MASTER

Framework Design to Assess OTIF hits and Quantitative Analysis of Root Causes

Alban Morales, A.S.

Award date:
2021

Department of Industrial Engineering & Innovation Sciences

Framework Design to Assess OTIF hits and Quantitative Analysis of Root Causes

Master Thesis

A.S. Alban Morales

Eindhoven, February 2021

In partial fulfillment of the requirements for the degree of:
Master of Science in Operations Management & Logistics
Manufacturing Systems Engineering

Supervisors:

Prof. dr. ir. Ivo Adan	TU/e
dr. Zümbul Atan	TU/e
dr. Nevin R. Mutlu	TU/e
Robert Garenfeld	ASML

TU/e School of Industrial Engineering

Series Master Theses Operations Management & Logistics
Track Manufacturing Systems Engineering

Keywords: Root Cause Analysis, A3 problem-solving, Cause-Effect Tree, OTIF, Supplier Performance Management

Abstract

One of the challenges of ASML's supply chain is to ensure material availability at the right time, quality and affordable cost. Currently, the company faces a logistics performance gap, along with the lack of a standard procedure to effectively conduct Root Cause Analysis and consolidate supplier feedback. The purpose of this research was to investigate the current situation of OTIF hits Root Cause Analysis and the further development of a framework that can be used to address a gap in performance. Additionally, the objective was also to better understand the influencing factors of the KPI, to later provide recommendations based on key findings. For this, interviews with process experts were conducted and key factors were identified. Subsequently, an ASML process standardization method and the "A3" problem-solving method were used to develop a framework that addresses the differences found in the process, while proposing improvements and a change plan to implement these new practices. In addition, a cause-effect tree was used to identify the influencing factors and map the possible causes of OTIF hits. Then, using the *Gain Ratio* and Pareto Charts, the most influential variables were ranked and recommendations were made. The results of the study produced a combination of initiatives aimed at improving current practices and providing tools that allow detailed analysis and troubleshooting of hits.

Executive Summary

This thesis aims to develop a framework to address the performance gap of a logistic KPI (OTIF), study the Root Cause Analysis (RCA) management process and discover the main root causes that impact its behavior, to finally propose recommendations based on key findings.

Introduction

ASML is one of the world's leading manufacturers of chip-making equipment, characterized as a low-volume, high-mix manufacturing organization. The project is carried out in the Supplier Network Management (SNM) department. SNM's mission is to ensure the availability of material at the right time, with quality and affordable cost.

Problem Description

Every year, ASML evaluates the objectives and communicates the supplier's performance. However, these performance updates are made regularly and shared every week. One of the main logistic KPIs used is OTIF; as the company needs its suppliers to meet the requested demand '**O**n **T**ime' (timely delivery) and '**I**n **F**ull' (integrity of goods received and documentation) to secure material availability. OTIF performance reached 83% at the end of 2019, with a 2020 target of 95%, and the vision to reach 99.5% by the end of 2022. To achieve this target, every cluster/team/supplier works on continuous improvement. Part of OTIF performance assessment is to determine root causes of OTIF hits ('On Time' and 'In Full' not met) and develop improvement plans to address these issues. It was observed that these analyses do not have the same level of detail on the causes of hits, the templates used, the categories and the monitoring methods. These analyses were not performed for all the suppliers and a procedure to consolidate their feedback is not present; therefore, to aggregate root causes by each cluster/team for analysis is not possible.

Due to this, the following main research question is proposed:

What are the main root causes of OTIF hits and how can ASML improve its way of performing RCA?

Methodology

The study is divided into two parts to better understand the complete KPI management process. First, the current situation of the department is analyzed and, based on the findings, proposals are constructed to fill the gaps. Second, the main root causes of OTIF hits are studied to find possible solutions to improve performance.

Analysis of Current Practice and Process Standardization

The first part of the study aims to understand the current practice regarding root cause analysis of OTIF hits and the application of continuous improvement methods. To do this, a *semi-structured* interview was conducted with the process stakeholders and process experts. A total of 21 interviews were conducted, with participants from all locations, all types of positions (OSC, Jr. LSM and LSM), but not from all teams. The information obtained from the interviews included the procedures followed by the company to perform RCA, the information

exchanged with the suppliers and the tools used for the same purpose. Commonalities were found between teams; however, there were relevant differences in the way of working such as frequency and purpose of meetings, the type of information shared with the supplier, how the feedback from the RCA is collected, stored and analyzed, and the handling of improvement plans.

Since some practices do not follow a standard, process standardization was proposed to create transparency and uniformity; with a potentially positive impact on performance, communication and coordination between parties. An ASML standard methodology (Figure 1) was used to develop the standard. Then, a problem-solving methodology (**A3**) was applied to develop a framework to address the opportunities mentioned above.

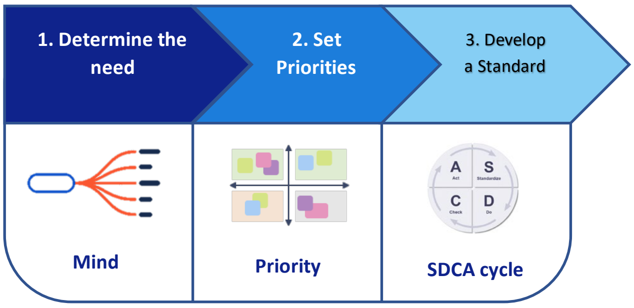

Figure 1. ASML's method to create a standard.

