Analysis of the Modernization Process of Automated Storage and Retrieval Systems

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Preface

The present work was written under the scientific and content-related guidance of Josef Xu M. Sc., research associate at the Chair of Materials Handling, Material Flow, Logistics (fml) at the Technical University of Munich

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Abbreviations

Abbreviation	Meaning
ASRS	Automated Storage and Retrieval Systems
BPEL	Business Process Execution Language
BPMI	Business Process Management Initiative
BPMN	Business Process Model Notation
CUA	Cost-Use Analysis
DIN	German Institute for Standardization
DMP	Decision-Making Process
e.g.	exempli gratia
EPC	Event-driven Process Chain
et al.	Et alii
etc.	Et cetera
FEM	European Materials Handling Federation
fml	Chair of Materials Handling, Material Flow, Logistics
i.e.	id est
OEM	Original Equipment Manufacturer
OMG	Object Management Group
PLC	Programmable Logic Controller
PMBOK	Project Management Body of Knowledge

SRM	Storage and Retrieval Machine
TUM	Technical University of Munich
RIP	Retrofit Implementation Plan
UML	Unified Modeling Language
VDI	Association of German Engineers

1 Introduction

1.1 Initial Situation

There are numerous reasons that lead warehouse operators to automate their facilities. Being technological and economical aspects decisive for the design and operation of material flow systems, companies search for higher system performances, costs saving, quality assurance, minimize human intervention or a smooth functioning of their material flow. [Hom-2008]

Among the different available resources used in intralogistics operations, automated storage and retrieval systems (ASRS) are one ideal and widely used solution for carrying out such processes in warehouses where the need of high system availability requires a relatively high degree of automation. Technology is constantly evolving at a high pace and automated storage and retrieval systems are not an exception to this, they need to adapt to an environment which is constantly changing. [Han-1987, P 56-66]

Components that suffer wear, age-related factors like obsolescence or the discontinuation of the production of critical components, and the availability of newer and more efficient components in the market or even new officially imposed obligation can lead to companies facing competitive disadvantage scenarios. [VDI-4403]

These numerous factors negatively affect the long-term functionality of the ASRS, something that the operators of these systems ultimately seek. Operators principally pursue this objective by carrying out maintenance activates in their systems. However, the impact of these factors is not equally the same for warehouse operators. The discontinuation of the production of ASRS spare parts reduces with the time their availability in the market, hindering and raising the cost of maintenance activities. [Xu-2020]

In this situation, warehouse operators have to make the decision of whether completely exchange their ASRS for new ones, or carrying out a modernization in their intralogistics systems, also known as retrofit. This decision is taken by the company that either owns or operates the warehouse. After a careful examination of the warehouse and considering the previous factors, it falls within the responsibility of the management board to take such decision. This decision will be based in a work result of the cooperation between the maintenance department and the so-called implementer. [Xu-2020]

Implementers are companies that give full or partial support to operators of ASRS in modernization processes by taking examinations of the installations, seeking the market for spare parts of the ASRS, designing a modernization plan that suits the individual operator installations and necessities, as well as taking over the construction and implementation work. Last but not least, implementers set a price to the modernization itself. [Xu-2020]

It is ultimately the operator's management board the one responsible to decide whether or not modernizing the installations and, for such thing, there must be an internal coordination between them and the maintenance department, as well as an external agreement with the implementer. Here not only the modernization price is the factor that plays a principal role in such decision-making process. Warehouses that require a retrofit increase the operating costs of the facility by having rising standstill times, more frequent and expensive maintenance, or higher energy consumption [VDI-4403].

Nevertheless, in order for retrofitting activities to take place within the operator installations, there must be taken into consideration several warehouse-relevant aspects that are beyond the scope of the management board. In-house operations flexibility and installation's availability are some of the many aspects that need to coincide with the retrofit requirements provided by the implementer, which makes such a process so complex.

This decision is one step of a wider modernization process that is not well defined and delimited. The reason for this is that not every operator has the same flexibility and needs and not every ASRS require the same modernization, therefore this makes the process to be individual to each case. This lack of delimitation of the process creates an unknown environment that may prevent some operators of automated storage and retrieval systems to venture in a modernization process and therefore biasing their decision. [Kar-2005, P 354]

Furthermore, the fact that the correct functioning of the warehouse plays a critical role in in-house operations generates a lower warehouse flexibility for modernization that would be affected by the implementation works which come along with a modernization. The fear of a possible standstill as a result of the implementation work is a decisive factor for operators in order to decide for a determined offer. [The-2020]

1.2 Objectives of the Thesis

It is evident that it exists a gap of information between the two main stakeholders of a modernization process, mostly because of the implicit individuality of the process. As mentioned before, this lack of definition may discourage some operators of automated storage and retrieval systems to modernize their installations and either delay or bias their decisions.

The aim of this work in coherence with the OptiFit project to which it takes part in is mainly to close the information gap between operator and implementer by thoroughly reviewing the modernization process based on the past experiences from operators of ASRS and implementers.

For accomplishing this goal, past modernization processes are analyzed from different perspectives, in order to define and represent an average retrofit process. This representation of the process aims not only to help operators of possible future modernizations to gain knowledge, but it would also give rise for weaknesses and potential improvements to get more visible.

Correspondingly going in the direction of bringing more useful information to the operator, one of the previously mentioned potential improvement of a modernization process will be furthermore deeply analyzed by means of specialized literature research and the conduct of further expert interviews with both operators and implementers, that will serve as a baseline for future smoother modernizations.

All these improvement pretentions and process analysis take place in this work after a careful literature examination embracing the scope of the topic which is here carried out. However, and due to the lack of literature about such a specific process, a big part of this Master Thesis requires of the conduct of expert interviews for data compilation, elaboration and validation of hypothesis.

The results obtained in this thesis will serve as a building block for the OptiFit research project from the Chair of Materials Handling, Material Flow and logistics (fml) in the Technical University of Munich (TUM). The OptiFit project aims to build a process model for the evaluation and preparation of operators to a modernization of their ASRS installations, helping them to assess better implicit retrofit characteristics such as urgency of criticality. This will ultimately build a better communication bridge between operators and implementers. The modernization process analysis and the potential optimization research which are here carried out fall within the scope of two milestones of the OptiFit project, which are “Raising awareness of retrofits” and “Transmitting knowledge about retrofit”. [Xu-2020]

It is important to emphasize that some of the statements and assumptions made throughout the master thesis are based on information obtained through tutoring with Josef Xu.

Additionally, the confection of the process as well as the development of the subsequent points where the potential improvements of the process are analyzed are possible thanks to the interviews carried out with an implementing company and a phone interview with an operating company. The interviews were transcribed into a protocol that can be found in Appendix A. On the other hand, the telephone interview will be cited throughout this text.

1.3 Structure of the Thesis

The work previously mentioned is structured in this thesis in 5 different chapters or sections, which subsequently are as well divided in individual subsections for a more precise structuration of the work. Figure 1-1 serves as a good representation of this division.

In the first place, the general topic which embraces this work is introduced and roughly described, together with an overview of the objectives of the work as well as its approach are included in Chapter 1.

Previous to the core of the work, the structural components and state of the art of the automated storage and retrieval systems is researched in Chapter 2. Furthermore, the maintenance of these system is taken into consideration here, together with a first grasp of what a modernization or a retrofit embraces. For concluding this chapter, a modelling language that will be used in the following chapter is presented.

A thorough examination of a retrofit process begins in Chapter 3. Here some of the influencing factors that trigger operators to retrofit their installations are described and as well serve as a starting point for the representation of an average retrofit process. The layout of the process helps to identify potential improvements in the modernization process, which are also here described and give rise to a further analysis in the following chapter.

1. Introduction

- Initial situation of automated storage and retrieval systems
- Objectives of the work
- Approach and structure of the work

2. Theoretical Framework

- Description, structural analysis and industrial usage of automated storage and retrieval systems
- Maintenance and modernization of automated storage and retrieval systems
- Introduction to modelling languages

3. Analysis of a Retrofit

- Definition of critical factors that influence a retrofit decision-making process
- Representation of an average modernization process
- Description of the potenial improvements of the process

4. Study of an implementation plan

- Introduction to urgency and criticallity assessment of discontinued spare parts
- Review of individual motivation for a determined implementation plan

5. Conclusion

- Work allocation in OptiFit project
- Summary and conclusions of the work

Figure 1-1: Structure of the Master Thesis (own illustration)

Chapter 4 sheds some light into some of the weaknesses and threats which are part of the process, revealed in the previous chapter, by means of a careful analysis and some proposals for improvement.

This thesis concludes with the allocation of the work in the OptiFit project in Chapter 5, closing the work with a summary and leaving room for further research.

2 Theoretical Framework and State of the Art

Chapter 2 offers a generic description of the ASRS, which goes from a technical analysis to the maintenance and modernization of these systems. This theoretical part of the thesis is based on the standards of the European Materials Handling Federation (FEM), the German Institute for Standardization (DIN) and the Association of German Engineers (VDI). Chapter 2 is divided into 5 different sections. Firstly, the automated storage and retrieval systems are defined and introduced in chapter 2.1, following by a technical analysis in chapter 2.2. The maintenance methodologies of these systems are discussed in chapter 2.3 and chapter 2.4 offers a first insight to retrofit of ASRS. This chapter concludes with a description of the modelling language in chapter 2.5 that will be used in a later stage to represent the retrofit decision-making process.

2.1 Definition and Use of Automated Storage and Retrieval Systems

A Storage and Retrieval Machine (SRM) is a manual or automatic handling and lifting device for storing into, or retrieving goods from the compartments of a racking installation [FEM-9.101]. ASRS are product-to-picker storage systems that uses fixed-path SRMs running on one or more rails fixed in parallel aisles with storage racks at both sides. [Ber-2000, P 1339-1340, Roo-2009, P 343-345]

Roodbergen et al. define that within the main components of ASRS are included the racks, storing devices (SRMs), aisles, input and output points and the order picking position. [Roo-2009, P 343-345]

SRMs can be designed to operate in different racking systems. High-bay warehouses, container racks or automated miniload warehouses, shelving racks and pallet rack are some examples of these racking systems. However, the first two systems are the ones that are most often found in warehouses that operate with ASRS. [VDI-3630, Hom-2008, Loo-2020]

A high-bay warehouse is system of metal structures that consists of pairs of opposite rows of shelving and floor-bound storage and retrieval systems. They are distinguished by low storage surface requirements, heights that to from 12m and up to 50 meters and may offer space for more than 100.000 pallet or container bins. This kind of racking systems allow them to be used for storing different sorts of long and flat goods, making them versatile for different applications. [VDI-4418, Hom-2008]

Figure 2-1 shows a representation of an ASRS concept with a high-bay warehouse as a racking system operated by storage and retrieval machines.

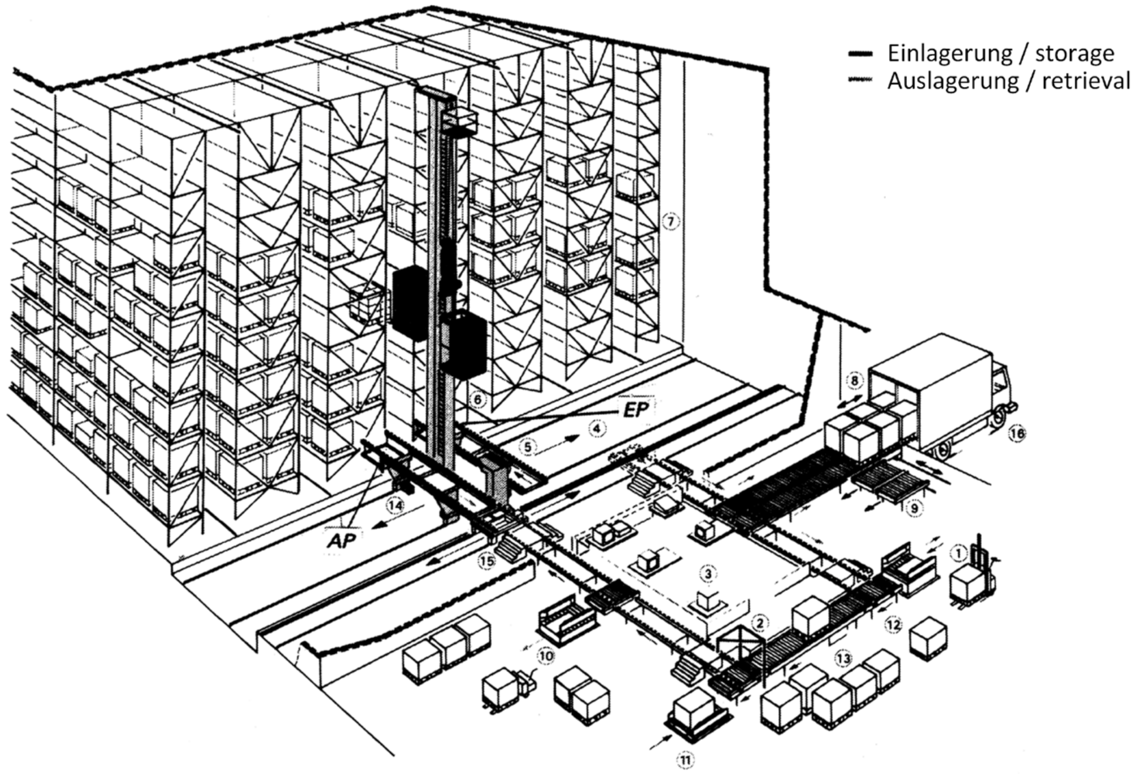

Figure 2-1: SRM in a High-Bay Warehouse [VDI-3561]

On the other hand, an automated miniload warehouse refers to the racking systems that transport and store products which are usually kept in standardized loading aids, such as containers, trays, cartons, etc. The standard VDI-3630 restricts the maximum capacities of the loading aids to approximately 50kg for containers and 300kg for trays. [VDI-3630]

Moreover, input and output points are connected to SRMs and racking systems, on the location the retrieved loads are dropped off and where the incoming loads are picked up for storage. Pick positions, pick stations or order-picking position is the location of the warehouse where the order is prepared by removing individual items from larger units of single articles retrieved from the racks. [Ber-2000, P 1339-1340, Hom-2008, Roo-2009, P 343-345]

2.2 Technical Structure and Components of Automated Storage and Retrieval Systems

A schematized representation of an SRM is given by Figure 2-2. In this chapter, the numbers written within the parentheses refer to the component indicated by the number of Figure 2-2. The vectors represented in the figure define the three main movements that an SRM can carry out [FEM-9.101, VDI-2692]:

- V_x: Travelling: Movement of the complete machine in the lane longitudinal direction.
- V_y: Extension and retraction: Movement of the load handling device in the cross-aisle direction.
- V_z: Lifting: Movement of the lifting carriage in the vertical direction.

