will be classified as A. Type B items comes as second priority items and type C items as a lowest priority items. Huiskonen (2001) argues in favor of a multi-criteria classification: "The most well known, and perhaps the most commonly used classification scheme in logistics is the ABC-classification according to the Pareto-principle. It is easy to use, and serves well the inventory management of materials that are fairly homogenous in nature and differ from each other mainly by unit price and demand volume. There-fore, ABC-analysis has retained its popularity among the practitioners in directing the control efforts and choosing the sufficient-enough control parameters without the need of item-specific analysis. However, as the variety of control characteristics of items increases, the one-dimensional ABC-classification does not discriminate all the control requirements of different types of items. (...) Using several criteria as a basis for classification is especially useful for spare parts that do possess several distinctive characteristics other than price and demand volume. This has led researchers to suggest different types of multi-dimensional classifications for spare part inventory management" (p126). Hence, we define ABC multi-criteria classification as a best practice for inventory spare parts management. Used ABC within automatic systems are uni-criterion ABC classification based on one criteria such as demand rate, price or criticality etc.

Which multi-criteria ABC classification do we want?

The ABC classification we proposed is a classification arranged by descending order of importance. This importance is rated using several criteria: criticality, demand rate and price. The identified ABC items are:

- A items or high importance items. A items are critical items. We believe 20% of items can cause 80% of equipment downtime.
- B items or medium importance items. B items are non critical, low moving and expensive items. 40% of items could be rated as B and account for 15% of importance.
- C items or limited importance items. C items are non critical, fast moving and cheap items. 40% of items could be rated as B and account for 5% of importance.

Step 1: Identify A items i.e. critical

An item will be classified as an A item if it is rate as critical by at least one client. An item will be classified at A (i.e. critical, vital for the production) by a client if it satisfies **all** of the following criteria:

- It belongs to high critical equipment.
- The client response time is below the supplier (or repair) lead time. The client response time will be short when there is no alternative spare part for the broken part or no alternative production facility available. The supplier lead time will be high when the spare is a non-standard part that needs to be manufactured according to specifications.

So, to find its list of A spares i.e. critical spares, a client must:

- ✓ first identify the list of spares that fits in a high critical equipment. This list is a list of potentially critical spares.
- ✓ and then, from this list of potentially critical spares, identify the ones having a supplier lead time over the response time they need and require from MRO. It means that for each potentially critical spares, a client must question itself whether it can manage its business without this spare during the supplier lead time. If the answer is no, the potentially critical spare must be rated as critical and must be stocked next to the plant with a high availability service level. If the answer is yes, the potentially critical spare is not critical and so not classified as A.

This criticality analysis does not integrate demand or price aspects. Non-availability of non-critical spares does not cause immediate equipment downtime. Our criticality analysis takes into account the criticality of equipments measured based on impact and probability of occurrences scores; and the MRO supply chain constraints and lead time compare to the client response time.

Step 2: Among remaining items (i.e. non-critical ones), distinguish between B and C items

Among remaining items (i.e. non-critical ones), an item will be classified as C if the cumulative demand over last passed year excess a certain quantity. Otherwise it will be classified as a B item. 4 is an adequate cut off quantity for Dow data as over one year, around half codes are issues less than 4 times and half codes have been issued 4 or more. Figure 24 proves that high movers are also cheap items and that slow movers are also expensive items. Either a demand or price criteria is adequate to distinguish between B and C items. Classification will be similar for demand or price criterion, expect for the cheap and slow moving item area which is close to the origin in Figure 24. If a price criteria is adopted, we propose 200 € as a threshold value to have as many B as C items.

The current criterion to classify an item as high moving within the current MSMS system is the following: the item supplier price is below a certain value, the item must have at least a minimum number of yearly usage's in history, the item annual usage over past year must exceed a minimum quantity and the item must not have more than a set number of consecutive zero usage months. We do

not recommend such complex criteria that are difficult to handle. Cut off values should be adequate which is not the situation as almost no item is classified as high moving in the current MSMS system. This ABC classification given by steps 1 and 2 is a given input for the inventory management system. Figure 13 summarizes results on the ABC multi-criteria classification we propose.

Step 3: Keep your classification updated overtime to take into account client needs changes in MRO inventory management.

We recommend conducting critical assessment at the spare parts level every 5 years leading to changes changing from and to A category. Demand or price assessment can be conducted every year leading to changes from B to C and from C to B.

H. Inventory analysis: price vs. Demand, ABC demand, ABC pricing and fast movers analysis

To understand how diverse MRO items are, we plotted demand and price for each unique codes issued from the warehouse between 2007 and 2011. Results are presented in Figure 24. Demands were summed up over time and over original and repair codes. Average price over time and over original and repair values was computed. Unvalued issues from the data sample were removed. Issues from warehouse 6274D were also removed as errors from April and May 2009 excel reporting spreadsheets. In total 29.500 unique codes have been issued from the warehouse from Dow and Styron in 5 years. As Terneuzen has 47.000 unique codes having warehouse information, this means that more than 17.000 codes have not moved from stock since 2007. This figure is surprisingly high. Among 29.500 unique issued codes, more than 9.000 codes have an issue quantity that equals one. Top fast movers and top expensive items are not plotted in Figure 24 to keep information visible.

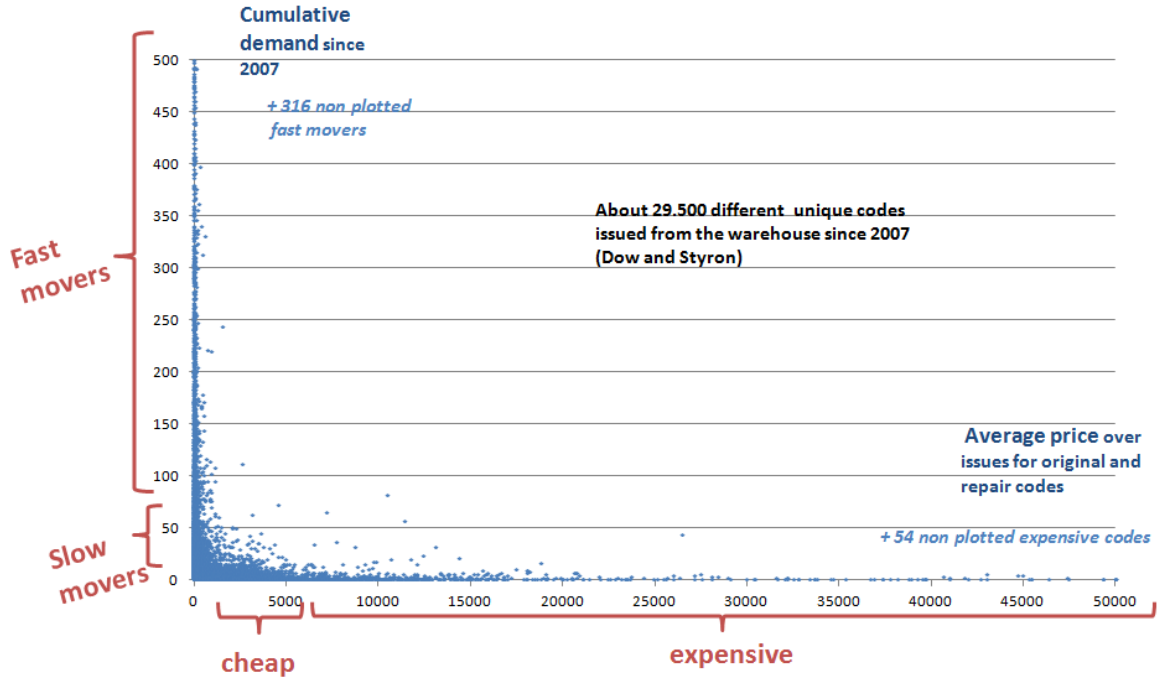

Figure 24 : diversity of codes issued from the warehouse at Dow Terneuzen.