Figure 2. Proposed Category levels

Each step of the A3 methodology was reviewed and specific proposals were elaborated where necessary. As a result, roles and responsibilities were defined through a RACI matrix, standard categories with different levels were proposed to label OTIF hits (Figure 2), an 'OTIF prediction report' was proposed to be shared with suppliers, practices for monitoring improvement plans were defined. Finally, to incorporate these new practices and standards into the company's way of working, a change plan was developed with alternatives based on the degree of difficulty and resource requirements.

Contributing Factors to OTIF hits

The second part of the study aims to discover the underlying factors that could affect the behavior of the KPI. For this, a cause-effect relation tree (Figure 3) was built with two different branches for the 'On Time' and the 'In Full' components of OTIF, since they show different levels of impact on the KPI.

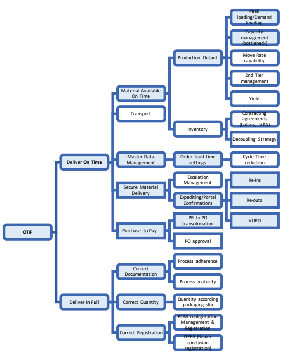

Figure 3. OTIF cause-effect relation tree

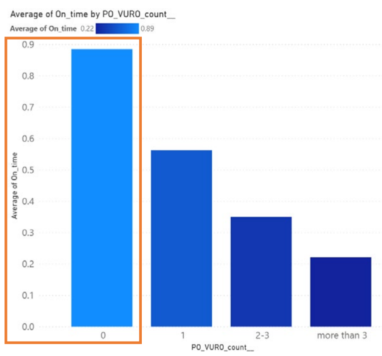

Figure 4. Average 'On Time' score by number of VUROs

For the ‘On Time’ branch, various sources were used to build a dataset with relevant fields (e.g. lead-time, net price, order quantity, demand frequency, expediting messages behavior). Then, *Gain Ratio* was used to rank the importance of these variables compared to the target variable ‘On Time’. As a result, the *number of VUROs* (Vendor Unwanted Reschedule-out), *Average days of delay requested in all the VUROs*, *number of Reschedule-ins* and *the Purchase Requisition (PR) to Purchase Order (PO) transformation* indicator were considered relevant. The analysis revealed that an increase in the expediting variables was related to worse performance of the average 'On Time' score (Figure 4). In the same way, a late PR-PO transformation showed poorer behavior on the KPI. Proposals were made to address nervousness, such as elimination of transaction errors and the use of dampening procedures to suppress expediting messages. In addition, the efforts to continue automating the PR-PO transformation could contribute to improve the indicator performance.

On the other hand, in the ‘In Full’ section the hits were already labeled according to predefined categories and subcategories; which allowed the construction of a Pareto chart to analyze the most important categories. The categories with the most hits were 'Missing information', 'Missing Papers' and 'Error Message'. For these incidences, the recommendation was to focus on the accuracy of stagnation labeling and updating of ‘problem-solution’ operational documents for day-to-day troubleshooting.

Preface

This research, conducted at the Technical University of Eindhoven and ASML, marks the end of the master's program in Manufacturing Systems Engineering (OML) and, consequently, my time as a student at the TU/e.

I am truly grateful to all the people I met who made my studies an incredible experience. I would like to take this opportunity to thank the people who helped me during this journey. First of all, I want to thank my supervisor at university Ivo Adan, who guided me through this research. I had a difficult time trying to scope and structure the project, and I always received insightful feedback and freedom to shape the project.

Furthermore, I would like to thank Floris Olsthoorn and Robert Garenfeld for the time at ASML. You guided me through this project and always provided valuable feedback and referred me to the right people.

I would also like to express my gratitude towards the European Supply Chain Forum (eSCF), TU/e and ASML for this opportunity. I have learned a lot during the process and have grown professionally and also as a person. I would like to thank my friends, BA team colleagues and interns at ASML for all the support and help they gave me. In addition, I would like to acknowledge the SENESCYT, IFTH, and the Ecuadorian government for providing the financial means for my master's studies.

I would like to especially thank my parents for their constant and unconditional support, who always reminded me why I'm here for. They have been the best role model I could have ever asked for, of love, kindness, resilience, hard work and perseverance. I owe you everything and I hope I have made you proud. I would also like to thank my grandmother and all my family enormously for always being there and cheering me on when times were not the best; there are not enough words to express what you mean to me.

Many thanks to all the people mentioned above and to all the people who contributed directly or indirectly to the realization of this work.

Andres Alban Morales

Contents

List of Figures

List of Tables

1 Introduction

This thesis is in the context of *Supplier Performance Management and Root Cause Analysis* within a chip-making equipment manufacturer. This project aims to develop a framework to address the performance gap of a logistic KPI (OTIF), discover the main root causes that hamper its behavior, and provide recommendations to reach desired performance.