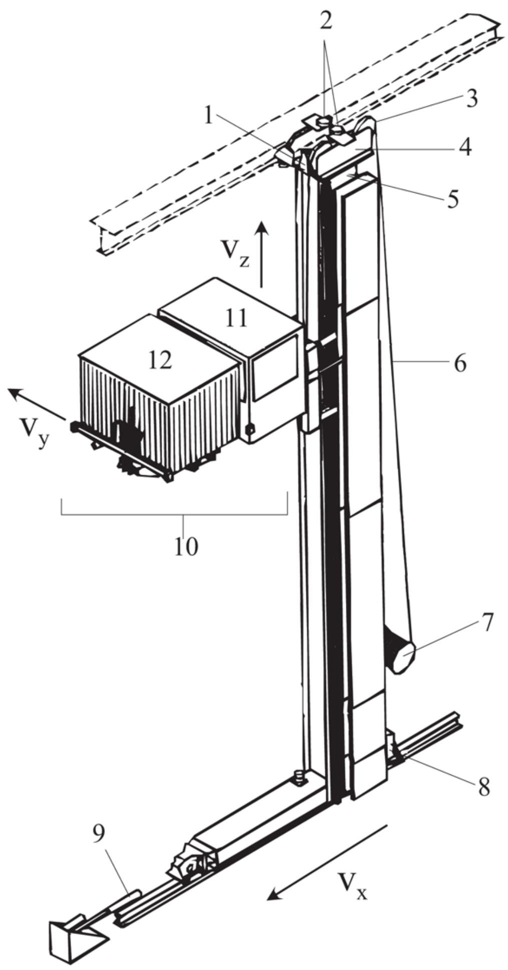

Figure 2-2: Structure of a SRM [Arn-2005]

The composition of a storage and retrieval machine can be structured according to FEM-9.101 into four different parts: Structure, travel drive, hoist unit and load handling device. The structure can subdivided at the same time into mast, travel carriage and lifting carriage. [FEM-9.101]

The mast (5) or masts serve as a load guiding structure of the SRM. It absorbs the bending moments which are generated by an eccentrical applied weight of the load. The mast is vertically positioned and guides the lifting carriage (10) during its lifting and lowering movements. The lifting, lowering and positioning of the lifting carriage along the z axis is powered by the hoist unit (7). [FEM-9.101]

The travel carriage is a wheeled frame structure which is attached to the mast, and by means of the travel drive (8), it can accelerate, decelerate, drive and position along the horizontal x axis. The rails, which can be positioned above and under the mast (depending on whether the SRM is suspended, floor-running or mixed), guide the travel carriage along the aisle. [FEM-9.101]

The movement on the y axis is performed by the load handling device. This part of the SRMs is attached to the lifting carriage and is able to lift the so-called load unit (12) and store it or retrieve it from the racks. Depending on the load to store/retrieve, the load handling device will be equipped with specific forks, hooks or gripping devices. [FEM-9.101, VDI-2692]

The time that a repetitive and precise movement of the SRM require along the aisle on the x and z axis is defined as cycle time, according to VDI-2692 standard. Apart from the travel time of the SRM, the cycle time includes the times for picking up the load and/or discharging, as well as any auxiliary time that the SRM requires (e.g., positioning time). [VDI-2692]

Depending on the requirements of the warehouse, an SRM can perform single or double cycles. In single cycles, the SRM performs only one storing or retrieval movement per cycle. On the other hand, in double cycle, the SRM stores and retrieves items from the racks on the same cycle. This double action is normally accomplished by first performing a storage and then a retrieval, with an empty travel in-between. This is possible assuming that the SRM has a unit-load capacity. Multi-load SRM are capable of performing multiple storages and retrievals per cycle. [Ber-2000, P 1339-1340, VDI-2692, Kou-2015, P 677]

ASRS can be classified in several ways, depending on its structure, operation mode, etc. FEM-9.101 suggests one classification according to the modes of control of the

ASRS. A manual controlled SRM would perform all movements guided by an operator, whereas in an automatically controlled SRM, all movements are predefined and performed automatically. A semi-automatically controlled SRM performs movements controlled by an operator in some directions and subsequent movements are carried out automatically. [FEM-9.101]

Alternatively, ASRS can be classified depending on the number of SRM and aisles available. According to Roodbergen et al., ASRS which have the same number of aisles and SRMs, meaning a SRM moves along the aisle without being able to leave it, are called aisle captive ASRS. Because of construction restraints or lower system requirements, the number of SRMs may be smaller than the number of aisles. In this case, the ASRS can be arranged so that the SRMs can switch rack aisles. This factor will influence the cycle time of the ASRS. [Roo-2009, P 343-345, VDI-3561]

2.3 Maintenance of Automated Storage and Retrieval Systems

The standard DIN-13306 provides a definition of maintenance as the “combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function”. [DIN-13306]

The following actions fall within the scope of the previous definition:

- Active maintenance: represents the physical actions to performed to restore the functionality of a faulty object (repair). [DIN-13306]
- Observation and analysis: Activities to check the status of the components such as inspections, testing and monitoring. [DIN-13306]

A difference between fault and failure is provided as well by DIN-13306. Although both terms refer to the inability of a determined object to perform its required function, the failure is the event that causes this inability and the fault is referring to the actual state of failure. [DIN-13306]

The costs related to maintenance can be divided into direct and indirect costs. The former takes into consideration the actual costs of the repairs, which are as well the easiest to track. Spare parts are the items that substitute another faulty item with the finality of maintaining the function of the system, are also included within the direct costs. The indirect costs on the other hand aggregate all costs related with the consequences of unplanned maintenance actions. Examples of these costs are revenue losses consequence of unplanned downtimes in production. [Ben-2016, P 12-13, DIN-13306]

Indeed, Mobley highlights that, depending on the specific industry, “maintenance costs are a major part of the total operating costs of all manufacturing or production plants” in which they “can represent between 15 and 60 percent of all goods produced”. Therefore, an effective maintenance management is highly considered, as it plays an important role in making the company more competitive. Maintenance management consider three approaches to maintenance: Run-to failure management, preventive maintenance and predictive maintenance. [Mob-2002, P 1-5]

Run-to-failure management is also named according to DIN-13306 as **corrective maintenance**, is the simplest of all three aforementioned approaches, in which an object is only repaired when it is already faulty and not before. Although this approach brings no cost to the plants before the break down of a component takes place, it can be the most expensive alternative for maintenance management. Associated downtimes or expensive spare parts inventory costs are some of the reasons. [Mob-2002, P 1-5, DIN-13306]

However, this previous approach is rarely found in practice, since most of the plants use at least minimum **preventive maintenance** methods, such as lubricating the machines. Preventive maintenance is a maintenance management method which takes into account time factors of the machine or components, such as operation and elapsed time and which objective is to prolongate the life of a determined component or machine by mitigating its degradation. This “time-driven” approach considers the so-called “bathtub curve”, represented on Figure 2-3. The bathtub curve shows how the failure probability of a component or machine is higher after its installation and at the end of its normal life period (aging failures). During the normal life of a machine or component, it is expected that its failure probability is rather low. [Mob-2002, P 1-5, DIN-13306]

Predictive maintenance differentiates from the previous method by being a “condition-driven” rather than a “time-driven” approach. Component times statistics go to a second level and forecasting and monitoring activities play an important role in this method. By analyzing these indicators, companies can obtain component-related data that allows scheduled maintenance operations to take place and therefore minimizing the probabilities of breakdowns and unplanned downtimes. [Mob-2002, P 1-5, DIN-13306]

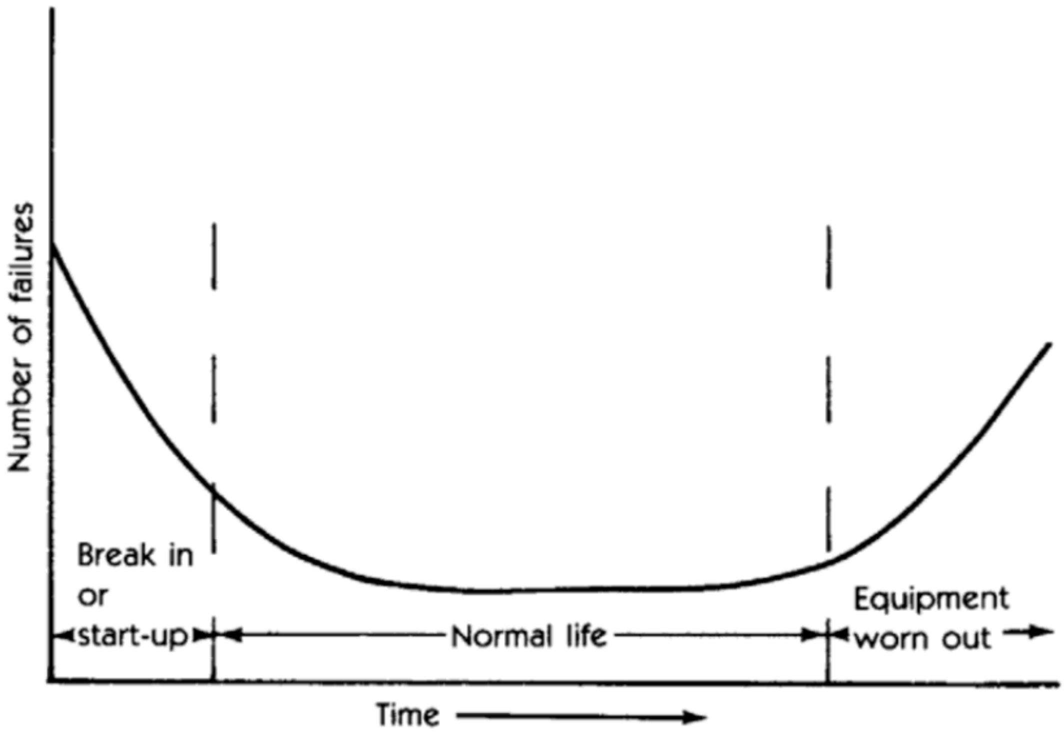

Figure 2-3: Bathtub curve [Mob-2002, P 1-5]

The European standard FEM-9.754 suggests that the maintenance of the ASRS should be carried out at regular intervals by qualified personnel and according to the manufacturer’s instructions. During maintenance works, all the SRMs operating in the aisle where the SRM is being repaired must be shut down. [FEM-9.754]

A shutdown shall be distinguished from other possible states of the ASRS. A SRM that is able to perform its required functionality is considered to be in an up state. If an SRM that is in an up state and it is performing its function, it is then in an operating state, whereas if the SRM is not operating but can be put again into operation if required, is in an idle state. [DIN-13306]

Conversely, if the SRM is cannot perform according to its requirements, it is considered to be in a disabled state, while a down state is considered if a disabled state is produced because of predictive maintenance purposes. In both cases, the SRM is considered to be shut down. [DIN-13306]

All these previous states influence the availability of the ASRS. The term availability, which is tightly bounded with maintenance, is frequently used throughout this thesis and refers to the readiness of an SRM to perform its functionality, provided that external resources are available. [DIN-13306]

2.4 Retrofit Definition and Scope

The term retrofit already appears on chapter 1 as a synonym for modernization. A retrofit or modernization is carried out with the objective of meeting new or changed requirements of a system by means of modifying the object or implementing new technological advantages. [DIN-13306]

A differentiation of the terms modification and improvement is also provided by the standard DIN-13306. On the first hand, the standard does not consider a modification as a maintenance action (although it may be performed by a maintenance department), as it involves the “technical, administrative and managerial actions” for performing a change in a system or function. On the other hand, an improvement involves the same actions as the modification but with the objective of ameliorating an intrinsic characteristic of an item without changing its original function. [DIN-13306]

However, it will be discussed in the following chapters of the thesis that in some cases a modernization is not mainly triggered by the need of meeting new or changed requirements. As a matter of fact, the influence of other factors, such as the discontinuation of the production of a component of the ASRS, may bring some companies to modernize their facilities.

It is extensively used throughout this thesis, especially in chapter 4.1, the term criticality and criticality assessment. When this term is used in this work, it is generally denoting how critical would be a failure of a specific component (or of the ASRS as a consequence of this failure) from the point of view of an operator of ASRS.

In this context, criticality can be understood as variable which takes into account the severity of a failure and the frequency with which this failure is reproduced. The frequency of a failure is a quantitative variable that can be easily measured. The severity of a failure, however, is a qualitative and rather subjective variable which measures the consequences of a failure in a system. For this reason, each operator of ASRS should assess a different severity to a determined failure depending on its plant. The-DIN-13306 standard suggests assessing the criticality of a failure with the help of a “failure-occurrence – severity matrix” as the one represented on Figure 2-4. According to this matrix, very severe but rarely frequent failures, and vice versa, are not assessed as highly critical. [DIN-13306]

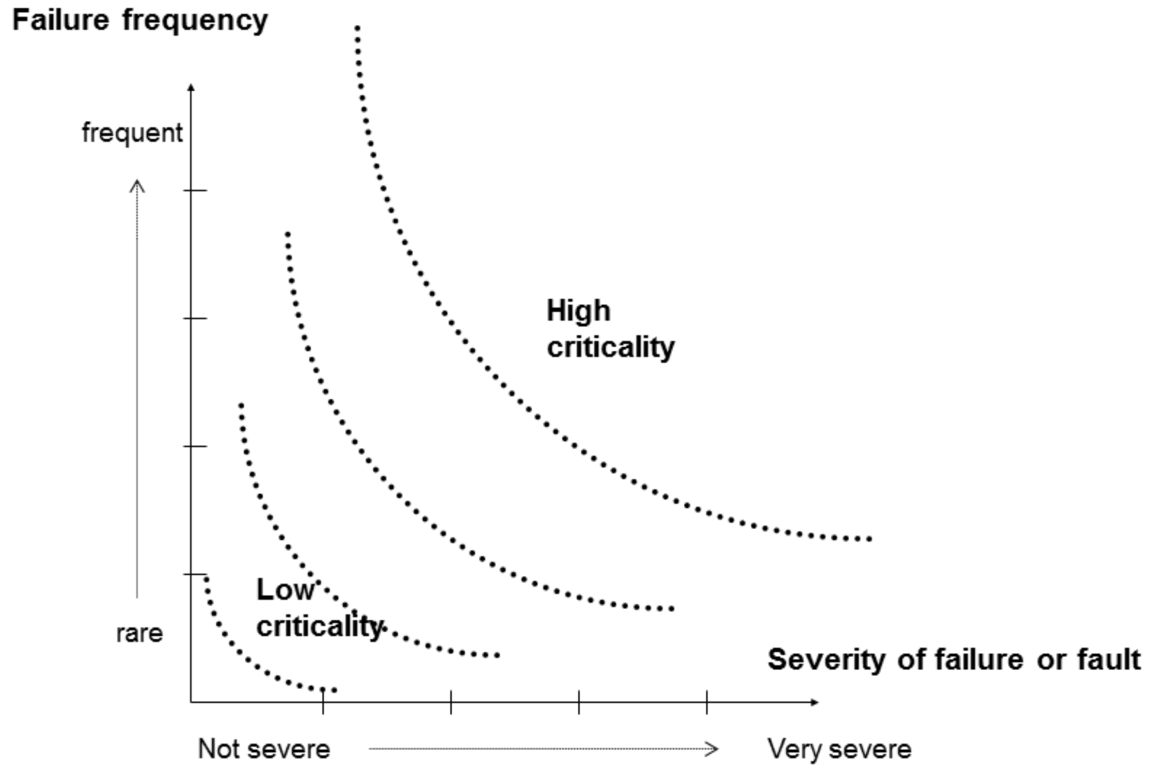

Figure 2-4: Criticality Matrix of a Failure or a Fault [DIN-13306]

A retrofit process is relatively unique to every warehouse operator. Even if the components that require a modernization are the same for two different ASRS operators, requirements of each plant may vary, having an influence in the retrofit process. A way of illustrating this assumption is considering two companies that need to change, for instance, a frequency converter. In this example, one of the two companies can plan a standstill of its warehouse whereas the other company cannot renounce to its warehouse for a limited amount of time. This factor, as many other, influences the retrofit process, making it individual to each operator of ASRS.