This demand vs. price analysis for codes that have indeed been issued from the warehouse reveals how diverse MRO codes are: fast movers will be cheap items and expensive items will be slow moving items. Figure 25 and Figure 26 go a step further in the analysis through ABC demand and ABC pricing analysis, respectively.

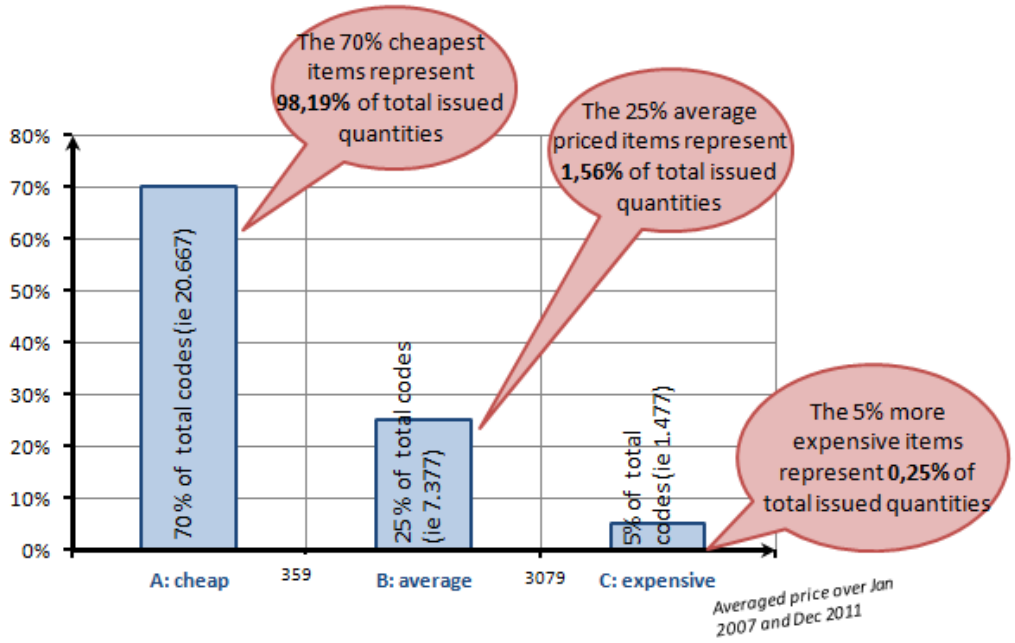

Figure 25 : ABC pricing for codes issued from the warehouse

Figure 25 shows the results of the ABC pricing analysis. 70% of codes are considered as cheap with a value less than 359€. Those 70% cheap codes represent almost all issues. The top 5% expensive codes are priced above 3079€ but will account for 0.25% of total issues quantities as they are slow moving items.

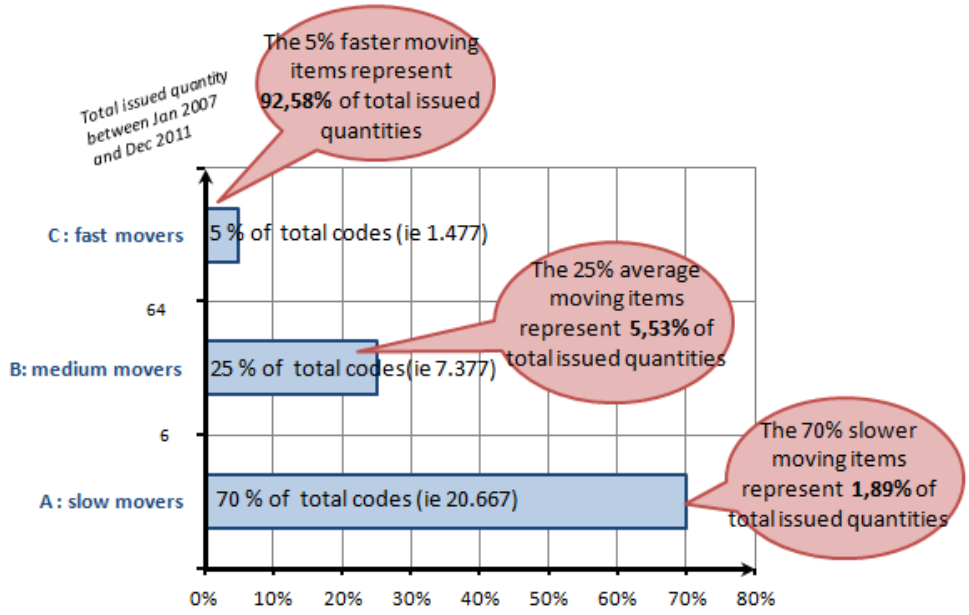

Figure 26 : demand ABC for codes issued from the warehouse

Figure 26 shows the results of the demand ABC analysis. 70% of codes are considered as slow movers with a cumulative demand over 5 years less than 6 total issued quantity. Those 70% slow moving items represent less than 2% of turnover. The top 5% fast movers codes have been issued more than 64 times and accounts for more than 90% of total turnover. The fact that 5% of codes are responsible of 90% of turnover is an interesting result. Figure 27 investigates further by showing the

cumulative turnover over the top 100 fast moving codes. 100 codes represent less than 0.5% of total codes.