In this chapter, the background of the study is presented. First, the company and department where the project will be developed are described. Secondly, the problem and the main findings are discussed. Along with this, the research goal, research questions, and research objectives will be developed. Lastly, the scope of the thesis and the research outline is included

1.1 Company Background

ASML was founded in 1984 in Eindhoven under the name of ASM Lithography, now is one of the world's leading manufacturers of chip-making equipment with over 24,000 employees, offices in more than 60 cities in 16 countries, and total net sales of EUR 11.8 billion during 2019. The company has its global headquarters in Veldhoven, the Netherlands with R&D and manufacturing locations in the Netherlands, the United States, China, Taiwan and Korea.

ASML is a focused Original Equipment Manufacturer (OEM) of Holistic Lithography solutions. Its products and services include patterning, metrology and inspection to chip manufacturers; providing high-performance hardware and software (ASML, 2020). The company is characterized as a low-volume, high-mix manufacturing organization where the wide variety of parts are subject to engineering changes required for the end-user. ASML is supported by several pillars that help the company to develop, manufacture, sell, transport and give support to customers. In the following section, Supply Chain Management (SCM) will be explained in further detail as it is the focus of the study.

Figure 5. EUV lithography system NXE:3400C

1.1.1 Supply Chain Management

SCM's mission is to guarantee material availability from suppliers to ASML's factories and then from manufacturing facilities to customers, offering support from end to end. SCM is part of the 'Operations' branch in the company, subdivided into Supply Chain Planning (SCP), Supplier Network Management (SNM), Product Lifecycle Management (PLM) and Customer Supply Chain Management (CSCM).

Supply Chain Planning
This department establishes the integral supply chain plan, evaluating the risk and the changes in customer demand. The Material Production Schedule (MPS) is built monthly based on the machine starts of the upcoming months. The MPS is updated based on changes in demand, upgrades requested by customers and production progress.

Product Lifecycle Management
Functions as a bridge between Development & Engineering (D&E) and suppliers, to ensure the supply chain is set up and ready for volume operations of new products.

Customer Supply Chain Management
Their objective is to support customers ensuring material availability, keeping system downtimes to a minimum and maintain effective production capacity. CSCM is also in charge of providing materials for upgrades and managing part repairs. Elaboration of forecasts for service requirements is also part of their responsibilities.

SNM will be the primary department in the scope of this thesis and will be detailed in the following section.

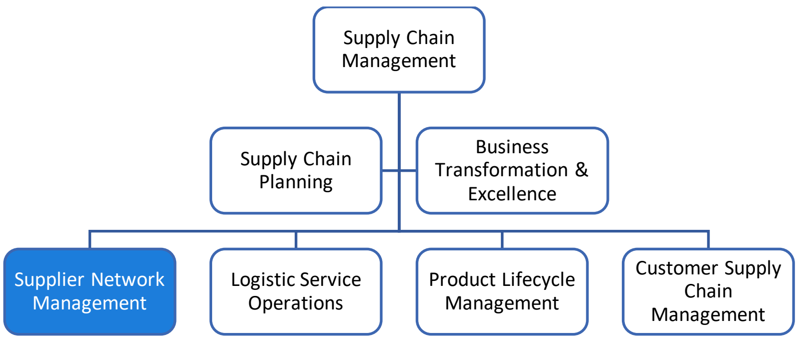

Figure 6. Supply Chain Management organizational chart.

1.1.2 Supplier Network Management

ASML relies on an extensive supply base of over 600 Product Related (PR) suppliers and over 4,000 Non-Product Related (NPR) suppliers. Long-term relations, close cooperation, and transparency with suppliers and partners are key to success (ASML, 2020). The extensive supply chain the company manages is roughly composed by:

- 44,339 12NC (material codes)

- 746 vendor codes
- 78.896 Purchase Orders (PO) per year
- 105 Complex Supply Chains identified based on multiple quantitative criteria

where the Mission of SNM consists of securing material availability at the right time, quality and affordable cost. In other words, its main objectives could be summarized in the management of material deliveries (in terms of Quality & Logistics) through 1st tier suppliers, manage critical Supply Chains (SCs) & nodes to timely deliver quality materials and (re)shape the supply base to adapt to the platform life cycle and business priorities.