Although the number of different possible retrofit processes can be high, the parts or components of the ASRS that can be retrofitted are limited. Mechanical components that suffer wear are, for instance, engines of the travel drive and hoist units, guiding rolls or the rails.

On the other hand, the failure of electronic components is in most of the cases a principal trigger for retrofitting a warehouse's ASRS. Frequency convertors, sensors or programmable logic controllers (PLC) are some examples of electronic components that are normally retrofitted. As an example, it is very common to find companies that upgrade their PLCs from the Simatic S5 family to ones of the newer SIMATIC S7 family, fabricated by the company Siemens.

2.5 Business Process Model Notation as a Model for Representing a Retrofit Decision-Making Process

2.5.1 Retrofit as a Business Process

From an operator of automated storage and retrieval systems perspective, the process of modernization of ASRS can be understood as a business process.

Becker et al. provide a definition of a process as the "chronological and logical sequence of activities that are necessary to process a business-relevant object". More specifically, a business process is a "special process that serves the fulfillment of the company's highest goals (business objectives) and describes the central business area". Additionally, Becker et al specially highlight the interfaces of the process to the company's market partners (e.g., customers or suppliers). [Nor-1972, Bec-2012]

Business process take place in a wide variety of contexts and therefore can be described using several different approaches. This fact brings the need of a uniform, consistent and standardized language for the description of business processes. The main benefit that brings the understanding of a standardized language is being able to better comprehend processes described by different authors. [All-2020]

2.5.2 Modeling of Business Processes

According to Kunze et al., "process models capture how work is performed in an organization and how business goals are achieved". The use of a modeling language for this purpose serve as a helpful tool for distinguishing important from unimportant concepts from processes. [Kun-2011, P 44-58]

Several modeling languages exist for describing a process. However, each language was designed for a specific purpose and therefore not all of them are suitable for modeling and describing a retrofit process. Allweyer proposes some examples of modeling languages [All-2020]. It is interesting to find how some of these modeling languages served as a baseline for developing other (more specialized) languages:

- Business Process Execution Language (BPEL): Developed from other modeling languages, BPEL is based on XML metalanguage. However, BPEL is limited by its lack of a graphical representation.

- Event-driven Process Chain (EPC): Mainly used for describing software processes, EPC is a modeling language previous to the Business Process Model and Notation (BPMN).
- Unified Modeling Language (UML): This standard is well-known for its application for object-oriented software designed, being not particularly appropriate for business processes.

In addition, Harvey suggests Petri Net (from which the EPC is based) or Pi-Calculus (a very technical methodology) as modeling languages alternatives [Har-2005, Kor-2006, P 161]. However, is the Business Model and Notation the modeling language that best captures the process of an ASRS modernization.

2.5.3 Business Process Model and Notation

BPMN is a modeling language that was originally developed from the Business Process Management Initiative (BPMI) [All-2020]. The use of this modeling language allows the visualization of business process in a flow-chart format at the human level, rather than the software engine level. [OMG-2011]

According to the Object Management Group (OMG), the BPMN "provides multiple diagrams, which are designed for use by the people who design and manage Business Processes. BPMN also provides a mapping to an execution language of systems, such as BPEL." [OMG-2011]

A BPMN diagram is composed of three main elements: events, tasks, flows and gateways. These elements are represented inside lanes which at the same time are contained in pools. Pools act as containers for sequence flows. These flows can cross the boundaries of the lanes but not the ones of the pool [OMG-2011]. For the representation of an ASRS modernization process, one single pool will contain different lanes, one lane for each participant of the process.

The following elements are the ones that are used for the representation of this modernization process, the description of which is provided by von Rosing et al. [Ros-2017]

Tasks: Are the substantial component of the diagram, they represent the steps or work packages of the flow. User tasks are carried out by a human performer. Additionally, a sub-process task is a type of activity within a process, which can be "opened up" and contains a lower-level process.

Events: Representation of something that "happens" during the course of a process [OMG-2011]. Basic events are start and end events. Other types of events used are message reception event, timer event (indicate waiting time) and catching signals, which indicate the start of a process within the process.

Gateways: Indicate how process paths converge and diverge within a process. The exclusive gateway is used when diverging for splitting routes (flows goes only to one branch), and when converging, only one branch needs to flow in the gateway for the process to continue. Parallel gateways are used for directing the flow to all branches when diverging and when merging, it awaits all the in branches to complete before continuing with the flow.

Flows: Represent the sequence of the process.

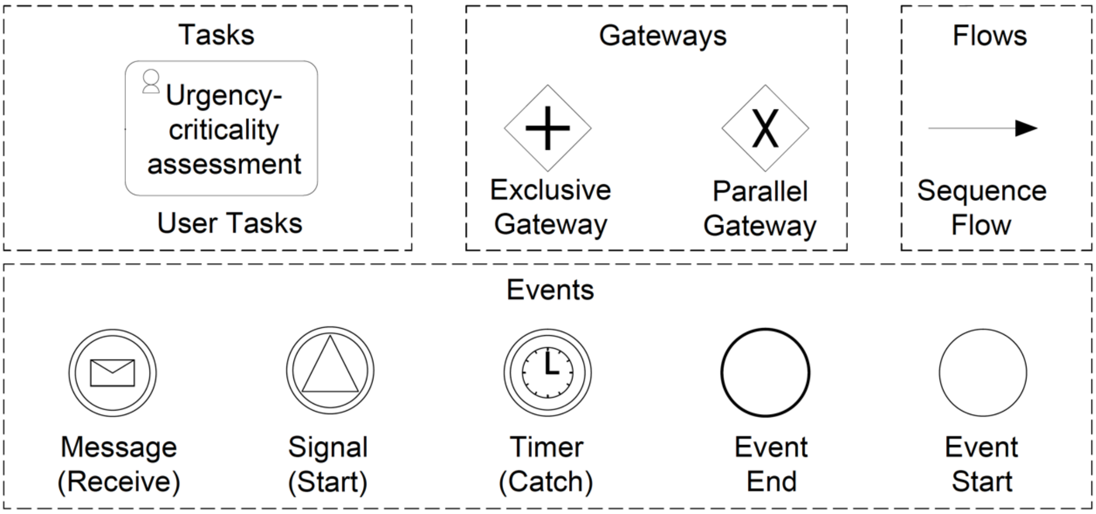

Figure 2-5: Elements of a BPMN Diagram (own illustration based on [Ros-2017])

3 Analysis of a Retrofit Decision-Making Process

In this chapter, the topic of modernization process or, more specifically, the modernization decision-making process is introduced, reviewed and its structure is broken down into its different components. First and foremost, internal and external factors that trigger operators to retrofit their installations are listed in chapter 3.1. Immediately after, the parties that take part into the decision-making process are identified in chapter 3.2. An introductory approach is given in chapter 3.3 and subsequently in chapter 3.4 the modernization decision-making process is thoroughly discussed, represented using one of the previously mentioned notations and successively dissembled in different units or steps. Chapter 3.5 concludes this block with an analysis of the process itself which should make visible potential improvements of such process.

3.1 Necessity for a Retrofit

A necessity for a retrofit or modernization can be better understood by formulating the following question:

> "Which are the reasons that cause an operator of ASRS carry out a modernization in their systems?"

The answer to this question draws the baseline of what a whole modernization process represents.

The findings of Prinz are used throughout this chapter as a basis for identifying the necessities for retrofit and subsequently as a starting point for developing the retrofit decision-making process.

Prinz suggests the term "primary" for categorizing the factors that by themselves are considered critical enough for a warehouse operator to carry out a retrofit. On the other hand, "secondary" factors refer to the influences, which by themselves and in a low level of incidence, are not sufficient for an operator to consider a modernization of their installations necessary, although in higher rates of occurrence or the accumulation of these "secondary" factors can indeed trigger a retrofit. [Pri-2020]

Both "primary" and "secondary" factors are at the same time subdivided into three different categories, depending on the source where the problem was originated. These categories are named as “status of the installations”, “organization”, “costs” and “environment”. [Pri-2020]

However, and since the aim of this work is not to focus on the factors themselves but at the retrofit process as a whole and at the same time acknowledging that the categories above mentioned manage to create a fair division of the retrofit causes at an organizational level, this classification does not perfectly adapt to the needs of a retrofit decision-making process (DMP). For specific purposes of this work, the interaction between the different stakeholders of a retrofit comes to the foreground and therefore, another classification of these causes is here required. The stakeholders of a retrofit DMP will be introduced and further discussed in Chapter 3.2.

In order to better capture the different groups or entities that participate in a decision-making process, the factors that trigger retrofits are classified in **internal factors** (3.1.1) and **external factors** (3.1.2).

3.1.1 Internal factors

Internal factors are one of the main reasons why companies need to adapt rapidly to changes [Gue-2018, P 161].

These factors are considered to fall within the boundaries that delimit the scope of a company. Galende et al. suggest a resource-based view as a fundamental perspective for intern change in an innovative company. This approach should take into consideration the importance of internal resources, which are divided into physical, financial, human or organizational. [Gal-2003, P 716-717]

Physical factors with a direct relationship with ASRS such as a decreasing system availability, a raising system failure probability or, in other words, an increase in the frequency of failures play a very important role in this category. Not as important but also falling withing the scope of this category is the versatility and aging of the system itself. These facts may also contribute to an extended duration of a failure. [Pri-2020]

On the other hand, a human factor like a reduced flexibility of the operator’s workforce contributes significantly to this retrofit necessity, as well as other no so critical factors such as a decreased energetic efficiency or the advantage of a company going through a good financial situation. The latter however is also strongly influenced by external factors. [Pri-2020]

3.1.2 External factors

Analog to the aforementioned internal motives for retrofit change, Lauer states in this case that “external change is caused by the market environment, politics, technology, ecology, the economy as a whole or institutions, as well as in the markets themselves, for example through increasing competition”. [Lau-2010]

Since companies do not completely isolate themselves from each other, they can be considered as open systems, so that they experiment information exchange with their environment. This statement always applies to companies, as they are integrated into numerous markets and they require of this integration, otherwise their viability is not ensured. Unless companies close themselves to the environment as much as possible, what is also called “hedgehog tactics”, systems must necessarily adapt to the changed environment. [Lau-2010]

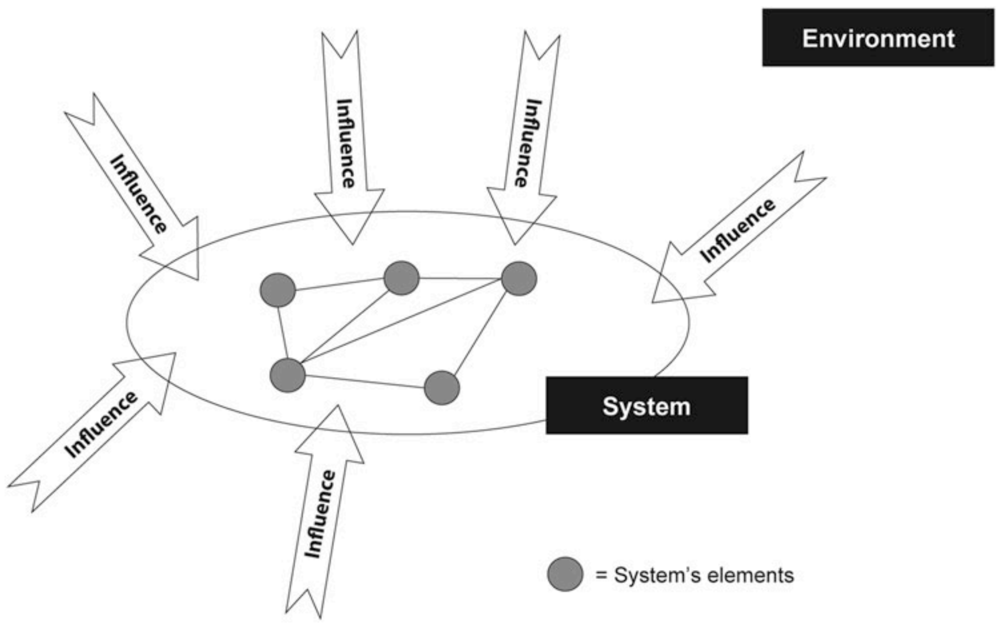

Figure 3-1: Influence of External Factors in a System [Lau-2010]

This statement seamlessly applies to what external factors equates to generating a necessity for modernization for automated storage and retrieval systems. Also, in this case, the environment influences operators in several ways.

First and foremost, one of the major problematic, if not the biggest concern, for companies that operate relatively aged automated storage and retrieval systems is the discontinuation of the production of ASRS spare parts. [The-2020]

A company that operates ASRS has no influence whatsoever in the production discontinuity of such parts; therefore, this factor can be categorized as an external factor. This particular factor, however, brings what can be named as a “responsibility dilemma”. According to Prinz, it can be stated that the responsibility of looking after whether a certain ASRS component is no longer being manufactured falls withing the tasks of the provider or companies which implement such systems in the installations of the ASRS operators. However, it is de facto the latter who is taking this responsibility of tracking such components in most of the cases. [Pri-2020]

In order to mitigate this problem, operators of ASRS can perform a “spare parts strategy”. This strategy basically consists of the provisioning of components that are considered essential for the functioning of the ASRS and at the same time vulnerable to suffer a production discontinuity because of the innovation speed of the particular component. However, this strategy presents different problematics, such as the high storage requirements that make unfeasible to store some components. This strategy will be thoroughly discussed in chapter 4.1.6.

Therefore, a good stocking strategy for spare parts is successful external factor for companies. Here is, according to Vollmüller, “The effect of a failure of a technical component on production is usually the dominant criterion that influences the spare parts strategy”. Since the manufacturers of these vulnerable components are detached from the operator but the spare parts strategy is carried out internally, spare parts are difficult to categorize as an external or internal factor. [Vol-2012, P 81-82, Pri-2020]

On the other hand, another factor that is alien to operators of ASRS but still substantially affect to the necessity of retrofitting an installation is an unforeseeable increase in the demand. this may affect to the system availability, which is already categorized as an internal factor. Additionally, what according to VDI-4403 is “a facility that no longer satisfies current guidelines or regulations” can as well be considered as a retrofit trigger. Ultimately but having smaller impact in retrofit necessity, a reduction in an implementer’s quality support externally influences the operator decision criterion. [VDI-4403, Pri-2020]

3.2 Retrofit Stakeholders

According to the Project Management Body of Knowledge definition of stakeholder (PMBOK), “a stakeholder is an individual, group or organization that may affect, be affected by or perceive itself to be affected by a decision, activity, or outcome of a project”. At the same time, “stakeholders may actively participate in the project or have interests that may be positively or negatively affected by the implementation or completion of the project” [Pro-2017]. Since a ASRS modernization it is considered to be a project, this definition strongly applies as well to a DMP.

The stakeholder par excellence are the companies that employ automated and storage systems as a resource for their intralogistic operations within their plants, which can be named as operators of ASRS or, in short, **operators**. This term will be used throughout the rest of the thesis.