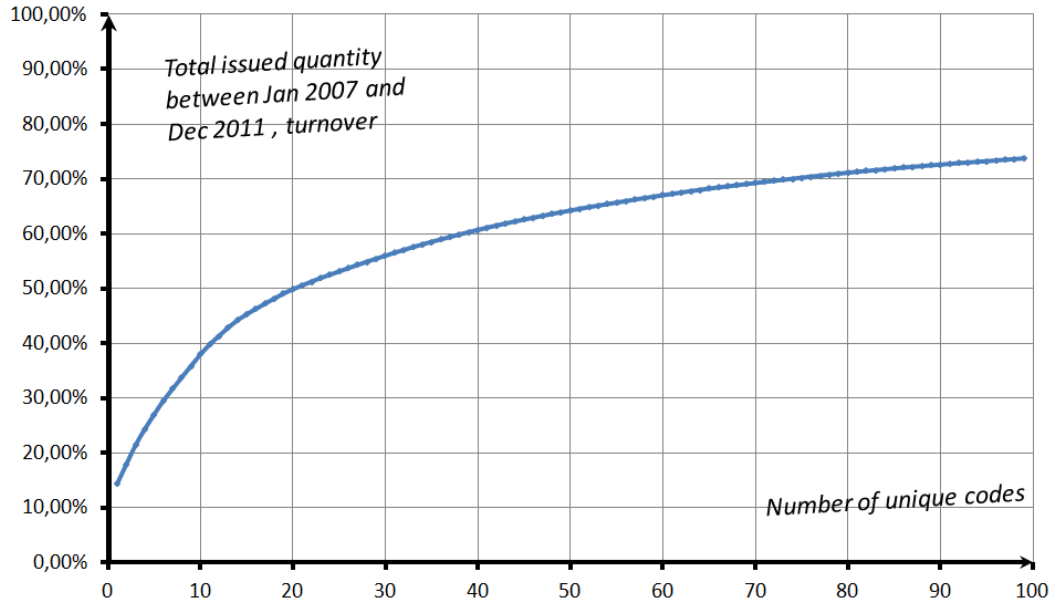

Figure 27 : demand ABC curve and fast movers analysis

Figure 27 shows the results on our analysis for top 100 fast moving items for Terneuzen warehouse. 1 unique code is responsible for 14% of turnover, 3 codes for 21%, 21 codes for 50%, 40 codes for 60%, etc, 2.834 for 95% and 29.521 for 100% of turnover. This fast moving analysis shows that a few items are responsible for large proportion of total warehouse turnover. It might be very valuable for Dow to have a fast moving program in place to ensure those items are located close to the client to avoid excessive transportation, to ensure they are well sourced and replenished in high volume batches. For example, among top 40 fast movers, 34 codes are managed through consignment stock which is rather a good result.

I. The outsourcing decisions

To support its MRO strategy and having the best MRO service at the best cost, a manufacturing company must take the decision to manage MRO in-house or to outsource it. This section addresses the following questions: What is outsourcing? Why would you consider outsourcing? What are the potential drawbacks of outsourcing? How to decide whether to outsource or not? How the strategy does impacts the outsourcing decision? How the management wishes impact the outsourcing process? What to outsource in MRO management? How to outsource? Answer to first sub research question is given.

What is outsourcing?

In general terms, we define outsourcing as a procurement activities of goods or services from outside organizations for goods or services that have been completed in-house in the past (Gilley,K.M.,& Rasheed,A., 2000). When the outsourcer firm decides to outsource goods of services, it might have the choice between outsourcing to the Original Equipment Manufacturer OEM or to a third party company. Applied to the MRO field, outsourcing to the OEM will be chosen when the machine is very specific and requires highly qualified specialized technicians such as for example, the machine manufacturing wafer in the semiconductor industry. Those industries are hardly encouraged to outsource the maintenance and MRO activities for those critical machines to the OEM that may sell them equipment availability. On the contrary, when the machines used are rather generic and common such as in the chemical industry, outsourcing will be done through Third Party Company. Total outsourcing MRO mean outsourcing the MRO function: MRO management will be handled by the third party company that takes over responsibility and ownership of MRO. Outsourcing MRO partially or totally must support maintenance activities through best MRO management: inventory optimization and logistics management, process improvement, management organization, specialized software and engineers; and consolidated and integrated supply chains. Grainer Integrated Supply is North America's leading business-to-business provider of MRO supplies, services and information. Brammer is the leading European MRO service provider.

Advantages of outsourcing

Why would you consider outsourcing?

On the one hand, outsourcing is an attractive strategy for an organization that wants to focus on its core competencies and outsourced peripheral activities that does not provide competitive advantage. Outsourcing those peripheral activities is a worthwhile decision if it allows achieving higher level of performance for the same cost of if it allows to lower the global cost while achieving the same performance level. The most important advantages of outsourcing are the following:

- **Cost improvements.** The outsourcing specialist could be able to deliver the service at a price lowest than the in-house cost. Unconsidering other aspects, outsourcing may be beneficial from a financial perspective if the required service is delivered at a lowest price. Moreover, in the short run, cost improvement could be even more important and comes to strengthen the outsourcing decisions by reduced investment in assets such as working capital (people, equipment, buildings etc). But those short run cost improvement should not be criteria when considering outsourcing as they do not provide long term savings and competitive advantage. Financial consequences of the outsourcing decisions must be assessed on a long term basis.
- **Increased flexibility.** Firms focusing on outsourcing can switch suppliers as new, more cost effective technologies become available. In addition, outsourcing allows for quick response to changes in the environment (Dess, G.G., Rasheed, A., McLaughlin, K., & Priem, R., 1995). In that sense, firms can rely on outsourcer to benefit from more efficient technology and increased flexibility.

- **Focus on core competencies.** By allowing outside specialist organizations to concentrate on certain tasks, firms may increase their performance by focusing more narrowly on the things they do best (Quinn, 1992). Then, outsourcing noncore activities is valuable. Before outsourcing non core activities to develop the core competencies, a firm should question itself in defining its core competencies.
- **Increased delivered service.** Outsourcing activities promotes competitions between outside suppliers. This competition ensures higher-quality of goods and services in the future (Kotabe, M., & Murray, J., 1990). Moreover, quality and service improvement may also be realized by outsourcer as they are considered as the best specialist in the world.
- **Reduced risks.** Outsourcing might be a way to transfer - or at least to share - the activity related risks to the outsourcing specialist. For example, outsourcing MRO inventory management will allow the outsourcer to get rid of risks related with obsolete items..

Disadvantages of outsourcing

What are the potential drawbacks of outsourcing?

On the other hand, outsourcing in-house activities also has disadvantages. Two identified disadvantages the following:

- **Reduced control.** When in-house performed activities are outsourced to a third party company, a risk of loss of control may exist if the appropriate monitoring and controlling tools are not put in place by the outsourcer. Those tools should measure the third party service performance at a high level. This measurement of the third party company can be done thought key performance indicators KPIs reporting and must be based on agreed services levels agreements SLAs. The outsourcer must keep control over the MRO business and spare parts availability to support its maintenance activities and prevent from costly downtime.
- **Loss of knowledge.** Outsourcing may reduce organizational innovation and may shift knowledge to supplier organizations (Bettis, R., Bradley, S., & Hamel, G., 1992). This transfer of knowledge can lead to a loss of long-run research and development competitiveness.

Criteria for considering the outsourcing decisions

How to decide whether to outsource or not?

From the two previous sections, we have seen that outsourcing has both advantages and disadvantages. Now that we have weighed the pros and the cons, it is needed to have a decision criterion when deciding to keep the activities in-house or to outsource. When examining the outsourcing decisions, the ultimate goal is to strive for long-run sustainable and competitive advantage. We argue there is two different ways to assess whether going for outsourcing of not. Below we propose two different criteria.

Criterion 1: Service performance criterion. For a given MRO budget constraint, if the third party company is able to achieve higher level of performance than the outsourcer company then the outsourcing decision is a worthwhile investment, otherwise it is not.

Criterion 2: Cost criterion. For a given and constrained level of performance, if the third party company is able to reach the desired performance at a total cost lower than the outsourcer company then the outsourcing decision is a worthwhile investment, otherwise it is not.

Both criteria require an appropriate scanning of the market suppliers. The selected market suppliers must be audited on both performance and price criteria. If the service performance criterion is used, then the best supplier is the one that achieve highest level of performance given the budget constraint. If the cost criterion is used, then the best supplier is the one that achieve the desired level of performance at the lowest price.

How the strategy does impacts the outsourcing decision?