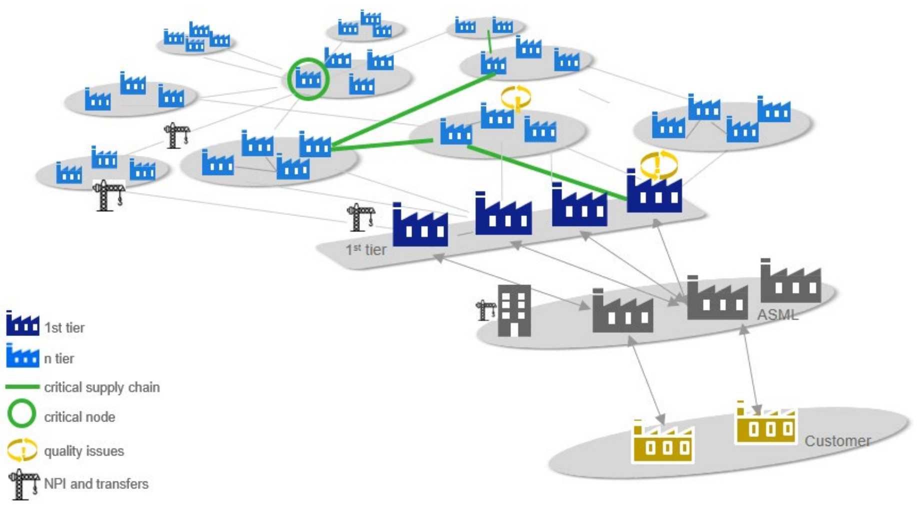

Figure 7. Complex Supply Chain

The department process landscape (Appendix A) is composed of three main processes. *SNM Controlling process* is responsible for managing **Supplier Performance**; the *Executing process* ensures material delivery and conducts inventory actions, while the *Supporting process* is in charge of human resources management, project portfolio management, documentation management and business analytics & reporting. All these processes should be measured to be controlled, although there are several Performance Indicators (PI) within the department, the main Key Performance Indicator (KPI)s are **On Time and In Full (OTIF)** from Logistics and **Material Quality Performance (MQP)** from a Quality perspective.

1.2 Problem Description

Every year, ASML evaluates the set targets and communicates the supplier's performance. However, these updates are performed regularly and the calculated KPIs are shared with the suppliers along with other measurements every week. One of the principal logistic KPIs used in the SNM department is 'OTIF'. The company needs its suppliers to meet the requested demand 'On Time' and 'In Full' to secure material availability, where every delivery is scored based on parameters explained in the section [OTIF 2.1.2]. If a supplier does not meet the required delivery date, this can cause a delay and hamper ASML's production process and compromise customer support or factory output. OTIF performance (Figure 8) corresponds to 83% at the end of 2019, with a 2020 target of 95%, and the vision to reach 99.5% of performance by the end of 2022 (16.5% gap).

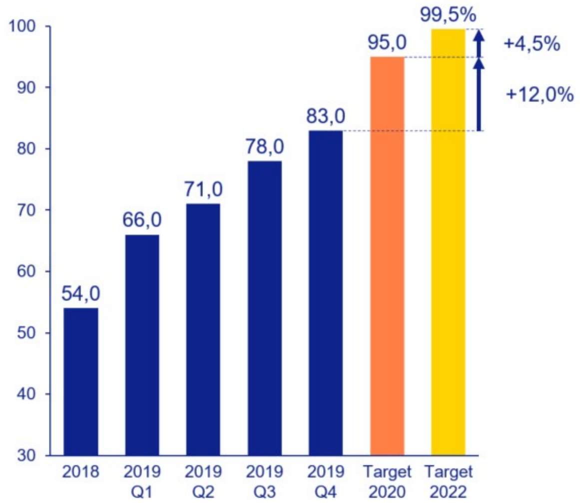

Figure 8. OTIF score and target for upcoming years

ASML started to take measures to achieve this goal, as Shared Safety Stock Decoupling and Vendor Managed Inventory (along with other projects) are being tested and implemented on some suppliers to contribute to the increment in OTIF performance. Preliminary analyses showed these measures could contribute (if successful) with a 3–4% increment in the total overall score. Therefore, the management wonders if these solutions would be enough to reach the desired 12% increment in one year. Nevertheless, every cluster/team/supplier is working on continuous improvement doing OTIF performance analysis, determining root causes of OTIF hits (On Time and In Full requirement not met) and developing improvement plans to address issues. It is clear that ASML is trying to understand what is impacting its OTIF score and how they can improve it.

From a quick screening in different clusters and teams, it was observed that these analyses are performed differently in relation to the level of detail of the causes, templates used, categories and monitoring methods. These analyses are not done for all the suppliers and their feedback is not consolidated (separate files per supplier per month); therefore, the aggregate root causes by each cluster/team remains a task that must be performed to obtain information on the main contributors of OTIF hits and eventually be able to link the root causes and improvements to an increase in performance.

As it can be seen in Figure 9, the last attempt to consolidate the Root Cause Analysis (RCA) feedback from suppliers was done at the beginning of 2019, with a scope of 29 suppliers (56% of OTIF hits); resulting in a ≈ 38% of no feedback confirmed by the supplier and ≈ 33% with an ASML related causes of hit; this leads to the assumption that there is no procedure to consolidate supplier feedback and there is still room for improvement within the company's processes. As a consequence, a thorough analysis of ASML's and supplier influence on overall OTIF performance is needed to drive structural improvement; thus, the efforts could be efficiently focused to close the gap and achieve the goal of 99.5% by 2022.

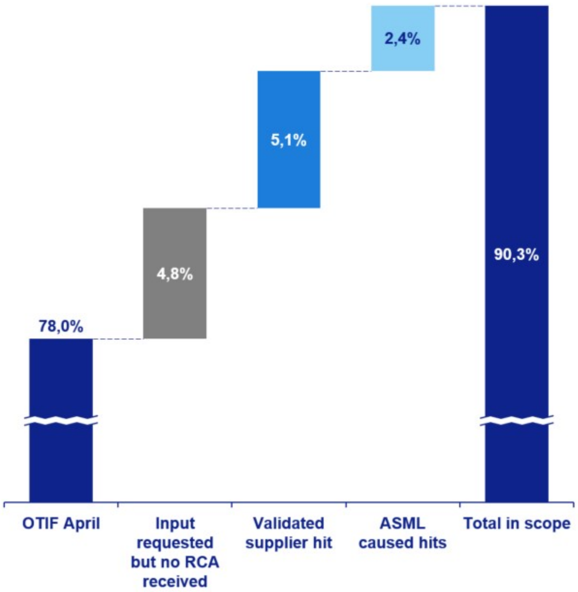

Figure 9. RCA feedback consolidation.