In the practice, there can be found two types of operators. On the one hand, some companies operate their own warehouses. This means, that they assume the maintenance of their ASRS. A good example of these operators are manufacturing companies that store raw materials in their facilities and require these raw materials for the production. On the other hand, some companies rely on external companies or service providers for storing their goods. As a consequence, the service providers have their own maintenance and logistic department, extern to the contractor company. Companies may want to distribute their products, for example, in the different countries in which they are selling. The high ownership costs of warehouses in this situation makes the contracting of service providers an optimal solution.

Although operators can be perceived as a singular stakeholder unit in further chapters of this thesis, several other stakeholders can be found within this unit. Since operators of ASRS are after all companies, these are internally divided in different departments which specialize in different fields and have different individual interests. Among the ordinary department division of these companies, the warehouse maintenance department plays an important role throughout the entire DMP. On the other hand, less involved in the process but no less important is the management or executive board, in short, management. Other involved departments with a rather marginal participation are, for instance, financial, legal and controlling department.

The aforementioned stakeholders are found within the operator’s boundaries. Taking a look at the external influence in the DMP, there are companies foreign to these operators, which are specialized in retrofits and whose function is to ultimately carry out the modernization process itself. These companies are called as retrofit implementers or, in short, **implementers**. These stakeholders are characterized for having the expertise of performing modernizations in intralogistics systems, gained from the experience of past modernizations. They therefore have the capacity of assessing more accurately timeframes, deadlines and urgencies.

Also extern to the operators are the Original Equipment Manufacturers (OEMs). These stakeholders are companies that in this case fabricate the components of the ASRS. As it will be seen in the following chapters, their influence in it is considered critical, as they have the authority of discontinuing the production of specific components of the ASRS consequently generating a necessity for a retrofit.

However, it is also found in the practice that some OEMs also offer retrofit implementations. Therefore, they are also considered implementers. An example of an OEM that is also a retrofit implementer is the Austrian company LTW Intralogistics, which kindly collaborated to the development of this thesis and which interviews can be found transcribed in the form of a protocol in Appendix A.

The responsibilities of each stakeholder in the DMP are represented in the BPMN by the definition of a stakeholder's lane in the same pool. For a better simplification of the process and because of space limitations, the stakeholders that will be represented in the BPMN with an own lane are the following:

- Management board/management (operator).
- Maintenance department (operator).
- Implementer.

The roles in the decision-making process of the aforementioned mentioned stakeholders will be further discussed in chapter 3.4.1.

3.3 Approach to the Modeling of a Decision-Making Process

The appearance of internal and external factors in different degrees lead operators of ASRS to contact implementers in order to agree and design a retrofit process, which would take place in the following months, depending on the urgency assessed to it (see chapter 4.1 Urgency and Criticality Assessment).

It is one of the main objectives of this thesis to model a retrofit decision-making process in a formal notation. This representation is thought to be helpful for operators of ASRS which are considering modernizing their installations, since it will bring useful information about the processes that are here taking place and about the allocation of responsibilities. Moreover, with the delimitation of the process it is possible to identify the possible imperfections of this process, consequently arising the awareness to the operator.

The approaching method for the delimitation and modeling of the DMP is by conducting different expert interviews with the stakeholders of the process. The retrofit stakeholders with greater importance in the process are the operator (which already experienced the retrofit process inside its facilities) and the implementer. The expert experiences from both parties were put into evaluation and consideration, so what can be considered an “average” decision-making process of a retrofit can be illustrated.

As a result, a detailed description of each step will be provided in the following chapter 3.4. Immediately after and as already commented, in chapter 3.5, the challenges problems and knowledge gaps that may take place in this process are identified and in chapter 4 some of them are further discussed. The whole decision-making process is modeled by using the BPMN described in chapter 2.5 as a representation standard. The BPMN representation can be found attached in Appendix B.

It is ultimately intended with this work the transfer of knowledge to operators of ASRS concerning modernizations. This knowledge transfer should help operators to better assess their necessity and urgency for the retrofit of their own ASRS, as well as helping them to make earlier decisions (see chapter 5.1).

3.4 Retrofit Decision-Making Process

A decision-making process can be misconceived as the mere final step of choosing one among other alternatives, it is indeed the combination of rather extended and complex processes that precede this act. Simon considers that a DMP is composed of the following three phases [Sim-1960]:

- Finding events for making a decision.
- Finding possible courses of action.
- Choosing among courses of action.

A retrofit DMP perfectly matches the previous definition and, in addition, the aforementioned phases can be reflected in such process. On this basis, the retrofit DMP also be divided in three different phases as well.

3.4.1 Necessity for Retrofit Identification Phase

The starting point of finding occasions for making a decision is, in other words, the identification of a necessity for retrofit. It was described in Chapter 3.1 the internal and external influences that trigger operators to modernize their ASRS. These factors however must be firstly identified by the different parties that are involved in this process so that the DMP can get started.

As previously commented in chapter 2.5.3, one of the particularities of a BPMN is the distinction between different lanes in one same pool. This feature invites to attribute the different steps of the DMP throughout the process to the three main stakeholders that participate here. Not excluded of this allocation are the factors that trigger a retrofit. This diversity of factors not only arise from internal and external sources, but also must be categorized according to the stakeholder which is responsible of the detection of such factors. Table 3-1 shows the categorization of the retrofit triggers according to their responsibility.

Table 3-1: Classification of the Retrofit Triggers According to their Source and Responsibility

Trigger	Source	Responsibility
Decreasing system availability	Internal	Warehouse management/ maintenance department
Raising system failure probability	Internal	Maintenance department
Reduced flexibility of the personnel	Internal	Warehouse management/ maintenance department
Spare parts availability	External	Maintenance department (and some implementers)
Spare parts strategy	Internal	Maintenance department
Increase in demand	External	Management
New legal requirements	External	Management/ Maintenance department.

These factors on their own may be reason enough for the operator to trigger what is named in the BPMN as the "necessity for change identification" and first step of a DMP according to Simon, "finding events for making a decision" [Sim-1960]. Are these factors not critical enough, the existence of other minor or "secondary" factors can aggravate the influence of these main or "primary" factors and therefore trigger the step "Necessity for change identification". This step is represented as a "catch signal" in the BPMN, since it is an indication that the retrofit assessment process takes place after here. It can also happen that neither factor is considered threatening enough, leading in this case to the operator being aware of the vulnerability of their system but not triggering action for retrofit.

The change necessity identification takes place in the maintenance department level, since retrofit measures are habitually triggered in particular by the company's own maintenance on the basis of inspections and maintenance reports from the implementers [Pri-2020]. Being said this, it is not exclusively a task of the maintenance department to take over this part of the process, as other operator's departments might also take part in (i.e., the legal department would participate in case of a change in regulations of ASRS). Figure 3-2 shows the section of the BPMN which contains the triggers for identifying a necessity for change.

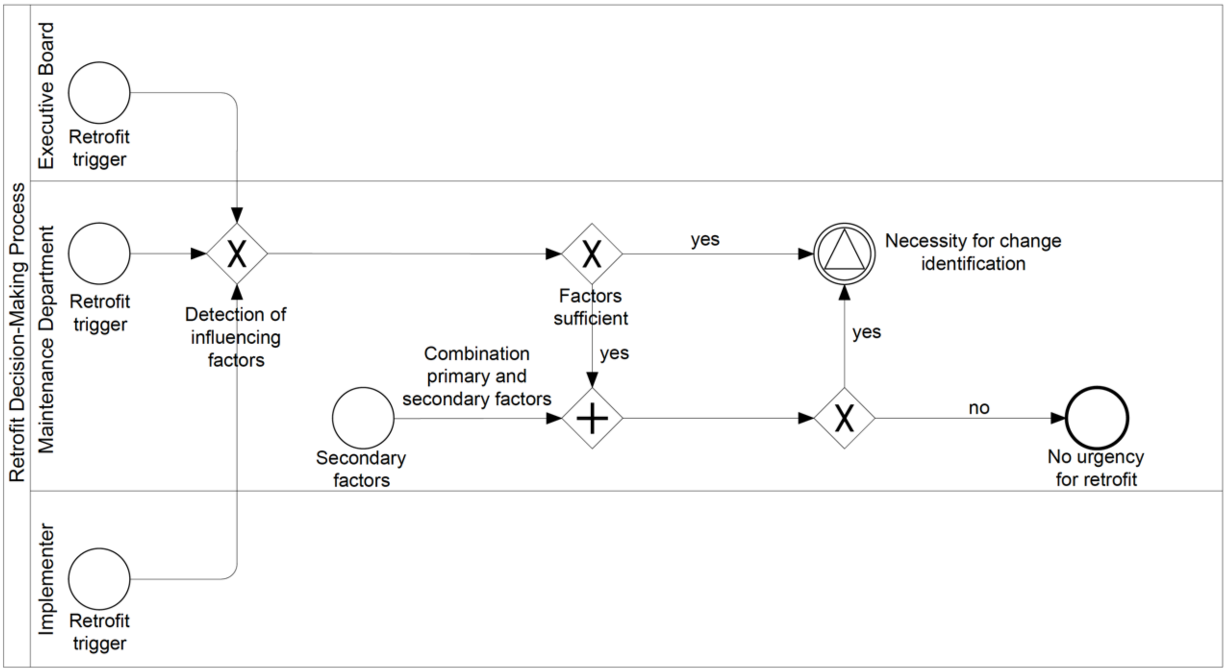

Figure 3-2: *BPMN Representation of the Triggers of the Identification of the Necessity for Change (Extract from the Retrofit Decision-Making Process)*

3.4.2 Offer Phase

It is at this point where the cumulation of stimuli reaches a threshold level and the decision process starts by mobilizing resources to deal with the arisen issues [Min-1976, P 254-255]. This materializes in the operator formally initiating contact with the implementer or implementers (if both parties had not yet started the communication prior to this point).

The decision of contacting only one or more than one implementer company would totally depend on the own preferences of the operator. Deciding for a company to implement a retrofit is not an easy task, although it may happen that some operators already built a solid and trustful business relationship with an implementer prior to the retrofit, assessing as unnecessary to contact other implementers, which would rise the costs of the modernization [Kau-2017, P 40-43]. In contrast, it is mostly the case that operators contact different retrofit implementing companies so that different perspectives and retrofit measures can be put into consideration. The cost of having one implementer company evaluating the conditions of the warehouse and drafting a first offer is a small fraction compared to the costs of the entire modernization. Furthermore, even the modernization costs may represent a smaller portion than the costs that are associated with a standstill in the plant (see chapter 4.1.3) [The-2020].

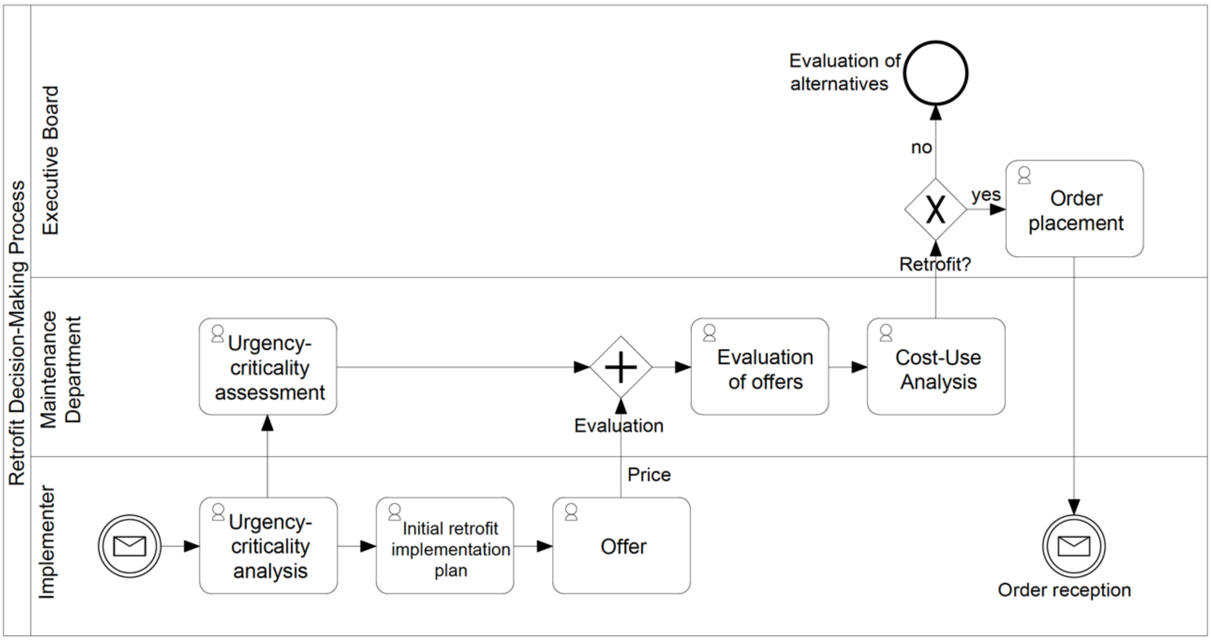

Figure 3-3: BPMN Representation of the Offer Phase in a Retrofit Decision-Making Process (Extract from the Retrofit-Decision Making Process)

The offer phase is shown in Figure 3-3 and finds its starting point the moment the implementer is contacted by the operator after the necessity of modernizing has been identified. As already mentioned, this behavior describes an average retrofit DMP, since it can also be that is the implementer which contacts the operator, for instance, communicating the production discontinuation of a component, being in this case the implementer the responsible of triggering this process.

Implementor's first step after being contacted is the realization of an **urgency assessment**. This step, theoretically carried out by both maintenance department and implementer, aims to find the most sensible date for realizing a retrofit in the operator's ASRS.

An urgency assessment involves the completion of a series of other steps, starting by carrying out an analysis of the condition of the ASRS components, searching for signs of wear or deterioration due to the aging of the system. Furthermore, if not already done previous to the offer phase, an analysis of the availability of spare parts is carried out here. The objective of this analysis is not only to investigate the rapidity at which the number of available spare parts in the market decreases, but also to find components within the installations that are exposed to a risk of being discontinued in the short or mid-term.

Following the analysis of the components condition and the availability of spare parts, a criticality assessment is carried out with the cooperation of both operator and implementer. This is a preceding evaluation that will shape the uppermost urgency assessment. Here, a more careful examination of the components, the failure of which would result in a standstill of the installation, takes place as well as the evaluation of the costs of a resulting standstill on the operator's installations.

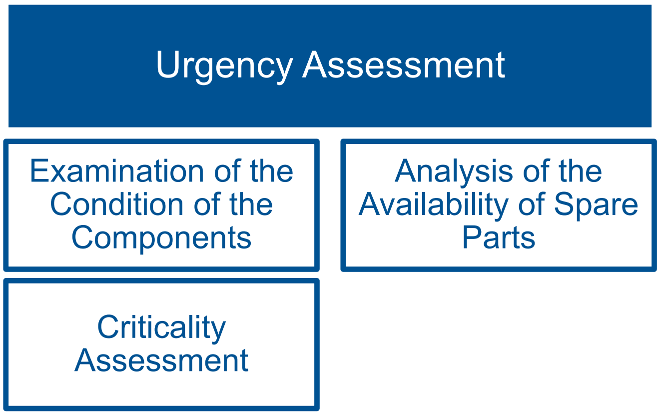

Figure 3-4: Urgency Assessment Retrofit Block

The urgency assessment should determine if the realization of the modernization takes place in the short, mid or long-term, allowing the implementer to design what is called an initial **Retrofit Implementation Plan (RIP).**

A RIP is a block of the retrofit process which comprises the determination of the different measures or timeframes to be accomplished by the implementer during the deployment of the modernization process. The RIP is found at two different stages of the retrofit DMP, firstly in the current offer phase and later in the implementation phase. The reason for this is that there is a defined time frame between the implementer is first contacted and a decision about the retrofit is taken. In this time frame, the implementer must submit an offer containing a RIP and, since it can take several months from the first delivered RIP until the actual implementation of the retrofit, the initial RIP needs to be progressively adapted to the issues that may come up in-between both dates.