Then the question that follows is: How to choose in between the two available criteria for outsourcing? We argue that the criterion selection depends of the organization strategy. If the organization has a function strategy, i.e. if it strives for the highest performance level given budget constraint, the service performance criteria is the adequate one. The function oriented organization will engage in outsourcing if it can achieve a better service given a predetermined budget constraint. On the contrary, we argue that the organization that has a business strategy, i.e. which strives for the lowest cost given service level constraint, will use the cost criteria when considering the outsourcing decision.

How the management wishes impact the outsourcing process? What is the situation for Dow MRO Terneuzen?

Dow MRO wants to have a business strategy. Then the cost criteria must be considered before outsourcing any MRO processes. Dow MRO must question itself. First of all they must set service level targets and assess their own organization to know whether they achieve the desired level of performance. If the desired levels of performance are already achieved, then the cost criterion for outsourcing is straightforward to use: for the same level of performance, the outsourcing is interesting if the third party cost is lower than the in-house cost. Then the MRO must know what the in-house cost is by assessing their budget cost and must know the third party cost by making a bid on the market. But if the current performance level is lower than the target levels, then the MRO organization needs to fulfil the gaps. In this situation, the organization needs to choose if they want to improve the service before outsourcing or let the improvement action to the outsourcing company. The cost criterion is less straightforward to use. If the MRO organization decides to improve before considering the outsourcing decision, then outsourcing is worthwhile if the price proposed by the outsourcing company is lower than the estimate future cost for performing the activities in-house. The estimate future cost includes the current cost and the costs for improvement. If the MRO organization wants to let the improvement actions to the outsourcing company then the cost criteria is used for the current situation and improvements must be agreed and contracted between the outsourcer and outsourcing companies. The decision tree depicted below summarizes the discussed steps. The decision tree also shows the symmetric path that a function oriented organization must follow.

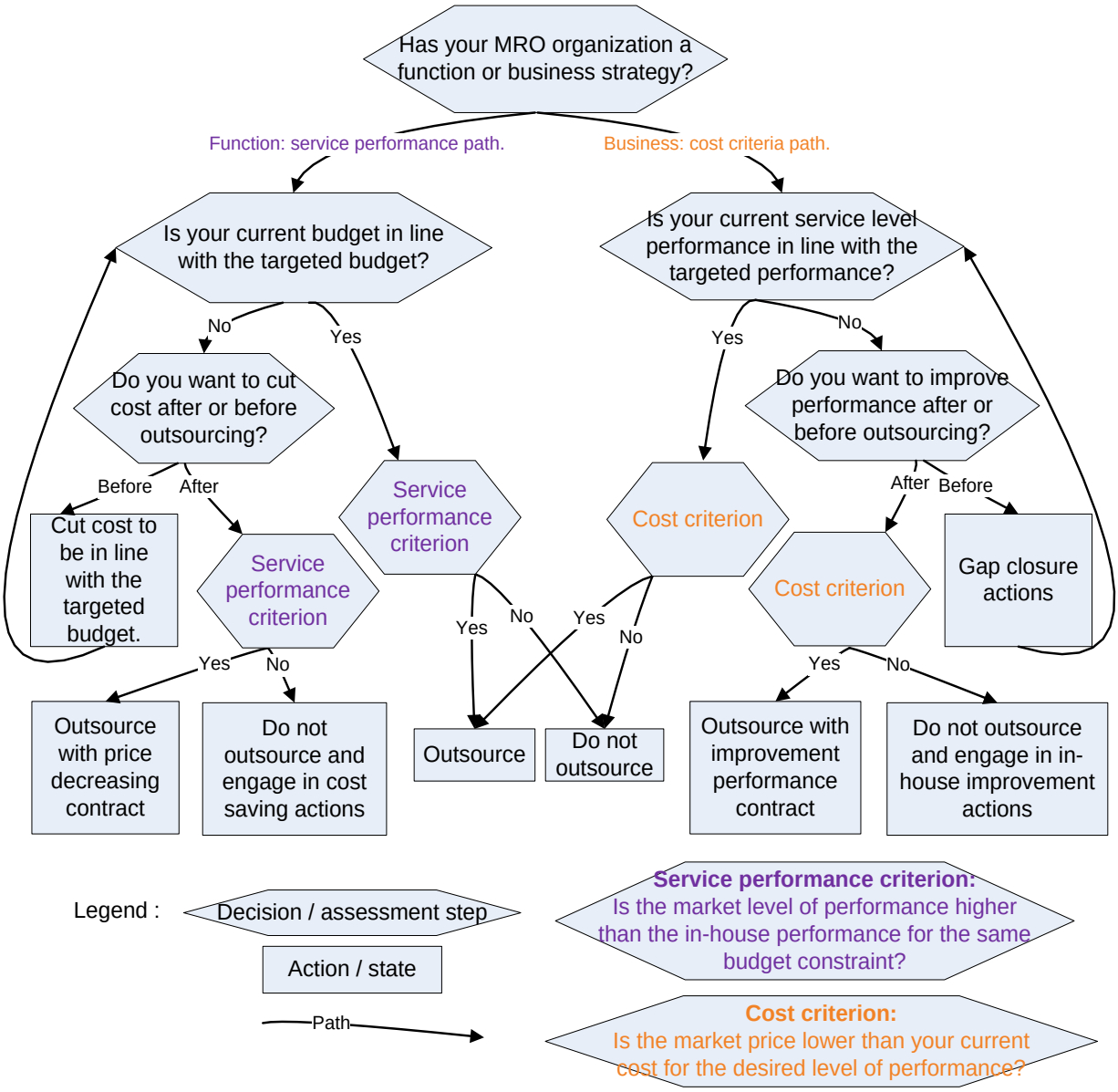

Figure 28 : The outsourcing decisions tree integrating the outsourcer strategy, situation and management desires

Whatever the decision path, the MRO business oriented organization needs to set service targets, to assess the current level of performance, and to investigate the in-house cost as well as outsourcing price and performance proposed by third party companies

Degree of outsourcing in MRO management: what and how to outsource MRO processes?

In the previous discussion, we had a global look on the overall MRO organization. The outsourcing decision tree was valid while considering the MRO as an indivisible entity. Indeed, the service level and cost criteria are based on overall assessment of the MRO. As a global look on MRO, we include all processes described in Driessen et al (2010) framework. Figure 6 reminds those processes. But, one may want to outsource only a portion or processes related with MRO. For example, Dow already made the choice to outsource the spare parts order handling process to Ceva logistics and will outsource its four repair shops in the near future. But all other MRO processes such are inventory management; supply management and assortment management are currently conducted within Dow.

In this section, we are going further in our investigation by wondering which MRO processes can be outsourced. Indeed, once the outsourcing decision is taken at a high level, we need to know what and how to outsource at the process level. This refers to the degree of outsourcing. According to Gilley (2000), the outsourcing strategy has two key dimensions. In other words, the outsourcing intensity is measured trough two dimensions that must be examine in tandem. The first dimension of outsourcing strategy is the breadth. Gilley (2000) defines breadth as the number of activities outsourced as a percentage of the total number of activities in which the firm would engage. Breadth refers to the "what" question. Applied to the MRO field, the breadth dimension of outsourcing strategy measures which MRO-related processes are outsourced. Driessen et al. (2000) identified processes are reminded in figure 6. The second dimension of outsourcing strategy is the depth. Gilley (2000) defines depth as the extent to which a firm outsources a higher portion of that activity on average. Depth refers to the "how" question that will be discussed in a few paragraphs. Breadth and depth examined in tandem reveal the outsourcing intensity and reflect the firm's overall reliance on outsourcing.