The problems that arise from the problem definition in the specific case of ASML are the following:

- (i) **There is not a procedure to effectively perform root cause analysis and consolidate feedback from suppliers.**
- (ii) **The efforts to solve performance issues are spread through the department.**
- (iii) **There is a lack of insight into the main root causes of OTIF hits (from supplier and ASML perspective).**

These problems will serve as the central topics of this thesis with the ultimate purpose of improving the current situation at ASML while gaining new research insights. The literature on Supply Chain Performance Measurement, Root Cause Analysis and Supply Chain disruptions are widely available. The challenge, however, is to synthesize a solution from the current state-of-the-art that is feasible to be implemented within the specific company setting.

1.3 Research Goal

This research aims to develop a framework that can be used in the ASML business setting to improve the current practice when addressing OTIF hits RCA. Additionally, the objective is to get a better understanding of the main root causes that hamper the OTIF KPI performance to effectively provide a path towards improvement to achieve performance targets.

1.4 Research Questions

Following problem definition and the research aim discussed so far, we formulate our main research question:

What are the main root causes of OTIF hits and how can ASML improve its way of performing RCA?

We define five sub research questions to answer the main research question and to structure the development of the project:

1. What is the current situation in ASML regarding OTIF hits root cause analysis and continuous improvement methods application? How are these methods implemented within the suppliers?
2. What are the suggested approaches for effective OTIF hits RCA?
3. How the proposed RCA framework could be implemented in ASML to guarantee its continuity and effectiveness?
4. What are the main factors that contribute to OTIF hits from ASML perspective?
5. What strategies could be used to potentially address the main causes of OTIF hits?

1.5 Research Objectives

The output of this study will serve as a master thesis, the research objectives described are related to the interested parties and are in line with the research questions mentioned in the previous section.

1. Investigate the methods and practices of OTIF hits RCA and continuous improvement plans within ASML. Investigate how these practices are implemented and interact with the suppliers.
2. Develop an RCA framework to address OTIF hits, record, consolidate and trace the status of improvement plans through time to drive process control and analysis.
3. Design a change plan for the implementation of the proposed RCA framework solution.
4. Study and understand the main factors contributing to OTIF hits based on ASML input and analysis of other potential causes.
5. Investigate potential solutions to the main causes of OTIF hits in order to tackle the current performance gap.

1.6 Research Scope

This research project will mainly analyze the behavior of the deliveries managed by ASML Veldhoven (NL01) from all its external suppliers. The OTIF score will be filtered to only "Volume Parts", which means supplies ordered by the Operational Supplier Management (OSM) department; excluding the New Product Introduction (NPI) parts. Additionally, the study will analyze the procedures within ASML's SNM department and interactions with their suppliers. The data collection and analysis will be limited to sources and available information from the department corresponding to 2019 and part of 2020. Lastly, the project does not include the implementation of the proposed solution.

1.7 Research Outline

This Master Thesis is organized as follows. In chapter [2] relevant concepts of Supplier Performance Management, Supply Chain Performance Measures, and Supply Chain disruptions are reviewed. Also, definitions and Root Cause Analysis methods are part of the section. Chapter [3] concerns to the analysis of the current situation of the company with regard to Root Cause Analysis applications. The analysis will be developed in various aspects relevant to the OTIF management process. Next to this, chapter [4] uses the main findings of the previous chapter and focuses on a methodology to standardize the process; in addition, it provides a potential change plan for the implementation of the proposals. Chapter [5] analyses influencing factors of the KPI with a visual methodology and proposes alternatives to reduce their effect on performance. Chapters [6] concludes this research by answering the research questions, outlines recommendations for ASML, research limitations, and provides future research opportunities.

2 Relevant concepts

This chapter aims to review relevant concepts related to Supply Chain Management, Supplier Performance Management and Performance measurements, from an ASML and literature perspective. A clear overview of the OTIF KPI is presented with its main definitions and components. Lastly, the importance of Root Cause Analysis and known methodologies are revised.

2.1 Supplier Performance Management

The performance of the company demands continuous improvement in several aspects, where effective collaboration with suppliers to meet end-customer requirements is crucial. Supplier collaboration depends on timely supplier involvement in each development key decision and the commitment of their know-how in design and execution. In addition, the discipline to deliver complete specifications, while having transparency regarding R&D expertise/industrial infrastructure and process/cost structure is fundamental for collaboration. ASML expects its suppliers to assess their own 1st-tier suppliers based on ASML requirements and, subsequently, that they ask their 1st-tiers to cascade this throughout the chain (ASML, 2020).