One of the blocks contained in the initial RIP is the determination of retrofit measures, which is, in other words, the determination of the components of the operator's installations which are going to be upgraded, as well as any complementary operation to be carried out in this process.

The establishment of an implementation time frame of the retrofit measures is included as well in the initial RIP. From the interviews with operator and implementor this step was identified as one of the most important elements of the offer, since it is here specified whether or not a standstill will be necessary for carrying out the implementation in the plant [The-2020].

It may happen that modernization works do not fully meet the initially scheduled deadlines. This can lead to delays in the implementation and consequently longer downtimes. In order to mitigate the consequences of this, a workaround plan must be included in a RIP as well. Although it is designed in advance, a workaround plan is however in practice very rarely used.

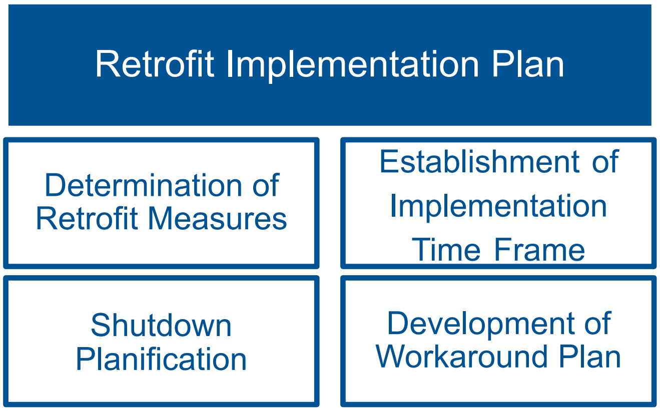

Figure 3-5: Retrofit Implementation Plan Retrofit Block

After the realization of the initial RIP, the implementers (or implementer) submit an official **offer** to the operator, in which includes of course an estimation of the costs. It is now where the operator collects all the different offers and puts them into evaluation.

This evaluation takes place in the maintenance department level and it materializes in a **Cost-Use Analysis (CUA)**. A CUA is an approach carried out by the operator which identifies all sources of direct and indirect influences which would affect to the total cost of a retrofit and brings them all together in a single analysis. There are several other factors apart from the cost of the retrofit itself that also influence the total costs of a modernization. However, it is also interesting for this analysis to consider the costs of not carrying out a retrofit (e.g., the costs associated with unplanned downtimes).

Nevertheless, this analysis is in actual retrofits not used in its full potential, since the identification of more factors is needed for the CUA to form a solid block.

The CUA serves as a detailed piece of information to be delivered to the management board, which will conclude the offer phase by what Simon was referring to at the beginning of this chapter with “the real act of deciding” [Sim-1960].

This section of the BPMN is the one in which the management board is actively participating (excluding the possible detection of retrofit triggers mentioned previously), since it is indeed within the top management scope to take such strategic decisions [Elb-2016]. Here, and taking the RIP and CUA as an information support, the management board must decide whether the retrofit takes place in their installations, or instead one of the previously mentioned alternatives are more suitable for the strategic interests of the company.

3.4.3 Implementation Phase

The last phase of the retrofit DMP starts with the reception of the order by the implementer which retrofit RIP better suits the needs of the operator in terms of costs, reliability and time frame requirements. Figure 3-6 illustrates the retrofit implementation phase.

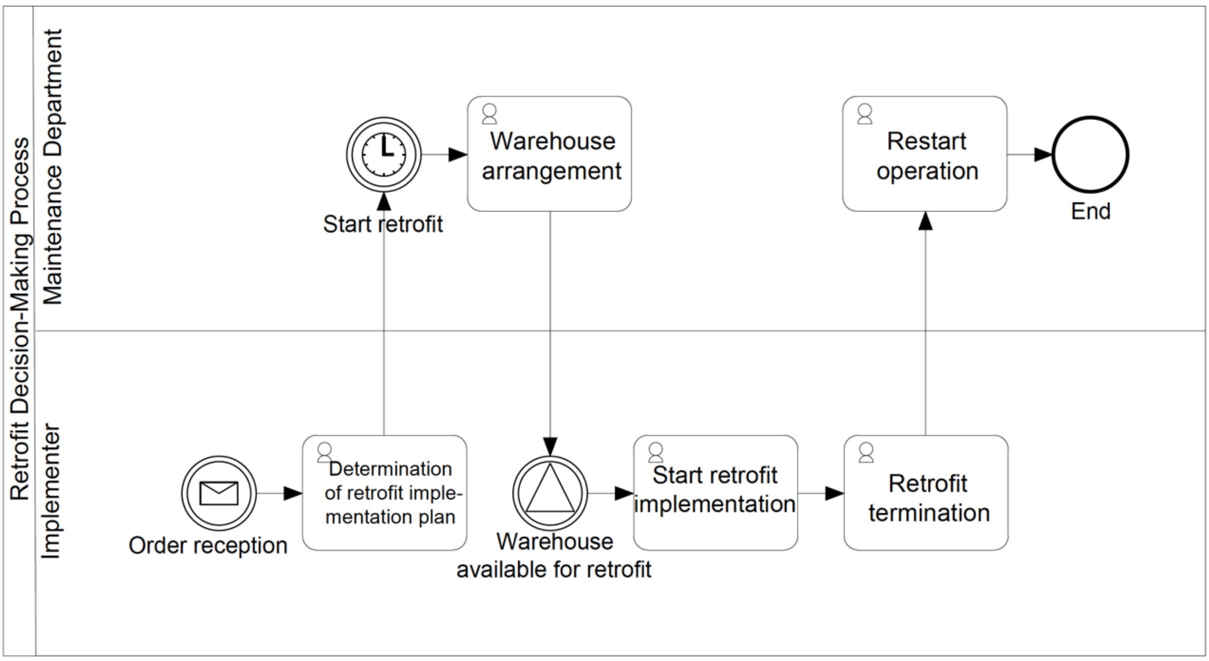

Figure 3-6: BPMN Representation of the Retrofit Implementation Phase in a Retrofit Decision-Making Process (Extract from the Retrofit Decision-Making Process)

It was formerly discussed in chapter 3.4.2 that a retrofit implementation plan is developed from the moment that it was initially designed prior to the offer submission until sometime before the implementation of such final RIP. The adaptations of the initial plan, as well as the establishment of the concrete date or dates for implementing the retrofit are considered in the BPMN block “Determination of the Retrofit Implementation Plan”.

The last step before the implementing works take place within the installations of the operator is the planification of the warehouse according to the designed plan. Here, the warehouse must get prepared for the implementation works, considering the shutdown plan contained in the RIP and depending on the agreed time frame. This means, if for example, the implementation works will take place in running operation, the goods stored in the storage racks of the lanes being restored must be previously rearranged in functional storage racks.

After this process block, the modernization operations take place in the warehouse of the operator according to the plan established in the RIP. The process from this point continues in a theoretically self-explanatory sequence, where after the termination of the implementation works, the installations are prepared to be back into normal operation. At this point, and if no issues come up as a result of the imperfections that appear after a new installation is completed, the retrofit DMP comes to an end.

After the retrofit, the implementer will still be giving firsthand support to the operator during normal operation in case any problem comes up and it is normally also agreed that the implementer will support the operator on a regular basis in the future by completing regular checks in the installations.

The diagram of Figure 3-7 summarizes the consecutive steps of the three phases of what was in this chapter 3.4 described as an average retrofit decision-making process.

1. Retrofit Necessity Identification

- Check internal and external factors
- Inital communication operator-implementer

2. Urgency -Criticality Assessment

- Analysis of the status of the ASRS components
- Analysis of the availability of spare parts

3. Initial Retrofit Implementation Plan

- Definition of measures for retrofit
- Determination of the implementation time frame
- Development of a fallback plan
- Plannification of shutdown and restart

4. Evaluation of Offers

- Comparison of offfers
- Evaluation of alternatives
- Elaboration of a cost-use-analysis

5. Implementation Plan Determination

- Adaptation of the intial Retrofit Implementation Plan
- Agreement of the retrofit date

6. Retrofit

- Approval of the Retrofit Implementation Plan
- Preparation of the warehouse
- Ramp-up

Figure 3-7: Simplification of a Retrofit Decision-Making Process

3.5 Identification of Retrofit Knowledge Breaches

It was outlined in chapter 3.3 that interviews with both operator and implementer were conducted in order to better assemble the process just described in the previous chapter (see Appendix A). It was emphasized by both parties that, from their experiences, the process normally goes according to the plan, in terms of deadlines, time frames and costs. However, the latter may vary depending on unforeseen problems that normally come with implementation of construction work, always within a more than tolerable range. [The-2020]

It is as well intended by the definition of an average retrofit DMP that companies that are contemplating a future retrofit as an alternative of improving their warehouses broaden their knowledge about it. Therefore, a delimitation of such process allows knowledge gaps or knowledge breaches that exist between operator and implementer to get more visible. Some of these breaches can be examined by means of a SWOT analysis, represented in Figure 3-8.

A **SWOT** analysis is one of the most frequently employed approaches used by companies as a part of their strategic planning process. The application of this analysis helps companies to identify and classify internal (**S**trength and **W**eaknesses) and external (**O**pportunities and **T**hreats) influences that affect the organization's future and therefore should be considered in a strategic decision-making process. [Alp-2013, P 1-3]

It is a **strength** of the DMP that a cost-use analysis is carried out. It was commented on the previous chapter that this CUA serves as the basis for the management board for making a decision about the retrofit.

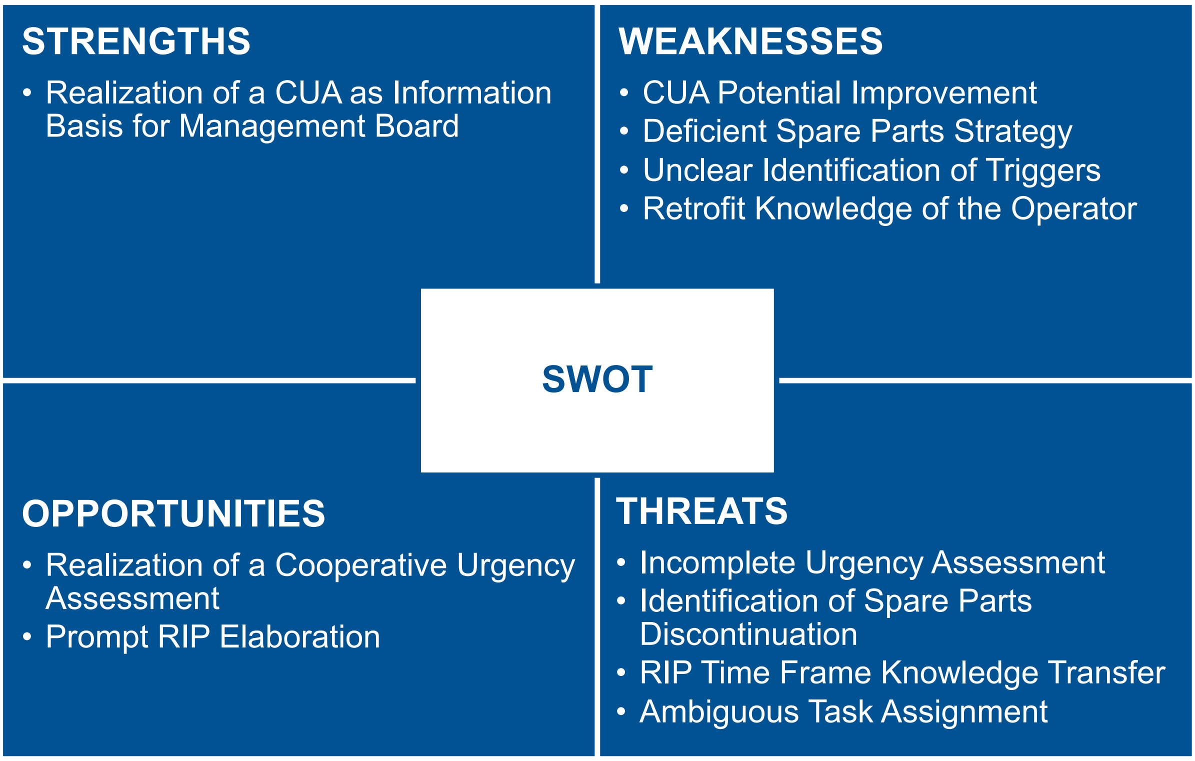

Figure 3-8: SWOT Analysis of a Retrofit Decision-Making Process

On the other hand, this may be considered as a **weakness** as well, since for the decision to be accurate, likewise the CUA needs to be as comprehensive as possible. For achieving this, not only the most noticeable costs related to the retrofit must be under consideration, the spotlight must also be put on other not so obvious direct and indirect retrofit costs. Other weakness that operators may commit is having an inefficient strategy for the spare parts, which is something that may be overlooked and can have a tremendous impact on a firm. Furthermore, it can also be that operators fail to promptly identify the retrofit triggers mentioned in the previous chapters, leading to late retrofit actions and exposing the operators to higher costs. Ultimately, it can be considered as a weakness that operator's knowledge for retrofits is generally rather low, if compared to the knowledge of the implementers.

Opportunities that are visible in the DMP are, for instance, a prompt elaboration of a RIP or "initial RIP". As commented in chapter 3.4.2, the elaboration of this initial RIP is, as well as the CUA, serves as a great help for the decision making. Moreover, the cooperation between implementer and operator for the realization of an urgency assessment is one of the strong points of the retrofit process.

It is perceived as a **threat** however if the aforementioned urgency assessment is either not correctly identified who is responsible for it, or it is not comprehensive enough to gather all the influences that affect the operator, which also includes a deficient identification of the production discontinuation of the spare parts. Additionally, the agreement of a time frame for implementing the retrofit, which takes place in the offer phase, is considered one of the most critical points of the process [The-2020]. A deficient communication caused by a knowledge gap between operator and implementer may lead to an inefficient elaboration of a RIP, incrementing the costs of the retrofit. Lastly, an ambiguous task assignment in any step throughout the process may threat the final result of the modernization.

The weaknesses and threats that were here identified have indeed some potential to be improved or mitigated. The following chapter analyzes more comprehensively some of the above-noted hurdles, with the intention to shed some light on the operator knowledge breach.

4 Potential Improvements of a Retrofit Decision-Making Process

This chapter provides a more extended dissertation about some of the issues that come up in the previous analysis of a decision-making process. The urgency and criticality assessments are examined in the chapter 4.1, where several factors that influence these assessments are identified and analyzed. Additionally, chapter 4.2 explores the RIP time frame selection by operator and implementer, offering with a survey based on past retrofit experiences.