Which MRO processes could be outsourced?

What to outsource in MRO management? The breath dimension of outsourcing strategy.

One may wonder why it is not possible to apply the outsourcing decision process described in Figure 11 to each MRO process separately. We see at least two reasons that impede us to do so. The first one is the difficulty -or even impossibility- to assess each process from financial and performance perspective. Both budget and performance levels are needed inputs in the outsourcing choice we previously described. The second difficulty comes from the dynamic interactions and interconnections in-between processes. For some processes, it might not be possible to handle them within different firms are they are to dependant from each other. For example, the organization responsible for the inventory control and management process should also be responsible for the demand forecasting process. It appears difficult to split them. In this philosophy, we propose a way to outsource the MRO management in a certain manner. As Dow case shows us, it is possible to outsource the spare parts handling process to a third party company as well as the repair shop control. Indeed, this spare parts order handling process can be decoupled from the remaining MRO management. As a remainder this process consists of the following steps: accept, adjust or reject the order, release spare parts on the order, and handle return order of failed repairables. Within Dow, this process has been outsourced to Ceva Logistics. The repair shop control can also be outsourced separately from other processes. When outsourcing the repair shop activities, information flow to inform the inventory control group on the parts being repair –quantity and expected return time- must be managed. The deployment process concerns the process of replenishing spare parts inventories using different parameters than those advised by the inventory policies and consists of defining the preconditions order process and managing procurement and repair orders. As such, we believe outsourcing deployment come in pairs with outsourcing supply management, inventory control or repair shop control. Inventory control decisions concern which spare parts to keep in stock, at which stocking location, in which quantities and how to replenish. We believe outsourcing inventory control and management is possible. But the outsourcing firm responsible for the inventory might require keeping under its responsibility key and crucial input processes for inventory management such as demand forecasting, parts return forecasting as well as supply management. This is the reason why we propose to group those four MRO processes when outsourcing inventory management. Last MRO process is assortment management i.e. decisions to set the spare parts lists and to maintain technical information on it. We do not recommend to any firm to outsource this MRO process as defining the spare part lists and gathering technical information - such as criticality, redundancy, commonality, specificity, substitution, shelf life, position in the configuration (or indenture level), repairability, type of supplier contract and expected supplier price - is business dependant and specific. But a firm can still make use of tool such as IHS

Intermat solutions for example in order to have a consistent MRO catalogue with complete and standardized descriptions as well as uniqueness of item codes over sites and suppliers. Assortment management is the starting point of MRO management as MRO catalogue information are needed in all other MRO processes. Figure 29 summarizes which MRO processes could be outsourced and how to group them in the outsourcing process and which processes we do not recommend to outsource.

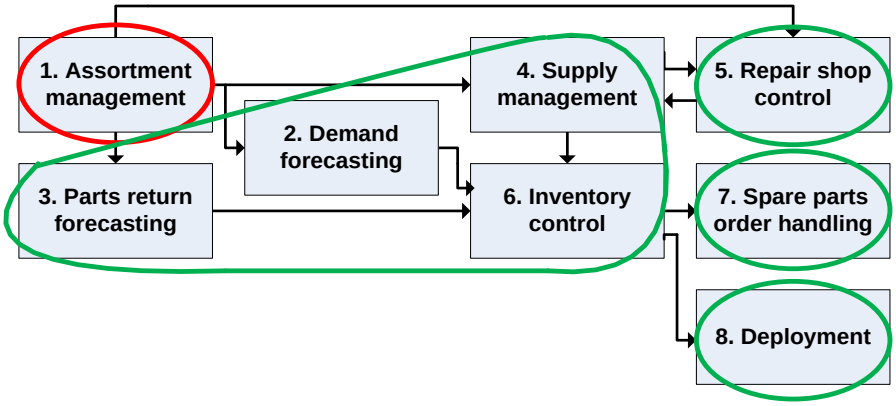

Figure 29 : Outsourcing proposition for MRO processes.

Moreover, it should be pointed out the drawback of a mixed outsourcing strategy. Indeed, companies that experienced a mixed strategy, i.e. outsourcing some processes and keeping other in-house, faced issued in seaming operations across processes and re-examine the case for in-sourcing. As a conclusion, when a firm decides to go for a mixed outsourcing strategy in outsourcing only some MRO processes, it is crucial to also monitor the links in-between processes to successful outsource.

How the MRO processes could be outsourced?

How to outsource? The depth dimension of outsourcing strategy.

Once a firm has decided which MRO processes to outsource and after selecting the third party company, the outsourcer must set the outsourcing contract and questions itself on how to outsource. This "how" question refers to the depth outsourcing dimension. As pointed out by Hertz et al. (2011) the service contract design has a major impact on the performance that has to be delivered in service execution and the revenues that are generated. Different types of business models affect the contract design in the scope of services offered. While some maintenance contracts (function-orientated use model) guarantee the functionality of a product for a certain time period, more advanced contracts (availability-orientated use model) guarantee the usability of a machine to a certain level (Meier, H.,Roy, R., & Seliger,, 2010).This concept includes a transition of a part of the production risks to the service provider. When choosing and negotiating the contract type many factors have to be considered as for example price competition, cost analysis, type and complexity of the requirement, urgency of the requirement, period of performance or length of production run, etc. (Roy, R., & Cheruvu, K. S. , 2009)

First key contracted element is the price or pricing mechanism. Most of outsourcing contracts have a mixed cost structure spilt over variable and fixed cost. Variable costs are for example tariffs for labor and spare parts service execution for each service execution. Variable cost with its charging mechanism reflects a transaction-based relationship between the outsourcer and outsourcing firm. This transaction-based relationship is opposed with relationship-based exchanges i.e. trustful relationship. Relationship-based contract will have a higher proportion of fixed cost. The trigger for a change of relationship from transaction-based to relationship-based is the desire of the third party company to optimize their use of installed products over an agreed period while benefiting from less

administrative effort and price reduction. However, the outsourcer firm may prefer a transaction-based pricing based on the transaction volume to be more flexible and agile. By outsourcing with a transaction based relationship, a MRO organization will move its cost structure from a fixed cost structure, when in activities were perform in-house, to variable cost structure. This change from a fixed to variable cost structure is interesting in a business perspective.

Second key contracted element is the service performance level. Service level agreements SLAs must be contracted to set clear target and expectations of both parties. Those contracted SLAs must be translated into Key performance indicators KPIs, such as inventory level or parts availability for example, in order to track and monitor performance. Trough SLAs and KPIs, both parties will manage MRO and obtain the desired outcome cost-effectively.

Depending of the type of contract and current situation in the outsourcer firm – for more details we refer to Figure 11 – targets for cost saving or performance improvement on some KPIs can be set in the contract based on an yearly or quarterly basis. Risk and gain sharing models included in the contract though bonus and penalty schemes are also important to include in the contract. Risk and reward sharing ensure aligned interests of both parties and commitment to measure performance gains. Risk and gain sharing model must be discussed and set during the contract design phase at the same level than price and service levels.