2.1.1 Performance Measurements

(Balfaqih, Nopiah, Saibani, & Nory, 2016) mention the importance of measuring the right thing at the right time in supply chains, to allow decisions to be taken timely. For ASML, supplier performance is a critical consideration when assigning new business, and the supplier performance score is used to evaluate suppliers within categories. The Supplier Performance Dashboard is the used tool to show actual KPIs against pre-set targets. These KPIs are updated and monitored on a monthly basis and used for regular performance reviews.

ASML forms a Supplier Account Team (SAT), composed of the company and supplier representatives, where its main objective is to improve supplier performance in order to realize committed targets, strategically and pro-actively managing five leading business aspects:

1. **Quality**
   Ensure top Quality of all required products and services. Quality KPIs are focused on measuring and reducing quality defects caused by the supplier and to analyze and solve the root causes of Material Notifications (MN) effectively.
2. **Logistics**
   Ensure continuity and flexibility of supply over the entire product lifecycle. Logistics KPIs ensure the availability of materials at the right time, with the needed quantity and quality to satisfy manufacturing, service, upgrades, new product introduction and development.

a) **OTIF**
KPI designed to ensure delivery on-time and with the required specifications. Since OTIF is the main focus of this study, it will be explained in detail in the following section.

3. **Technology**
Guarantee access to Technology, sharing of know-how, and introduction of new products. These KPIs aim to evaluate the support offered by the development capabilities and available technology at the supplier, to ensure minimum supplier deviation notifications. Moreover, its mission is to verify that the suppliers do not only focus on the process (capability) but also on the performance.

4. **Total Cost**
Ensure competitive total cost and cost of ownership behavior throughout the Supply Chain. The objective is to create incentives for the suppliers to contribute to the industry cost roadmaps and to increase cost awareness, specially non-quality costs and incentivize enablers for cost reductions.

5. **Sustainability**
Ensure a Sustainable Supply Chain through the use of high ethical and professional standards; ASML expects responsible supply chain management from their suppliers. The suppliers should be capable to continue the delivery of the products and services at acceptable predefined levels after a disruptive event. These KPIs measure the satisfaction of internal stakeholders and the focus on continuous improvement by scoring how the plans develop through time.

2.1.2 OTIF

ASML's large network of suppliers must be managed on their performance with regards to the logistic performance of their deliveries. It is important to measure and understand this metric both quantitative and qualitative considering the data is coming from ASML and external sources. OTIF KPI is intended to ensure that new buys and repairs are received accordingly to the agreed delivery date, with the complete amount of goods and the correct documentation and registration.

This KPI is also used to improve Operational Logistics Performance and to strive towards continuous improvement. Therefore, the SNM department needs clear objective measurements to monitor and drive supplier logistic performance efficiently and effectively. This KPI is measured on a weekly basis, available for all the stakeholders within SNM and shared with the suppliers by e-mail with a detailed view of their hits.

2.1.2.1 Calculation Method

The OTIF score is calculated per supplier every week based on their delivery performance according to several parameters. There is a procedure and systems support in place to do the calculations, deliver and share the KPI score to the interested stakeholders. OTIF score relies on several sources to gather all the data needed, and its logic is well documented and regularly checked to improve its accuracy. It gives an instant overview of logistic performance on any level of aggregation (cluster, team, vendor) and eliminates the manual effort of business users for standards reports. When an ad-hoc analysis is needed, the used data for the calculation is also available for special filtering, grouping or aggregation rules.

On-Time Parameters:

Last confirmed requested delivery date

- Based on accepted purchase orders against standard lead-time. New date updated via confirmed reschedule-ins or reschedule-outs.
- New Buys and Repairs are included.

Goods Receipt date

- Goods receipt date as entered/scanned by warehouse clerk.

Delivery window

- The current parameter to determine if the delivery was on time, check if the Goods Received Date falls within the period **−5 and +3** business days from the last 'Agreed Delivery Date'.

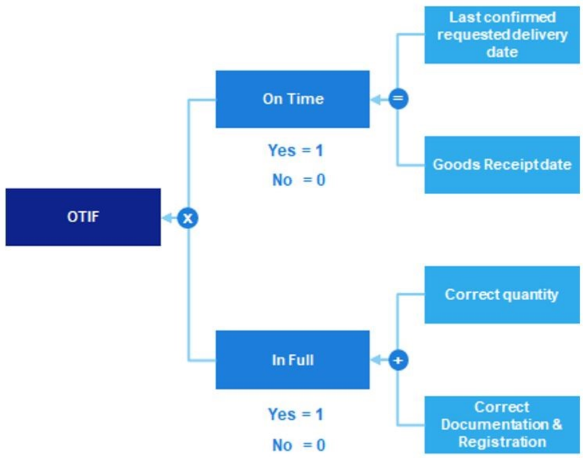

Figure 10. OTIF structure with parameters

In Full Parameters:

Correct Quantity

- Goods receipt quantity as delivered, counted and entered by warehouse clerk in line with requested quantity in the purchase order.

Correct Documentation and Registration

Cases when the requirement is not met:

- If a delivery does not meet certain parameters (documentation missing, incorrect registered quantity, etc.), a 'Stagnation' is created, to clarify the source of the fault. A closed 'stagnation' validated to be caused by the **supplier** is counted as a hit.
- When a Defect Part for Analyze (DEFA), a repair order, is received at ASML without root cause analysis completed by the supplier.