4.1 Urgency and Criticality Assessment

4.1.1 Urgency-Criticality dependency and Responsibility Allocation

Dutton et al. provide a definition of urgency, affirming that "urgency indicates the **perceived importance** of taking an action on an issue and, conversely, the perceived cost of not taking an action". This perception is generated as well from a combination of several judgements and assessments which are connected to the visibility and the exposure of certain issues, which at the same time make the perceived need of adapting the current situation of an organization dependent of the urgency of a strategic issue. [Dut-1987, P 283]

Correspondingly, Morgeson et al. associate urgency as the degree to which an organization must respond to an event in order to "capitalize its occurrence or mitigate its negative consequences" and at the same time they link urgency to criticality by defending that criticality is "the degree to which an event is important, essential or a priority". [Mor-2006]

In the previous chapter, the urgency-criticality analysis and assessment were allocated in a retrofit DMP in the offer phase, being the first step performed after the implementer was contacted. Including these steps in both lanes contributes to one of the threats identified in chapter 3.5, "ambiguous task assignment". However, what makes this block hard to allocate is that the input from both stakeholders is necessary for the assessment to be precise.

- **Operators** are the ones that better know their facility and its needs and weaknesses.

- **Implementers** have the retrofit expert knowledge, and the experienced tracking of spare parts is normally related with an implementer (although they are not necessarily responsible of carrying this task).

It is then theoretically advantageous for the operator that a cooperation between both parties exists and persists for developing this evaluation. It is important to point out this weakness of the process so that it gains visibility and can be taken into consideration to a greater extent.

4.1.2 Approach to a Criticality Assessment

In chapter 4.1.1, the relation between the terms “urgency” and “criticality” was introduced. Applying these definitions to ASRS modernization processes, it is in practice considered that a determined retrofit urgency is assessed based on a lowermost criticality assessment. In other words, high component failure criticality generates a higher urgency for a retrofit, but not the other way around.

First of all, it is fundamental to distinguish what the term “criticality” refers to when it concerns a ASRS retrofit. Ultimately, this term refers to how much an event affects an organization, and these events take place in two different levels, macro and micro level.

- A **Macro** level of criticality specifies the degree to which the failure or a standstill of the ASRS affects the overall operation of the plant.
- A **Micro** level of criticality focuses on, considering the different factors that affect components of ASRS, to what extent the failure of a certain component influences a standstill of the ASRS.

Although similar, both concepts should be analyzed separately to achieve a greater understanding of this topic. Both levels of criticality are discussed in further detail in the following chapters. The criticality assessment is in this work approached from a macro level (chapter 4.1.3) to a micro level (chapter 4.1.4).

4.1.3 Macro Level Criticality Assessment

A macro criticality level connects the operation of the ASRS to other areas of the operation of a plant (e.g., production). For some operators of ASRS, **unplanned downtimes** in their warehouses can be considered as the critical scenario concerning their intralogistics systems.

Nevertheless, not every company operates their ASRS the same way or not every warehouse plays the same role in the functioning of an operator’s business. These factors make the criticality assessment to an unplanned standstill strictly individual to each operator. In order to measure to what extent a standstill in the automated storage and retrieval systems would affect the whole operability of the plant, or in other words, how critical are unplanned downtimes in the ASRS, the following factors should be considered:

- Allocation of the ASRS within the operator's chain of processes.
- Flexibility or strictness of deadlines in which the company maneuvers.
- Opportunity costs of not sticking to those deadlines.
- Warehouse dependency of the ASRS.
- Duration of a standstill.

Although this is not the most common situation, it can be that downtimes in ASRS have little negative influence on the plant operations of some companies. For instance, a warehouse that can access their storage racks by other means (e.g., using a forklifts), has less dependence on the ASRS and therefore can assess lower criticality to an unplanned standstill of their ASRS.

In practice, these situations are rarely found and unplanned downtimes in the ASRS are normally assessed with high levels of criticality. A company that because of a failure in their ASRS cannot meet deadlines or its production system cannot be fed will with all certainty face big economic and business losses.

From the factors that affect the criticality of unplanned downtimes, the duration of a standstill brings a special interest. A few hours standstill cannot be considered to have the same influence as a standstill that lasts for several days. However, the factors that determine the duration of a standstill take place in a lower level, the micro criticality level.

4.1.4 Micro Level Criticality Assessment

The micro level criticality assessment focuses on the failure influence of a determined component in the overall ASRS. It is here the objective to analyze and determine the failure of which components of the ASRS is critical.

In a ASRS failure situation, the failure of a component which production has been discontinued is in most of the cases considered as a worst-case scenario. In comparison with a component that is still being produced, there are several factors that increase the duration of the stillstands or the reparation costs.

These factors can be classified into two groups, major and minor factors. Some of these factors are also affecting spare parts that are still in production. Nevertheless, the influence in discontinued spare parts in stronger and therefore, the following assumptions are only taking into consideration discontinued components.

Two **Major** factors are considered to have a greater influence in the criticality assessment.

- Spare parts availability: spare parts that are discontinued do not necessarily mean that they can no longer be found in the market. However, because of the discontinuation of production, the availability of these parts will be reduced with time and this reduction will be reflected in the price and acquisition efforts.
- Failure frequency: Chapter 2.2 provided a description of the different components that form SRMs. Naturally, each component is designed for performing a particular function and is exposed differently to wear and deterioration. This ultimately affects the frequency with which a component fails.

Minor factors, on the other hand, influence the severity of a standstill of the ASRS to a lesser degree than major factors. The greater or lesser influence of these factors will result in a deviation from the criticality assessed with major factors. The following influences are some examples of minor factors:

- Third-party support measures the independency of an operator to perform a reparation of a failed component. This is takes into consideration the expertise and specialization level of the own maintenance department.
- Spare parts strategies are developed internally by operators in order to mitigate the possible damage that the failure of a discontinued component may cause. It basically consists in the procurement of spare parts that have either been discontinued or are exposed to a discontinuation in the short term. This topic is further discussed in chapter 4.1.6.
- Maintenance time have a direct influence in the duration of stillstands. Maintenance times may vary depending on if it is the in-house maintenance department or external implementor who is repairing or exchanging a component. Although is here classified as a minor factor, long maintenance times can have severe consequences for operators.

4.1.5 Criticality Matrix

The possible combination of factors and scenarios and the intrinsic subjectiveness of the criticality assessment lead to the determination of criticality standards being not totally feasible.

However, taking into consideration the aforementioned statements, an approximation of this assessment could be represented by a criticality matrix, like the one shown below in Figure 4-1.

The criticality matrix is conceived by taking as a model a probability and impact matrix, method which is frequently used in project management for assessing risk in projects. [Pro-2017]. Equivalent to the risk assessment matrix, the higher negative influences of a specific variable are represented with red colors, the lower with greens and intermediate with yellows.

It is important to remark that this criticality matrix is an estimation of how different variables can influence a criticality assessment of an operator and that this specific example is designed based on the information obtained from the interviews that were conducted with operators and implementers. A criticality matrix should be adapted to each particular case depending on individual criticality standards. To illustrate better the functionality of a criticality matrix, the following scenarios in which major and minor factors combine can be considered and plotted in the matrix. In accordance with the previous chapter, the failures are relating to discontinued components.

Scenario A: High scarcity of spare parts and high failure frequencies represent a very critical scenario.

Scenario B: The criticality assessed to the previous scenario can be mitigated by an efficient spare part strategy.

Scenario C: High scarcity of spare parts triggers a not so high criticality if the component fails very seldomly.

Scenario D: High availability of spare parts create critical scenarios if the maintenance or repair times are high.

Scenario E: High failure rates become problematic if the own maintenance department cannot repair the failed component and the required repair time is high.

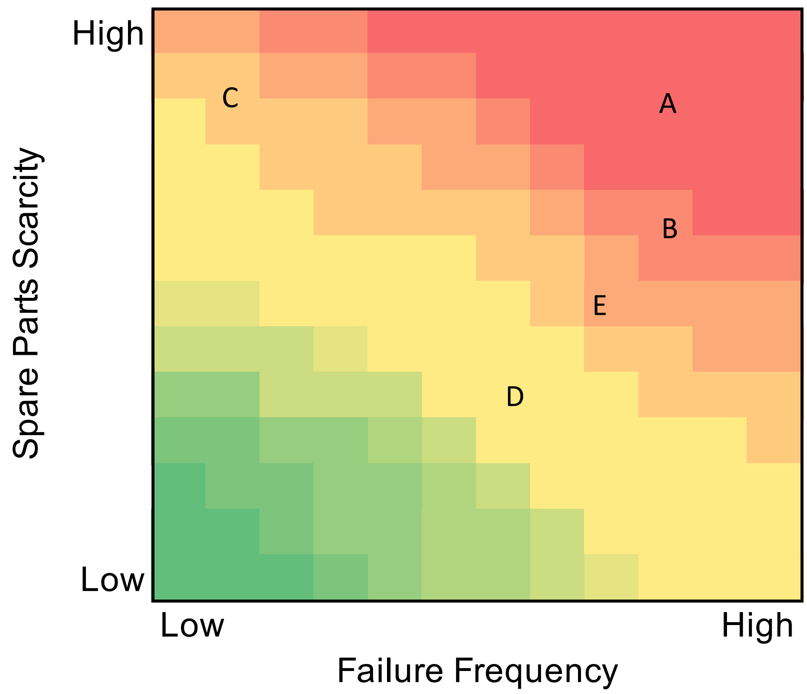

Figure 4-1: Combination of Scenarios in a Criticality Matrix (Based on the Findings from the Interviews)

Despite the matrix being solely an estimation, it can be observed how the criticality is greater for higher values of y axis (spare parts scarcity) than for higher values of x axis (failure frequency). An explanation for this is that the failure of a component very scarce in the market exponentially increases its price and great efforts and prolonged delivery times can be as well expected.

4.1.6 Spare Parts Strategy

Warehouse operators have little or no control on the appearance of major factors in their systems, especially when it comes to the production discontinuation of spare parts. In order to mitigate the influence of major factors, operators need to boost the minor factors that can be internally controlled. A minor factor that can be internally controlled by ASRS operators is the spare parts strategy.

As commented in chapter 4.1.4, spare parts strategies fundamentally consist in the procurement of components which risk or exposure to suffer a production discontinuation is rather high. In order to efficiently approach a spare part strategy, the specific spare parts that need to be stored must be identified, as well as the storage volume of these spare parts. The selection of spare parts must be approached considering the storage feasibility as well as a micro level criticality assessment.

The evaluation of the components which are **feasible to store** is a fundamental part of an efficient spare parts strategy. One of the bases of the lean manufacturing methodology is that any activity that does not add value to a product is considered as waste or “muda”, being the main objective of this to eliminate this kind of waste, which includes the inventory and the excessive storage of stock [Tej-2011, P 288]. Therefore, overstoring spare parts of ASRS would be excessively costly and counterproductive and contrarily an insufficient storing of spare parts can be excessively risky.

What the term storage feasibility refers to is that there is some sort of ASRS components which prolonged storage is not reasonable. This is in most of the cases electronic components. In some cases, these components are sensible to the environment in which they are stored and require of specific low oxygen and moisture conditions, the lack of which may damage its functionality [Zha-2015, P 236-237]. On the other hand, other electronic components need regular maintenance, something that most operators ignore. For instance, frequency convertors must be charged every 24 months in order to keep the capacitor in a good state.

Storage feasibility has to be balanced likewise with the failure frequency and probability rate of this component. It is therefore reasonable to stock electronic components besides its storage problematics if its elevated failure rate forces operators to regularly replace such components.

Criticality assessments are also essential for the adequate selection of the components to be acquired and stored. This serves for the identification of the spare parts which are crucial to maintain the production process, that means, the lack of which would generate a discontinuity in the process. [Now-2015, P 151-158, Kol-2018]

In micro level criticality assessments, the market availability of discontinued spare parts is considered a major factor and in spare parts strategies plays a fundamental role. It is therefore important for operators to keep track of the discontinued spare parts, which is achieved by the communication with OEMs or implementers and carried out in what according to Kolinska et al. name as spare part’s availability management, one of the most significant factors ensuring the continuity and efficiency of a production process [Kol-2018].

4.1.7 Tracking in Spare Parts Strategies

The discontinuation of a determined component from an ASRS does not necessarily mean that an operator should assess here a very high urgency that leads them to an immediate retrofit, since spare parts could still be accessible in the market for the near future. Nevertheless, the availability of a discontinued spare part will be reduced with time and suffer a consequent increase in the price. Therefore, the behavior of the variation of the number of available spare parts in the market must be here followed and analyzed. This variation behavior strongly determines the operator's spare parts strategy.

Operators of ASRS can find different alternatives to estimate the number of available spare parts in the market, such as regular checking of the spare parts price on E-Commerce platforms. However, it is in most of the cases the simplest approach to directly get in contact with OEMs.

It is also interesting to carry out a periodic analysis of the market price of discontinued components and examine the price volatility. A component which price has been fix for a relatively prolonged amount of time is less convenient to be owned in stock as its availability can be expected to be stationary for the short term. Contrarily, a component which suffers frequent rises in its price serves as an indicator of scarcity, which makes this component more interesting for stocking [Pri-2020].

The former scenario can be estimated to behave in a similar way as the Figure 4-2 shows. In this case, the value of the number of available components is static until the production of this component is announced to be discontinued. After this point, the sum of components available in the market experiments a linear reduction over time until the number of available components reaches, in theory, to zero.

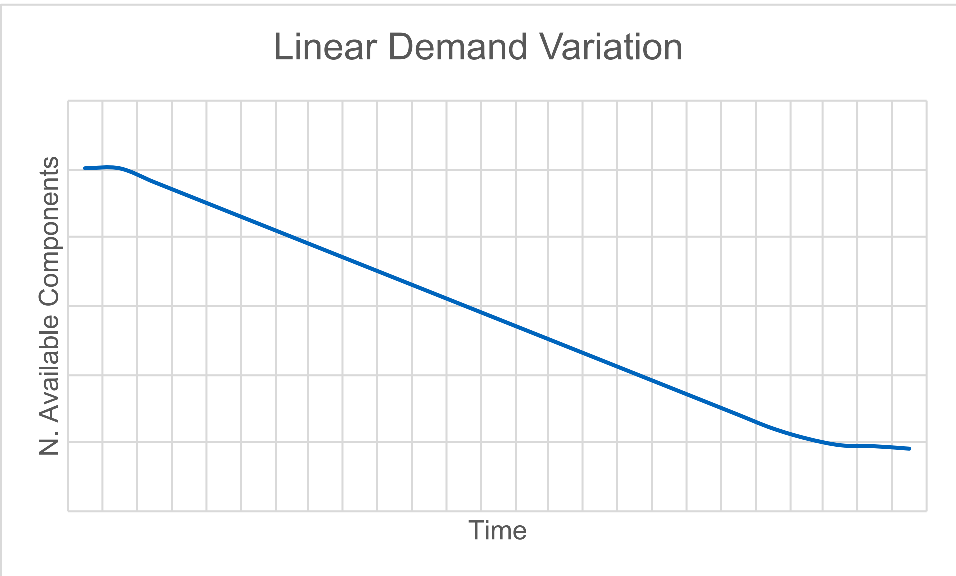

Figure 4-2: Estimation of a Linear Demand Variation

The graph shows eventually a stabilization in a determined low value of the y axis. This is because the price of the component is indirectly proportional to its market availability, so for such low values of availability, the price the component must be high enough for the operators of ASRS using this component to already have either provisioned their stock with this component or modernized their installations.

The latter scenario, where the availability and price are more volatile, can experience a behavior similar to the one on Figure 4-3. The number of available components is static as in the previous case until the production discontinuation is announced. On this point, the reduction in number of components in the market suffers a decrease analogous to a $y = 1/x$ function until it stabilizes in a y value close to zero, or zero (applying the same reasoning as before).