Other important agreed topics to be contracted are the response time, the interface management system, the assessment and monitoring tools as well as the execution and decision processes.

In a nutshell, the contract design with its agreed SLAs, KPIs, cost structure, response time, gain and risk sharing model etc will reflect the depth dimension of the outsourcing strategy for the outsourced processes. For example, in inventory management outsourcing, consignment can be seen as a first level in the outsourcing strategy, Vendor Managed Inventory VMI as a second level.

Drivers, conditions and key success factors in outsourcing MRO

From previous section, we now know:

- advantages and disadvantages of outsourcing;
- cost and performance criterion when choosing to engage in outsourcing;
- how the MRO strategy, current situation and management desires influence the outsourcing decision process and contract design;
- and which MRO processes could be outsourced and how those are outsourced i.e. what the key contracted elements are.

In the coming and latest outsourcing section, we are investigating the contextual drivers and conditions that impact the success of outsourcing. The identified influential elements of outsourcing success are:

- **The firm and MRO settled strategy.**

In his survey, Gilley (2000) proposes two firm strategies: having a cost leadership or pursuing an innovative differentiation strategy. He shows that outsourcing lead to higher financial and innovative performance for firms having a cost leadership strategy. He finds similar results for innovative differentiators. Then we conclude that the firm and MRO settled strategy does not impact the success of outsourcing. However, as explained in Figure 28, the MRO strategy impacts the decision path process for outsourcing.

- **The firm and MRO business size.**

We argue that the firm and MRO business size are drivers that condition the choice to engage in outsourcing. The bigger the firm, the more and diversified MROs are needed to support the

maintenance activities. Complexity rises with the firm and MRO size which will lead, at a certain point, to the need to engage in outsourcing to benefit from specific and specialized tools and experts to handle this complexity proposed by Third Party Company. We argue that the interest to engage in outsourcing increases with the firm and MRO business size. As Dow Terneuzen is an important site, this might prompt in outsourcing MRO.

- **The MRO client environment.**

When a MRO organization does not only supply one company –the one it belongs to- but supplies several companies, we argue that the chance to engage in outsourcing is higher as it gives more credibility. Dow MRO in Terneuzen supplies both Dow and Styron. It might be more credible from Styron perspective to have MRO service delivered by a Third Party Company rather than his counterpart.

- **Future firm and MRO growth opportunities.**

The more growth opportunity in terms of organization size and number of clients for the MRO organization, the more interesting to outsource MRO processes. Argumentation comes from two previous explanations. The maintenance value park represents a growth opportunity as the MRO supply surrounding companies. The interest of outsourcing is higher with the maintenance value park perspective.

- **The MRO current and targeted cost and performance levels.**

As discussed in Figure 28, the in-house and market achieved financial and service performances compared to the set target will be the criteria for engaging in outsourcing. For example, the best the market financial and service performance compared the in-house organization, the more chance to engage in outsourcing.

- **The management wishes.**

When a firm does not achieve the targeted financial and performance levels, the management wish to close this gap in-house might postpone the outsourcing decision and process.

- **The level of environment dynamism on the MRO market.**

We could argue that the benefit of outsourcing is higher in dynamic environment as the outsourcer might quickly benefit from new technologies via its third party company. An environment is dynamic when the market player number is high, technology changes and innovation is there. However, Gilley's study (2000) shows that the benefit of outsourcing is better in stable environment and worse in dynamic environment. We can explain this result by the high (re)negotiating cost in dynamic environment.

Conclusion

We have weighed the pros and the cons of the outsourcing decisions. We also proposed a step-by-step decision process in deciding to engage in outsourcing that takes into account the MRO strategy (business or function) and MRO and market financial and service performance levels. We proposed to group certain MRO processes from Driessen et al. (2010) framework in the outsourcing process and we do not recommend to outsource assortment management. To know how to outsource MRO processes, we discussed key elements that must be set in the contract design phase. Moreover, we investigated environment conditions that impacts on the probability to engage in outsourcing MRO processes.

Applied to Dow MRO Terneuzen business case, our decision shows us that Dow first need to set performance target and assess the current achieved performance. If the MRO market is able to deliver the same -or better- performance that the one achieved in-house at a lowest cost, then it is wise to engage in outsourcing. In Dow case, environment factors pushes forward for outsourcing as the

business is important, the MRO supplies more than one company, the growth perspective are good regarding the maintenance value park.

In a report, Kranenburg (2006) notices that in most situations, the maintenance spare parts service is provided by another party than the owner of the equipment. This means that outsourcing of MRO applies in most cases. When corrective maintenance activities are outsourced to a third party, he explains how the owner of the equipment and the service provider agree upon a certain expected performance level in a contract, the service level agreement: "Performance requirements in the service level agreement typically specify constraints on the (expected) system availability, i.e., constraints on the availability of the equipment at the customer. Either a minimum required (expected) up-time of machines, or directly related measures are used. Given these system availability constraints, the service provider aims to minimize its total cost." (Kranenburg, 2006, p14). The same hold for MRO outsourcing but the service level agreement will be based on the spare parts availability.

When engaging in MRO outsourcing, a firm must take care of the following key aspects and success factor: contract design with pricing mechanism, service levels agreements, risk and gain sharing model etc but as well monitoring of the third party company activities through relevant key performance indicators and reporting. Trustful relationship is latest ingredient to make the outsourcing story a success story. Outsourcing should be a win-win situation for both engaged parties. Within Dow, the Discipline Activity Specialist is the right role that must takes the responsibility for monitoring of MRO outsourced processes. Before deciding whether outsourcing of MRO processes adds value to Dow, first step must be to assess the MRO organization from a both performance and financial perspective.

J. Description of possible inventory management policies

Parameters definition:

- S: order-up-to level
- Q: fixed order quantity
- R: fixed ordering interval
- s: re-order point

Possible Inventory management policies:

- (R,S): periodic review with fixed ordering interval and order-up-to level
- (R,Q): periodic review with fixed ordering interval and fixed ordering quantity know as the economic order quantity (EOQ) model
- (s,Q): continuous review with fixed re-order point and fixed ordering quantity
- (s,S): continuous review with fixed re-order point and order-up-to level
- (S-1,S): continuous review and order-up-to level in a one-for-one replenishment mode
- (R,s,S): periodic review with fixed re-order point and order-up-to level : every R, if the inventory level is less than or equals to s, order such that the inventory position at least equal to S
- (R,s,Q): periodic review with fixed re-order point and order quantity: every R, if the inventory is less than or equals to s, order Q

K. Visited companies in Terneuzen surrounding

For defining best in class MRO organization and associated best practices, Dow MRO discipline activity specialist and I have lead interviews to several MRO managers across companies in Terneuzen surrounding. The interviews were semi-guided interviews. Questions addressing different topics and to discuss all MRO processes were prepared. For details on the list of addressed questions, we refer to the end of this Appendix. During discussions, MRO managers were really open and willing to share problems and knowledge with their Dow MRO manager peer. From the openness and enthusiasm of interviewed MRO managers, we see room for creating MRO networking to allow discussion on MRO issues and solutions. Most companies managing MRO face the same issues regarding coding, data quality, management of obsolete items, inventory optimization etc. Sharing practical knowledge could bring a lot to those companies. MRO networking across companies might be a first step in pooling inventories or services (purchasing, repairing, etc) in-between companies. *Figure 30* shows which companies we visited and their location.