Therefore, if the delivery *Goods Receipt date* falls within the *Delivery Window*, it receives an **'On Time'** = 1. The same case applies to the 'In Full' requirements, if the delivery has *Correct Quantity* and *Correct Documentation and Registration*, it receives an **'In Full'** = 1. To achieve **OTIF = 1**, an item should meet both requirements, otherwise, it is scored as a 0 (a hit).

Table 1. Possible 'On Time' and 'In Full' combinations.

On Time	In Full	OTIF
1	1	**1**
1	0	**0**
0	1	**0**
0	0	**0**

2.2 Supply Chain Performance Measurements

The proposed project falls under the broad field of Supply Chain Management. For the purpose of this study, the following definition by (Hugos, 2011) was chosen, where SCM is defined as "the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served". Effective logistics and SCM can provide a major source of competitive advantage. The costs of satisfying customer demand can be significant and yet, surprisingly, they are not always fully understood by organizations. However, logistics activity does not just generate a cost, it also generates revenue through the provision of availability thus it is important to understand the profit impact of logistics and supply chain decisions (Christopher, 2011).

The importance of measures and metrics in the success of an organization cannot be overstated because they have an effect on strategic, tactical, operational planning and control levels of the operation. For this reason, performance measurement comes into play in companies, which is defined as the process of quantifying the effectiveness and efficiency of action (Farahani, Asgari, & Davarzani, 2009). (Arzu Akyuz & Erman Erkan, 2010) and (Parker, 2000) describe the following as the purposes of a performance measurement system: a) Identify success b) Identify whether customer needs are met c) A better understanding of their processes d) Identifying bottlenecks, waste, problems and improvement opportunities e) Ensure decisions are based on facts f) Enabling and Tracking progress and g) Facilitating a more open and transparent communication and cooperation.

(Piotrowicz & Cuthbertson, 2015) conducted a survey of 51 companies -46 were located in Europe (EU/EEA)- to find out what methods and tools were used to capture performance. Based on the literature, the author created a list of approaches identified in companies or proposed to measure Supply Chain (SC) performance, these include:

- SC measurement system
- SCPM framework
- Balance Score Card (BSC)
- Frameworks based on the scorecard approach/modifications of the BSC
- Economic Value Added (EVA)
- Process-based measurement
- Fuzzy-set approach
- Supply Chain Operations Reference (SCOR) model

There are hundreds of performance measures used by different organizations in different industries. Besides the methods used, various approaches have been proposed to classify metrics for Supply Chain Performance, based on different criteria. For instance, (Elrod, Murray, & Bande, 2013) categorize measures into quality, financial, time, product flexibility, overall performance, and innovation. (Hugos, 2011) divided the measurements into Customer Service, Internal Efficiency, Demand Flexibility and Product Development. (Beamon, 1998) categorized the measures as either qualitative or quantitative, detailing sub-categories for each branch. (Gunasekaran, Patel, & Tirtiroglu, 2001) describe a balanced approach where measurement goals consider the overall supply chain goals; these metrics have been divided at strategic, tactical and operational levels, and be financial and non-financial measures, as well.

2.3 Supply Chain Disruptions

One of the most important challenges confronting supply chain managers in today's highly uncertain and globalized business environment is how to proactively cope with disruptions that can impact the complex supply networks that define modern organizations. Lean and dispersed global networks of suppliers, manufacturers, distributors, and customers must come to terms with the potential consequences of 'day-to-day' supply-chain disruptions. Parts shortages, changing customer requirements, quality issues, ramp-up and deployment issues, and different forms of production issues are some of the leading causes of disruptions (Hendricks & Singhal, 2005)

The risk of experiencing disruptions are higher now and in the future than in the past due to new practices and developments in supply chain management. These practices may have led to improving the efficiency and profitability of the supply chain; however, they may have also become a weakness. (Gurnani, Mehrotra, & Ray, 2012) list several examples:

- Increased Complexity
- Focus on efficiency
- Outsourcing and partnership
- Over-concentration of operations
- Single sourcing
- Limited Buffers
- Poor planning and execution

At the same time, some potential approaches that can deal more effectively with disruptions are given as a) improving the accuracy of demand forecasts b) integrate and synchronize planning and execution c) reduce the mean and variance of lead time d) collaborate and cooperate with supply chain partners e) invest in visibility f) build flexibility in the supply chain g) postponement strategy h) invest in technology (Ziaei & Amalnick, 2016).

(Wu, Blackhurst, & O'grady, 2007) present a network-based modeling methodology to determine how changes or disruptions propagate in supply chains and how those changes or disruptions affect the supply chain system. Nonetheless, the model may be segmented to evaluate only the portions or sub-networks that are affected by changes in an initial marking. This approach is not well suited to apply for a whole system analysis or a supply chain composed of thousands of products, since the calculation may not be feasible or scalable.

2.4 Root Cause Analysis

There is a vast amount of literature on Root Cause Analysis (RCA) across several industries and environments. RCA is considered as one of the most useful themes being used by practitioners around the globe for quite a long time in industrial problem-solving on quality and productivity, plant safety, accidents, etc. (Sarkar, Mukhopadhyay, & Ghosh, 2013). These analyses can be of enormous value, they capture both the big-picture perspective and the details. They enable system evaluation, analysis of the need for corrective action, monitoring and trending. An investigation of the root cause should be done as soon as possible after an error or variance occurs; otherwise, crucial information may be overlooked (Williams, 2001). Given the above, we can define RCA as a method used in a reactive mode to determine the causes of the problems that have occurred as well as being used as a powerful tool for continuous improvement (Reid & Smyth-Renshaw, 2012).