A few reasonings can be extracted from this high volatility situation. In the first place, the rapid reduction of spare parts in the market after the discontinuity announcement is a clear sign that the number of companies that operate ASRS using similar technology is large. It is hence interesting for an operator to recognize that at an early stage after the announcement, that an early quick reduction of this number can lead to an even more severe availability fall, since a behavior similar to Figure 4-3 is probably also expected from other operators, which may at the same time speculate with this reduction and proceed to enlarge their stock of this specific spare part.

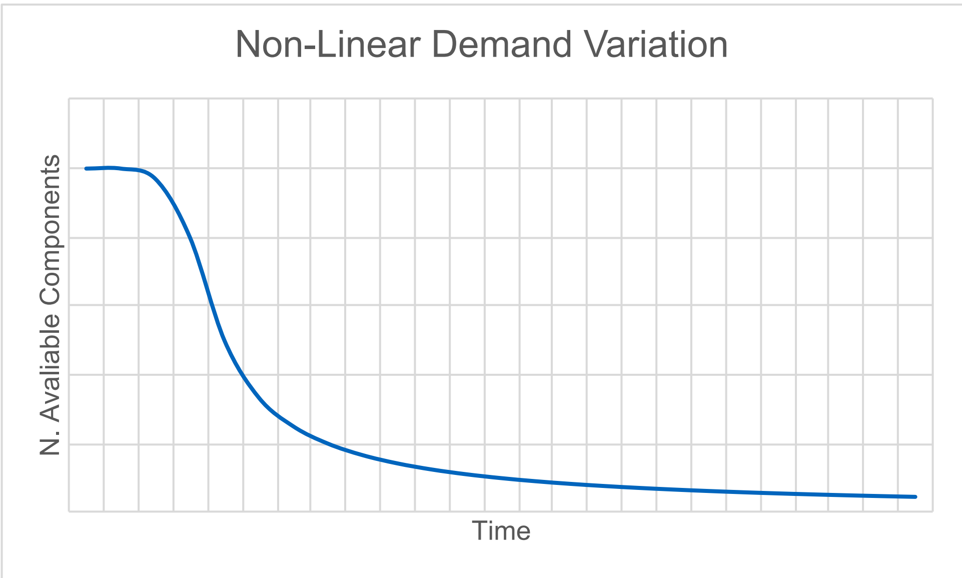

Figure 4-3: Estimation of a Non-Linear Demand Variation

4.1.8 Renouncement of Spare Parts Strategies

It is also possible to assume that if the behavior of the number of available components in the market decreases to a value close to zero, but not equal, the procurement of spare parts after a production discontinuation is not totally necessary, since it can be expected to always be a marginal number of spare parts in the market.

Although this is a very risky approach, it can result being a cost saving strategy, especially for a later reaction of the operator where the price is already high for the spare part, if the component is not frequently failing or if the operator has already stock of it.

For these particular cases where spare parts strategies are not taken into consideration, several factors must be indeed contemplated. In case of not owning stock of the discontinued spare part, a downtime influence assessment should be here carried out. This assessment requires the knowledge of delivery times as well as reparation times of the component for estimating the overall duration of a standstill. In addition, Kolinska et al. define a reliable “spare part’s supply chain” by studying the reliability of delivery (deadlines meet), transport (undamaged order) and logistic infrastructure (supporting equipment) [Now-2015, P 151-158, Kol-2018].

It is however mostly habitual the procurement of such spare parts, until the variation in the component price reaches a point where it exceeds a threshold value for the operator that trigger its need for a retrofit.

4.1.9 Urgency and Criticality Overview and Findings

Since this chapter covers a wide topic and the information provided is rather extensive, it is interesting to have an overview of the topics here covered.

The urgency-criticality assessment takes place in the offer phase in a retrofit DMP. These two terms are tightly bounded to each other, since the numerous factors that influence the criticality of a failure determine the urgency for a retrofit.

A criticality assessment can be carried out in two different levels. Whereas a macro level studies the downtimes influence of ASRS in the operation of a plant as a whole, micro level focuses on component-related criticality. Both macro and micro criticality assessments are influenced by different factors that affect each operator in a different manner, resulting in criticality assessments being strongly individual to each operator.

In particular, factors that influence the failure criticality of a discontinued component can be divided into major and minor factors. A suggested way of approaching a micro level urgency assessment that gathers the influence of both major and minor factors is the design of a criticality matrix. This makes it easier for the operator identify an individual criticality.

A way of mitigating the major factors that fall beyond the control of the operators is by carrying out spare parts strategy. In order to do so, operators must identify the spare parts that are feasible to store as well as track the availability of spare parts in the market.

Implementers have wide knowledge and experience in these areas. Therefore, a solid communication between operator and implementer in this extent is highly recommendable.

4.2 Introduction to the Problematic of the Retrofit Implementation Plan

4.2.1 Retrofit Implementation Plan Background Problematic

It could be observed in the previous section that despite the complexity of the process, some parts of it have a certain potential to be optimized, in order to make the process smoother for both operator and implementer. However, is the retrofit implementation process the one that most operators find critical and therefore brings more attention.

This RIP can be more easily understood by analyzing the background knowledge of the two main stakeholders of an average retrofit process as the one described in chapter 3.4.

It is not rare to find situations where a company has been operating its plant for a long time without any support from the manufacturer that either provided this company with ASRS or that even retrofitted them. Yet if this is not the situation, it cannot be compared the knowledge that operators have on the functioning and necessities of their plants to the one that implementers have.

The same applies the other way around, implementers possess the retrofit knowledge that other stakeholders from the retrofit DMP lack, not only because of their past experiences, but also their business connection with suppliers or OEMs.

This situation brings a problematic asymmetrical information between different stakeholders, where symmetric or asymmetric properties between different negotiating partners can have an influence on the process and its outcome. [Pfe-2000, P 21-23]

However, symmetry and asymmetry in negotiations do not necessarily correspond to common understanding, therefore information exchange about interests and priorities plays here an important role to reach outcomes that are more beneficial for all parts. [Tho-1991, P 161-163, Pfe-2000, P 21-23]

4.2.2 Problem Identification

Verma states that "Communication is one of the important variables, held responsible for rise and fall, success and failure, progress and regression of any organization" [Ver-2013, P 63]. This statement applies in a very sensitive way to the problematic described in chapter 3.5 of the agreement for an implementation time frame for retrofits. Specially in this part of the retrofit process, the communication between operator and implementer plays a critical role.

In a retrofit negotiation, both parties control different types of information (some examples are mentioned in Table 4-1). In order to balance the size of information, and aiming to achieve a more profitable communication flow, an analysis of a retrofit implementation plan shall provide useful information to warehouse operators. Therefore, in the following chapters will cover the retrofit implementation plans that were applied to other operators along with their motivations to adopt a determined timeframe.

Table 4-1: Knowledge Area of the Different Retrofit Stakeholders

Operator	Implementer
Operation of the plant and warehouse	Spectrum and feasibility of implementation alternatives
ASRS system availability	Spare parts tracking
Warehouse flexibility for standstills and rearrangements	Retrofit experience

4.2.3 Analysis Approach

Chapter 3.4 allocates the RIP in the overall retrofit DMP after the cooperative completion of the urgency and criticality assessment and right before the submission of the offer to the operator. Therefore, this case initial RIP must comply with the urgency and criticality previously assessed.

In order to shed light to this topic, several sources of information were considered. In the same line as in the previous chapters, expert interviews with operator and implementer were conducted (interview protocols can be found in Appendix A). Additionally, an extended research was carried out as well using (all) the articles related to ASRS retrofits in the journals ModernisierungsFibel from the years 2016 to 2019. The data from these journals was gathered and employed for elaborating the survey.

In the following chapter 4.2.4, the diverse alternatives that were found in the ASRS retrofit articles from ModernisierungsFibel journal are presented and debated. Moreover, in chapter 4.2.5, the aforementioned alternatives are surveyed and compilated, allowing some reasonings to be made.

4.2.4 Alternatives for Retrofit Implementation Time Frames

The implementation works of a retrofit may take place in a multitude of different alternatives, which as a general rule are provided by the implementer to the operator of ASRS. However, these multitude of different alternatives steam out of the in this chapter discussed **principal alternatives**.

It is worth mentioning that the preference for these alternatives may depending on the operator's necessities and plant restrictions. As it was discussed in the chapter 4.1.3 Macro Level Criticality Assessment, it will depend on the influence that, for instance, the criticality assessed to a standstill in the plant. A company with a very high-risk assessment for downtimes in its facility will have completely different preferences than another company which, because for the reasons already mentioned, assess no or low criticality to a standstill. Therefore, it is the implementer's responsibility exclusively to bring information about the possible alternatives but is ultimately responsibility of an operator to come up with the most appropriate alternative for the warehouse.

Furthermore, preferences do not only depend on whether a standstill criticality assessment is high or low, also depending on the degree of modernization that the ASRS require. Plants that "regularly" retrofit their warehouses will need less implementation times resulting in cheaper retrofits, whereas plants that are seldomly retrofitted their warehouses (every 10 or 20 years) will require longer and significantly more expensive retrofits.

One of the least costly alternatives is the **implementation during running operation**. Despite being the name fairly self-explanatory, it does not normally mean that the company's in-plant operation is not affected by this implementation. In most of the cases, a retrofit implementation during running operation requires of the rearrangement of the warehouse, so that the lane which ASRS must be retrofitted is shutdown while the other lanes function at a relatively more demanding capacity (due to the increase in the goods stored as a consequence of the rearrangement). If it is the case that all the lanes must be modernized, then the protocol repeats until all lanes are covered. If the ASRS availability is high, then more than one lane could be closed at the same time, decreasing in this way the costs of the modernization.

This alternative also requires that the warehouse is not operating at its maximum capacity, otherwise this implementation during running operation alternative would only be feasible if the construction of auxiliary storage racks either inside or outside the plants are possible.

Another also interesting alternative is the **implementation during vacation period**. This alternative is the one which less impact has on the plant, since, depending on the modernization degree, the whole implementation could be carried out uninterruptedly during this vacation period. This alternative however has also some drawbacks. First of all, a vacation period in which the plant is totally shutdown is something that not all the operators of ASRS can benefit from. Secondly, even if an operator of ASRS disposes of this production interrupted period, it may almost certainly coincide with a festivity such as Christmas or Easter, which would implicitly rise the price of the implementer's personnel that must work during this period.

If the previous alternatives cannot be used by the operator, then it is also possible to realize an **implementation during the weekend**. This method is still a better alternative than a standstill but still presents several drawbacks as well. Best case scenario would be to be able to carry out the entire retrofit implementation in solely one weekend. Although the price of the implementer's personnel would also rise in comparison to the alternative of implementation during running operation, this alternative would theoretically not affect negatively to the functioning of the plant, as well as not requiring any rearrangements of the store goods. This alternative is in most of the cases feasible for plants that are regularly retrofitted, since the implementation times are shorter.

However, since this is not always feasible, the previous alternative must be extended to an **implementation during consecutive weekends**. Although this alternative still benefits of not affecting the in-plant processes from the previous alternative, an exponential rise in the implementation costs must be taken into account. The explanation for this is that the implementer, the moment of arriving to the operator's warehouse, needs to carry out several operations to prepare the lane or lanes to be retrofitted during the weekend (as it will also happen if the implementation took place during only one weekend). Additionally, after finishing the works for that weekend, the operators must carry out a second preparation of the retrofitted lanes so that they can still be used in the week to come. This process repeats itself the following weekend when the implementer's operators must carry on with the work. This preparation, after arriving and before leaving, takes working time from the operators which have to perform this every weekend and which salary during the weekend is also higher and which must work for more shifts in order to make a good use of the weekend time. Moreover, it must be added to the costs of the retrofit the expenses of transport bringing and re-turning each weekend the operators and the materials needed for the modernization. Because of this preparation times, normally implementers require the warehouse to be shut for an extra day each weekend.

It is as a general rule the least preferred alternative to carry out an **implementation with a stillstand** in their facilities. On the majority of cases, this is the only alternative for an operator to host a modernization in their ASRS and therefore the implementation works take place during several shifts on the same day, as well as are planned to take place on a lower demand season. It may be also the case that, for some operators, having downtimes in their facility is not very critical and can afford to implement using this alternative, which benefits of having also lower direct retrofit costs, as the implementation works can take place continuously during the week, which means that high operator salaries are not paid.

However, it is sometimes the case that operators opt for a combination of any of the previous presented alternatives. It can be sometimes found that operators prefer to host a retrofit implementation in a "long weekend". This normally means to shut down the warehouse either on the previous Friday or the following Monday, or both.

Other companies may have not so long vacation periods and therefore need implement on the weekends as well, or even carry out implementations works in running operations until the ASRS needs to be shut down and do this last part during a weekend.

The variation and combination of implementation alternatives, as just seen, is rather wide and therefore needs to be carefully analyzed, specially by the operator, which is the stakeholder that better knows the needs of their installations. Nevertheless, this analysis is not possible without the input from the implementer, which has to previously define the duration required for the implementation works.

Table 4-2 offers a summary of the previously mentioned alternatives, considering their advantages and drawbacks.

Table 4-2: Summary of Retrofit Implementation Alternatives

Retrofit Alternative	Advantages	Disadvantages
Running Operation	Economic retrofit.	Long duration of a retrofit if the number of SRMs is high. Warehouse rearrangement requirement (low capacity). Impact on warehouse operation.
Vacation Period	No impact on warehouse operation. Continuous implementation.	Not all operators have vacation period shutdowns. Implementer's personnel salary rises.
One Weekend	Low influence in operation.	Only possible for "small" retrofits. Implementer's personnel salary rises.
Consecutive Weekends	Low influence in operation.	Very expensive retrofit. Planned standstills are most of the times necessary.
Planned Standstill	Continuous implementation.	Very high influence on operation.

4.2.5 Survey of the Individual Optimal Time Frame for a Retrofit Implementation

It was commented at the beginning of this chapter that communication is not only a success factor of successful change management, but also comes in the form of a potential failure factor, normally caused by misinterpretations can lead to misunderstandings and consequently to conflicts [Lau-2010]. A right communication between operator and implementer leads to successful decisions, in this case applied to the determination of the most suitable alternative for implementing a retrofit in the operator's installations.

Out of 37 articles about modernization of automated storage and retrieval systems that can be found in the ModernisierungsFibel journal from the years 2016-2019, 27 delivered useful information that could be used for developing a survey, which is represented in form of a graph in Figure 4-4. This survey shows which are the most preferred time frames for a retrofit implementation.