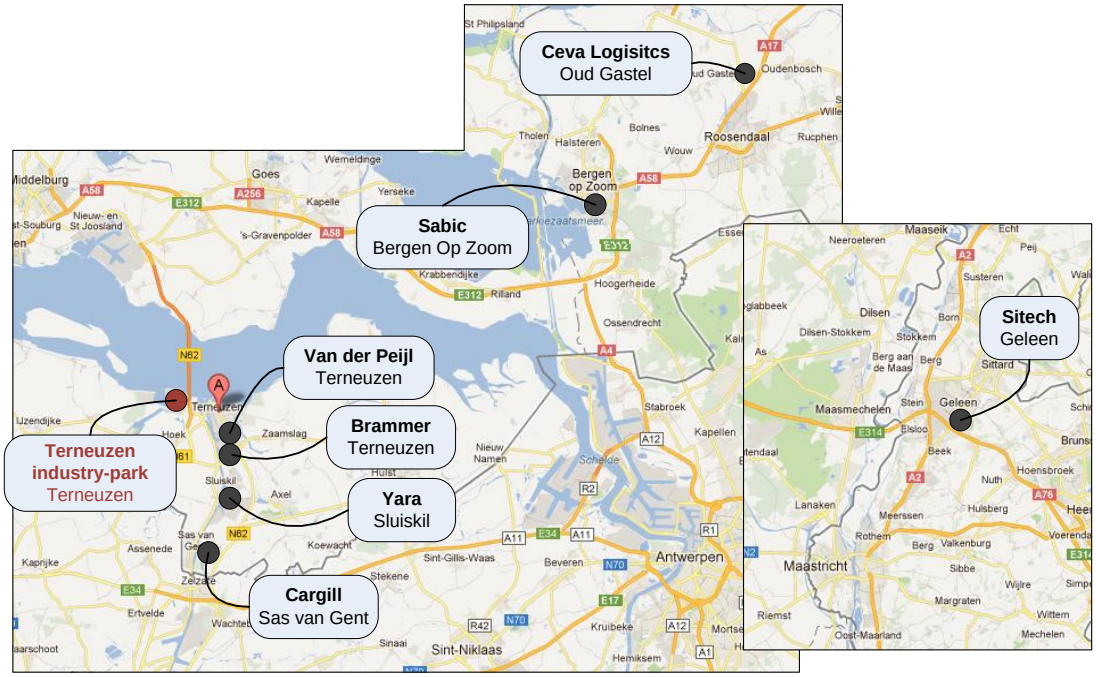

Figure 30 : Interviewed companies in Terneuzen surroundings.

We briefly give key output of interviews. Addressed questions during the interview are detailed at the end of this Appendix.

- **Brammer**

Brammer is the European leader in distribution of mechanical MROs. For each client, Brammer works in close cooperation to understand the clients business and needs. Value proposition, cost saving program, service levels, keys performance indicators are then agreed and contracted.

- **Cargill**

Critical and expensive spares are shared and managed globally over sites, at the continent level. A project has been initiated to have visibility over Lille, Gent and Bergen op Zoom sites to pool inventories in a virtual warehouse. Pooling inventories first require sharing coding. As many other companies, they do not have service levels agreements in place for MRO. However, they measure their performance thanks to some key performance indicators KPIS: return asset base, turnover for each group of parts, number of suppliers, and number of adjustments in stock. The adopted MRO

classification is identical with the multi-criteria ABC classification we propose as a best practice. For replenishing stocks, order points and order quantities are computed from historical data.

- **Ceva Logistics**

Ceva Logistics is providing logistic services to Dow for the MRO business: they are responsible for the receiving of MRO from suppliers and stocking of goods. They also take care of all transportation from the warehouse to the MRO clients, and from and to internal repair shops. Oud Gastel site is a multi user site from which they supply several companies, most of them being retailers. For Ceva, Dow MRO business is specific due to the specific MRO needs and non conventional shape of MRO items. Ceva Logistics is providing services to Dow from Sluiskil site.

- **Sitech (DSM service provider in Chemelot industry-park)**

Sitech is a new company created in 2005 by DSM. Sitech is DSM service provider in Chemelot industry-park, located in Geleen, nearby Maastricht. Among provided services are maintenance, purchasing and MRO activities. We selected Sitech as a company to interview as it was valuable to understand differences and similarities for MRO management in Chemelot and Terneuzen chemical industry-parks. For spares, they specify whether the spare should be available and stocked at the plant, at the warehouse or at the supplier level. The more critical the spare is, the closest to the plant. They face challenges in sharing inventories in-between plants.

- **Sabic**

The MRO Sabic organization in Bergen Op Zoom succeed to have a very low return rate (less than 1%) thanks to a good planning work process and to reliability history building history on returns. They have a very high stock accuracy thanks to a closed managed warehouse and specific cycle counting programs in place. No spare parts classification has been adopted within the organization. Repairable items are flagged as repairable in the system. In the future, their MRO organization wants to have unique global descriptions over their European sites to be able to pool inventories over sites. They want to move from a decentralized control to a centralized control of all their sites thanks to virtual warehouse idea.

- **Van der Peijl**

Van der Peijl is a local MRO vendor that supplies common and generic spares to local companies, among Dow. Dow orders MRO electronically, thanks to a communication platform. Delivery date and price are agreed and contracted. They have no SLAs or KPIs in place. However, they daily track availability of stocked items, number of outstanding and outstanding deliveries. Investment recovery process is in place with suppliers. Replenishment parameters for fast movers are based on demand forecast. Stock levels and replenishment parameters for slow moving items are set manually, based on the contracted customer needs. In case of an allocation issue over customers, a first in first out rule applies.

- **Yara**

Yara share a few common spares over their sites in Sluiskil and another Yara site in Germany. Critical spares are stocked on site, non-critical spares remains at the original equipment manufacturer OEM location. The MRO response time to the business is 3 days if the spare is on stock, about 1 week if not on stock. A quality control and inspection is in place for in and out warehouse movements. They face difficulties in managing and tracking supplier delivery time as well lead time of external repair shops. They are currently working on a project with Accenture for parts optimization on a tool to recodify and classify parts, including criticality.

Questions addressed to MRO leaders:

Those questions were adapted for interviews within Ceva logistics, Brammer and Van der Peijl.

General questions:

1. The MRO environment
   - **1.1.** The MRO across your sites: Are the stocking sites near the manufacturing site? How many? Do they all have the same status or are they global vs. local warehouses? Global or local processes? Centralized or decentralized control?
   - **1.2.** The client for the MRO business: Who does one MRO entity serve? One of several businesses within your company? One or several company?

2. Strategy for MRO, MRO seen at a high level:
   - **2.1.** What is the strategy for the MRO organization?
   - **2.2.** How the MRO and the remaining maintenance organizations are interconnected/ disconnected?

3. The size of your MRO business:
   - **3.1.** How many parts do you keep on stock? (Which corresponding value?)
   - **3.2.** What is your RAB return asset base?
   - **3.3.** How many do you issue from stock to the plant each year in number? (And in value?)
   - **3.4.** How many are returned from the plant each year in number? (And in value?)
   - **3.5.** How many parts are thrown each year because they are obsolete? Do you have a slow moving program? Do you have counting cycle? Among those obsolete parts, how many do you sell in investment recovery purposes?
   - **3.6.** Can we deduce your turnover?

4. Overall performance for the MRO:
   - **4.1.** Do you measure the MRO delivered service? If yes, how? (E.g. availability, response time, overall cost, spare parts inventory turns, percentage of parts that become obsolete each year, quality, response time, price…) Do you have KPIs in place to assess the MRO performance? Targets?
   - **4.2.** Do you prioritize MRO objectives?

5. Which processes for the MRO? assortmenent management, demand forecasting, parts return forecasting, supply management, repair shop control, inventory control, spare parts order handling, and deployment ?
   - **5.1.** What are you main processes? How do you decouple the MRO management problem?
   - **5.2.** How do you assess those processes? Do you have KPIs in place for each of them?
   - **5.3.** Do you outsource some processes? Why? How?

6. Critical assessment. How to overcome issues and improving?
   - **6.1.** Which problems do you face in practice?
   - **6.2.** What would you like to improve and how?
   - **6.3.** How high would you rate your MRO organization on a scale from 0-Stone Age to 10-state of the art? What do you miss to be state of the art?
   - **6.4.** Do you share spare part stocks with other companies?

If Yes: How do you set stock levels? How do you face responsibilities issues? Do you have rules for allocation problems? Do you make service differentiation across clients?
If no: Would you be willing to share stocks and/or processes/resources with other companies having the same spare parts than you if it allows economies of scale and cost savings?

Specific questions related with different processes: in an ideal world… Some or even many questions might not find direct answers. If so, the interesting point will be to understand why those questions are not directly addressed and solved.

1. Assortment management: the decisions to have or not data on a given spare part and to maintain technical information on it
- **1.1.** How do you decide on which spare parts you keep information i.e. is a given part is included in the assortment or not? Rules of thumb on cost, failure rates, criticality aspects?
- **1.2.** How do you gather and maintain technical information for the parts included in the assortment? E.g. of technical information: criticality, redundancy, commonality, specificity, substitution, shelf life, position in the configuration (or indenture level), reparability, type of supplier contract, expected supplier price, risk of obsolescence, stocking conditions.
- **1.3.** Is a code unique for a spare part over suppliers, over businesses, over sites etc?

2. Demand Forecasting:
- **2.1.** Do you have a method to forecast the demand of spare parts?
- **2.2.** If yes, does this method use historical data or know future demand from preventive maintenance activities or a combination of both? For planned demand, do you forecast only for expensive items? For unplanned demand, do you use inter-arrival rate and variability to choose the appropriate forecast method?
- **2.3.** Do you use of the following forecasting method: reliability based forecasting i.e. using failure rates and operating conditions or time series based forecasting i.e. using historical data and statistics?
- **2.4.** Which processes make use of this forecasting input? Purchasing, inventory management, supply management, etc?

3. Parts return forecasting:
- **3.1.** How do you manage with the retuned parts from the plants? Do you have specific procedures?
- **3.2.** Do you forecast this return flow?
- **3.3.** Do you have agreed hand in time or do you forecast the return time?

4. Supply management:
- **4.1.** Which are your types of supplies among external supplier, internal repair shop, external repair shop and re-use of parts?
- **4.2.** Which are the decisions criteria used to select the supply source among repair or procurement costs, costs of the contract, costs of the repair shop capability and resources and inventory holding cost?
- **4.3.** When choosing between repair a part or buying a new one i.e. determining if the part is repairable or not (consumable), do you conduct a level-of-repair-analysis (LORA) upfront?
- **4.4.** How do you maintain information on suppliers characteristics such as historical prices, discount quantities, repair or procurement agreed lead time, type of contract, minimum order quantities and multiple quantities?

4.5. In particular for the repair time agreed with the repair shop and the procurement lead time contracted with the supplier?

5. Repair shop control:

5.1. How do you decouple the repair shop from the remaining MRO organization? Is there both agreed lead time and workload per unit of time?

5.2. At a tactical level, how do you determine the capacity of the repair shop in terms of machines, tools and numbers of employees and shifts? Are those capacity decisions based upon the estimated repair workload and variability from demand and parts return forecasting?

5.3. At the operational level, how do you schedule the jobs so that they meet their due date? Ho decides the due date? What drives the due date? Which objective, model, priority rules for the repair jobs?

6. Inventory control:

6.1. Which spare parts classification do you use? Which criteria: slow moving vs. high moving, expensive vs. cheap, generic vs. specific, repairable vs. consumable, critical vs. non critical etc? Which cut off value(s) for the used criteria? Do you have an ABC classification?

6.2. In particular, do you use the criticality criteria? If yes, which method do you use to assess the criticality level of a part?

6.3. From this classification, which strategy and replenishment policy for each homogeneous group of parts?

6.4. How do you determine the replenishment policy parameters i.e. frequency of replenishment, order quantities and safety stocks? When do you replenish when a spare has been issued?

6.5. How do you characterize the environment for the inventory control i.e. single or multi echelon, numbers of locations, numbers of items, multi indenture structure or not with its degree of complexity, emergency shipments and lateral transshipments used or not, multiple service criteria, budget constraint?

6.6. How do you tackle obsolescence issues within the warehouse?

6.7. Do you make use of simulation tools for assessing and choosing your replenishment policies and parameters?

6.8. How do you optimize the spare parts stocks?

6.9. How accurate is your stock?

6.10. Who is responsible for the stocks?

7. Spare parts order handling: this process concerns the following topic: accept, adjust or reject the order from the maintenance organization for planned and unplanned job, release spare parts on the order, and handle return order of failed repairable spares.

7.1. With the remaining maintenance organization, do you have agreements on order quantities, order priority, order lead times?

7.2. When does the MRO adjust in time and/or quantity an order coming from the maintenance?

7.3. Objective criteria for accepting or rejecting an order? Is the acceptance step done manually or automatically?

8. Deployment: concern the disregard by manager of automatically generated advises.

8.1. Several reasons for deployment as new information available, exceptional order means deployment should be the exception. How often do you use deployment?

8.2. Is there a feedback loop for adapting the forecast for example when deployment occurs?

L. Dow Global Maintenance Work Process GMWP

This Appendix is an extract from Dow GMWP and shows the GMWP architecture and where and how MRO is involved.

A.0. Establish maintenance strategy
0.0. Improve reliability
1.0. Create value added work order
2.0. Plan and schedule maintenance
    2.1. Plan Job
        2.1.10. Identify equipment/material requirements
    2.2. Obtain material
        2.2.3. All material availability confirmed?
    2.3. Schedule Job
3.0. Do maintenance
4.0. Setup, assess & evaluate PPM & MRO program
    4.1. Setup PPM & MRO program
        4.1.1. Setup MRO & PPM inspection plans
    4.2. Condition assessment
    4.3. Evaluate PPM & MRO programs for effectiveness
        4.3.2. Evaluate spare parts requirements
    4.4. Spare part determination
        4.4.8. Perform risk assessment review and determine MRO strategy to be followed
5.0. MRO
    5.1. Manage inventory addition request
    5.2. Manage existing inventory
        5.2.2. Maintain existing inventory
            5.2.2.2. Slow moving process
    5.3. Issue & return process
    5.4. Stock take
    5.5. Inventory receipts