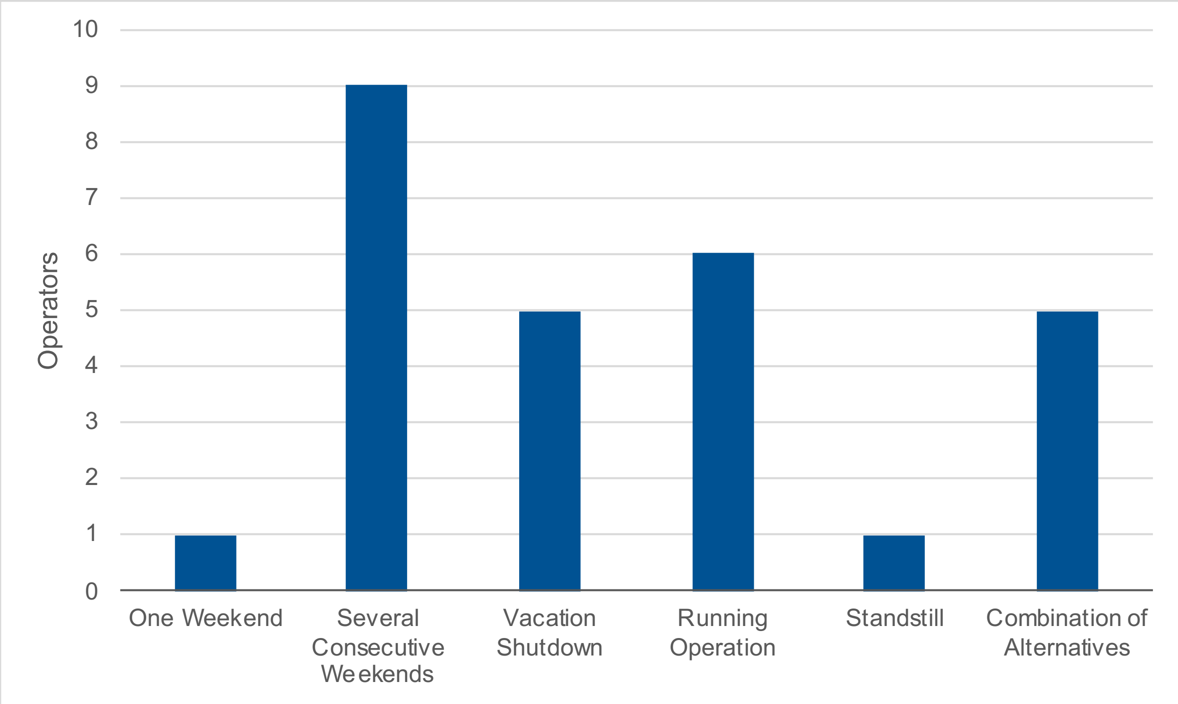

Figure 4-4: Most Preferred Retrofit Implementation Time Frame Alternatives (source: ModernisierungsFibel)

The study shows that a third of the surveyed firms decide on several consecutive weekends as the best option for implementing the retrofit. Furthermore, this option matches the results obtained from the interview conducted with operator and implementer, which both of them stated that weekends was normally the most frequently picked option.

Some of the motives explained in the previous chapter might be the reasons for companies not choosing to implement during vacation period or on running operation, options that *a priori* seem to be less costly.

On the other hand, it can be observed how implementing during solely one weekend and implementing with a stillstand in operation are rather edge cases.

An interesting point here is how 5 out of 27 companies decided to use a combination of the previous alternatives. However, no patter could be observed in the selection of an alternative time frame, all the companies decided to use the previous alternatives in totally different combinations.

5 Conclusion

It was frequently emphasized throughout this work how retrofits are firmly individual to each warehouse operator. This retrofit intrinsic characteristic makes the modeling of a retrofit process challenging, in which boundaries cannot easily be set. However, synergies between different retrofit process can be identified allowing the shaping of blocks along the processes.

The modeling of such process permits distinguishing the different hurdles present in this process. In order to shed some light on this issue, two of the most conflictive blocks of the process, where communication between stakeholders plays a fundamental role, where analyzed.

The same issue affecting the modeling of a retrofit process appears as well in the analysis of the different blocks. Urgencies for retrofits are stablished according to the criticality assessed to a ASRS failure. influences that take place in macro and micro levels are identified and must be individually weighted out for the elaboration of an effective criticality assessment. Here, the utilization of tools, such as a criticality matrix, can be of a great help for ASRS operators to gather all criticality influences. Operators can at the same time mitigate the effect of the external influences by, for instance, carrying out spare parts strategies.

In addition, the determination of the time frame for a RIP is a conflictive topic, where interests collide, and which can be improved by a transfer of information to warehouse operators.

5.1 Allocation in OptiFit Project

It was already commented in at the beginning of this work that this master thesis forms part of the research project OptiFit from the fml department in TUM. The OptiFit project starts from the same initial situation as this work.

The aim of the OptiFit research project is to develop a methodology that helps both ASRS operators and implementers throughout a modernization process. For achieving this, the methodology intends to close the operator’s knowledge gap, sensitizing the operators by transferring knowledge about retrofits as well as supporting them in their decision-making process, with the ultimate target of implementing the retrofit at the right time. [Xu-2020]

In order to achieve this objective, Xu suggests four blocks that are fundamental for improving a retrofit process. These blocks are illustrated in Figure 5-1. [Xu-2020]

Figure 5-1: OptiFit Methodology for the Optimal Support of Operators and Implementers during Modernization [Xu-2020]

Taking a look at the overall work from the previous chapters, provided in following chapter 5.2, it can be observed that it is not possible to allocate this work to just a single block of the ones from above.

The representation of an average retrofit decision-making process developed in chapter 3 and constitutes the main part of the work. The delimitation of this process can serve as a guideline to warehouse operators in a process that might be unknow for them, broadening their knowledge about retrofits.

The analysis of the retrofit DMP makes visible a series of weaknesses or obstacles that can affect warehouse operators when they venture into a modernization process. The detected hurdles and virtues of this process are listed in a SWOT analysis in chapter 3.5, and the awareness of these obstacles sensitize the operators of ASRS for retrofits.

In chapter 4, two of the retrofit obstacles are carefully analyzed, focusing on the complications that could affect ASRS operators if these are not sufficiently considered. It is here intended to bring more knowledge to warehouse operators, providing also a first insight to an urgency assessment.

5.2 Summary

The long-term functionality of ASRS is mainly achieved by warehouse operators by the maintenance of these systems and when necessary, via a retrofit. Retrofit implementers assist operators through the modernization process of their facilities. However, numerous obstacles arise throughout this process, largely due to a knowledge deficit or gap of warehouse operators. This knowledge gap hinders them to assess correctly the urgency for a modernization in their warehouses, leading to retrofits not being taken at the right time. [Xu-2020]

With the fundamental objective of closing this knowledge gap, both warehouse operators and retrofit implementer companies where interviewed to obtain the necessary information that allowed the modelling of a retrofit decision-making process. However, the modelling of this process is limited by its intrinsic individuality. Since there are no two identical retrofit processes, it was here represented an average process that best gathers the most important steps.

A retrofit DMP can be divided into three phases. The different internal and external influences that trigger retrofits are detected and processed by the operator in the initial phase or necessity for retrofit identification phase. If these influences are sufficient for triggering a retrofit, an examination and planification process is carried out by an implementer which concludes with the submission an evaluation of the offer, which takes place in the offer phase. In the last phase, the implementation of the measures is carried out in the warehouse of the operator.

This definition of a retrofit decision-making process facilitates the identification of different obstacles that affect operators throughout the retrofit process. The awareness of these possible situations opens an opportunity for operators to be better prepared against these events, so that they can either avoid them or mitigate their damage.

The discontinuation of the production of ASRS spare parts is a key trigger for retrofit. For this reason, warehouse operators cannot correctly assess an urgency for a retrofit without taking into account how critical would it be a failure of one discontinued component for operation of the whole plant. Criticality is approached in both a macro and micro level. In each level several factors are considered that in different combinations can entail different degrees of criticality, which must be assessed individually by each operator. To mitigate this issue, it is important for operators to carry out a careful spare parts strategy, where the storage feasibility as well as the tracking of discontinued spare parts are considered for the identification of spare parts that must be procured.

Thanks to the input of both process stakeholders, a conflictive point was identified in the process. In most of the cases the determination of a time frame for the implementation works becomes a challenging step and therefore this decision needs of a strong cooperation between ASRS operators and implementers. Through the interviews to operators and implementers as well as the research in specialized journals, it was observed that retrofits are mostly taking place either exclusively during weekends, during a plant closure in a vacation period (if possible); or during running operation, closing individual aisles and rearranging the warehouse. Despite of an existing tendency for retrofitting during different weekends, operators of ASRS make big efforts to devise retrofit plans that best suit their interesses, ultimately attempting to avoid downtimes of the warehouse as far as possible.

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Appendix A Interview Transcripts

Interview Protocol

fml Chair of Materials Handling, Material Flow, Logistics - Technical University of Munich

Project	Analysis of the Modernization Proces of Automated andstorage system			
Company	Chair fml			
	Date	**Duration**	**Location**	**Protocol recorder**
	27.08.2020	13.30-15.00	Online Meeting	Mr. Pérez-Manglano

Attendees	Mr. Pérez Manglano (TUM)	Mr. Baldauf (LTW)

Content / course	
1.	**Introduction**
	1. Personal presentation 2. Presentation of the structure of the Interview 3. Comparison with available data
2.	**Presentation of a retrofit process estimation**
	1. Description of the estimated process 2. Identification of differences with a real process 3. Request for a description of a real process experience Questions/comments 1) Triggers can be recognised by operators and later contact the implementer 2) Implementation plan is strictly found in the offer phase 3)Implementation plan is a decisive factor for clients
3.	**Focus on the individual steps of the process**
	1. Questions to the individual steps of the process Questions/comments 1) The urgency of a retrofit is estimated together with the client. For this, the availability on the market of discontinued spare parts plays an important role and basically determines the urgency. 2) Operators have to consider how long and how often can they close its warehouse 3) The warehouse shutdown is critical to most of the clients (not to all) 4)The operator offers different solutions or alternatives for implementing the retrofit 5) It is mostly preferred to retrofit on weekends 6) Reason: Some operators cannot afford to close their warehouse 7) The implementation in different weekends exponentially increases the price of the retrofit 8) Fallback plans are very seldomly used. 9) Very old facilities involve challenging retrofits, where planning must be done by short-term steps. Fallback plans play a more important role
4.	**Conclusion**
	1. Space for solving remaining questions

Interview Protocol

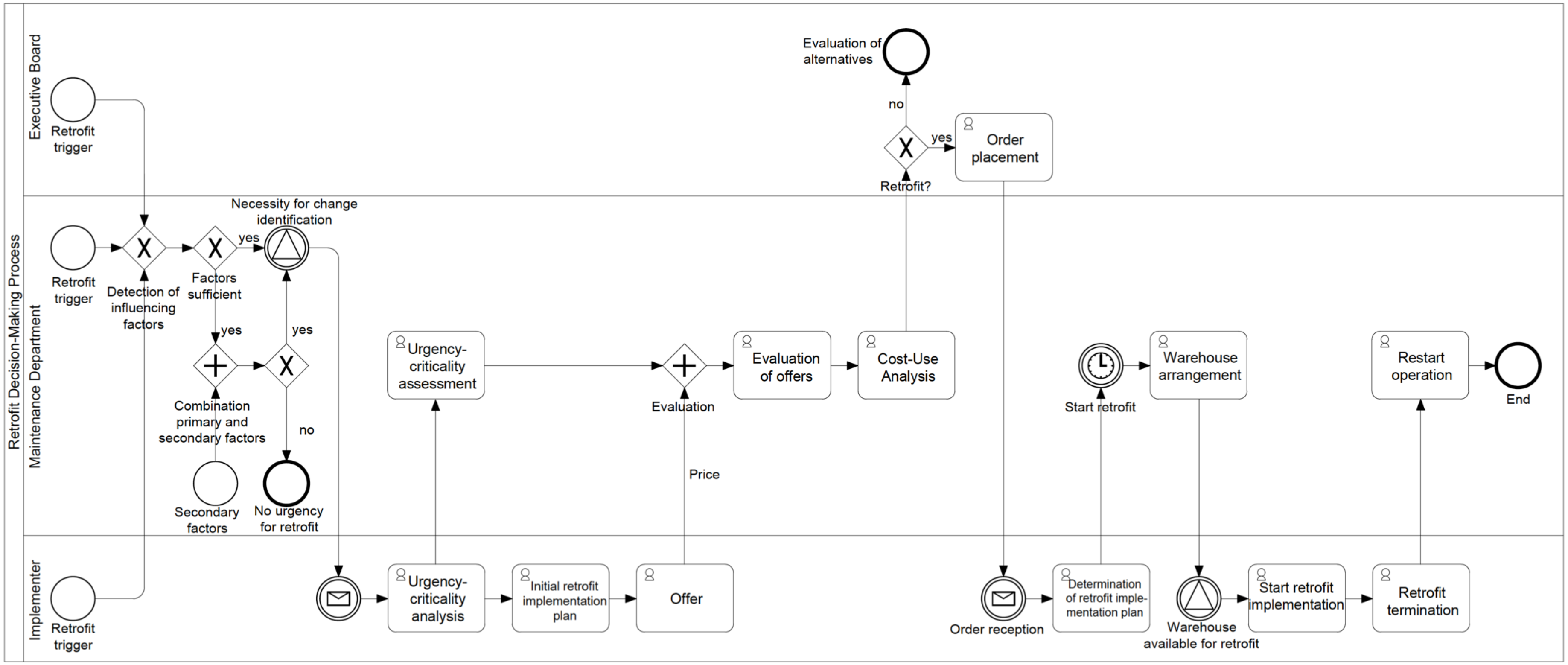
fml Chair of Materials Handling, Material Flow, Logistics - Technical University of Munich

Project	Analysis of the Modernization Proces of Automated andstorage system			
Company	Chair fml			
	Date	**Duration**	**Location**	**Protocol recorder**
	26.11.2020	10.00-11.30	Online Meeting	Mr. Pérez-Manglano

Attendees	Mr. Pérez Manglano (TUM)	Mr. Hirschbühl (LTW)
	Mr. Baldauf (LTW)	

Content / course	
1.	**Introduction**
	1. Personal presentation 2. Presentation of the structure of the Interview
2.	**Validation of the retrofit process** 1. Presentation of the modelling of a retrofit DMP Questions/comments 1) The model closely represents the reallity 2) The process is very individual to every client
3.	**Knowledge gap: Urgency-criticality assessment**
	1. Description of the problematic 2. Description of the knowledge area of the retrofit stakeholders 3. Identification of the factors influencing the assessment 4. Communication of the issue to the client Questions/comments 1) The most critical is a long unplanned standstill 2) Implementers cannot contact every client for informing about a disc-continuation of a spare part: huge effort and no economic benefit 3) Spare parts availability can be checked on the internet. Most of the 4) Successor products: can fit some clients, but not all (retrofit) 5) Complexity for storing electronic components: e.g. frequency con-verters must be charged every 24 months. Maintenance required
4.	**Knowledge gap: Determination of a time frame for implementing**
	1. Description of the problematic 2. Presentation of a possible solution Questions/comments 1) One of the most challenging parts of the project. Most of the times, weekends need an extra day for preparing: downtime is necessary 2) From the implementers perspective, implementing in consecutive days is the most efficient alternative 3) Alternatives are presented to the client. They must come with a solution (e.g. plan downtimes or rearrange the warehouse) 4) Temporarely renting an extra warehouse/space in a warehouse can be a solution for some clients (low warehouse requirements) 5) Operators that retrofit requirements can be retrofitted in a single WE 6) Problems come with retrofits every 10-20 years. More expensive and standstills are often necessary.
5.	**Conclusion**
	1. Space for solving remaining questions

Appendix B Decision-Making Process Representation in BPMN



Declaration of Authorship

I hereby affirm that I have independently written the thesis submitted by me and have not used any sources and aids other than those indicated.

Munich 01/12/2020

Place, date, signature