If the root cause of a problem is not identified, then one is simply addressing the symptoms and the problem will continue to exist. For this reason, identifying and eliminating the root causes of a problem is of utmost importance. However, the literature lacks the means to select the appropriate root cause analysis tool based on objective performance criteria (Doggett, 2005). Various approaches and tools have been studied by many authors, such as (Reid & Smyth-Renshaw, 2012), (Doggett, 2005), (Williams, 2001), (Livingston, Jackson, & Priestley, 2001) and (Sarkar, Mukhopadhyay, & Ghosh, 2013); the following are the most prominent methods found:

- Failure Mode and Effects Analysis (FMEA)
- Five Whys
- Pareto Chart
- Fishbone or Ishikawa diagram
- Sigma DMAIC methodology
- Ford's 8D model
- A3 Thinking
- Cause-and-effect diagram
- Current reality tree
- Interrelationship diagram
- Apollo Root Cause Analysis (ARCA)
- Kepner-Tregoe (K-T) approach

Problem-solvers and decision-makers are likely to select a tool based on convenience rather than on its actual performance characteristics. In his investigation, (Doggett, 2005) provides a framework for analyzing the performance of three RCA tools: cause-and-effect diagram, the interrelationship diagram and reality tree. This analysis presented the advantages and disadvantages of each tool, with different levels of causal yield and selected causal factor integrity to better understand the assumptions of each method.

(Gangidi, 2019) goes a step further from the traditional 5-Why's technique by separating a problem statement into 3 categories occurrence-specific, human and system components and performing individual 5 Whys on each of these components, hence the term 3 x 5 Why's. This integrated methodology will enable the identification of deeper issues that are causing the problem. Effective execution of this methodology can provide tremendous results in defect reduction, yield improvement, operational efficiency improvement and logistics management type of projects. On the other hand, (Reid & Smyth-Renshaw, 2012) criticizes the use of the why question method, because those why answers could incur the wrong cause of action, committing resources resulting in additional costs. Thus, proposes the applicability of the 5W+1H (what, why, when where, who, how) technique, which is used by many managers in understanding a problem to define the root cause. The 5W+1H methodology is insufficient in identifying the root cause because of the variations triggered by asking the question 'why'.

Additional considerations in the root cause analysis are the types of data required, their accuracy and precision, over what period the data will be collected (short or long), and the analysis methodology used to identify key process input variables (Martin, 2014). According to (Livingston, Jackson, & Priestley, 2001), three key components that need to be applied to ensure effective root causes analysis incident investigation, namely:

1. A method of describing and schematically representing the incident sequence and its contributing conditions.
2. A method of identifying the critical events and conditions in the incident sequence.
3. Based on the identification of the critical events or active failures, a method for systematically investigating the management and organizational factors that allowed the active failures to occur, i.e. a method for root causes analysis.

When the performance of logistic KPIs is unsatisfactory, it is pertinent to identify the root causes before attempting to rectify the situation. Detailed and systematic root cause analyses based on quantitative data are required to effectively improve logistics performance. Common methods like value stream design or simulation studies use too many assumptions that render them unsuitable for complex supply chains with many products or processes. The objective is to identify the underlying reasons for insufficient KPIs and develop actionable changes to continuously improve and adapt the supply chain to changing conditions (Schmid, Maier, & Lasse-Härte, 2020).

In his study, (Schmid, Maier, & Lasse-Härte, 2020) propose a model-based analysis of confirmation data to identify the root causes of unsatisfactory logistic KPIs. A framework is developed by defining generic cause-and-effect relationships between the relevant logistic KPIs and influencing and disturbing factors. The results show the occurring cause-and-effect relationships for particular use cases and deduce the root causes for insufficient logistic KPIs. However, the practice adopted for the identification of root causes is in many situations quite arbitrary and lacks a systematic, structured approach based on rigorous data-driven statistical analysis. Therefore, after the use of various methods for cause identification, (Sarkar, Mukhopadhyay, & Ghosh, 2013) aim at developing methodologies for validation of potential causes to root causes to understand the ground reality unambiguously.

3 Current Situation

This chapter aims to extract information about the current situation in ASML regarding OTIF hits root cause analysis and continuous improvement methods application. To reach these goals, interviews are set up and conducted with process stakeholders and process experts. The main topics are, the procedures followed by the company to perform RCA, the information exchanged with the suppliers and the tooling used for the same purpose. Once the interviews were conducted, the information is summarized and analyzed to give a complete overview of the process, its similarities and differences between roles, teams or clusters.

3.1 Methodology

Interviews are widely used as a data collection method when the phenomena are not directly observable, they provide in-depth information from participants' experiences and viewpoints of a particular topic (Turner, 2010). These interviews should provide a better understanding of the current processes and tools used in ASML for OTIF management. Therefore, a structured approach is needed to consistently gather information.

3.1.1 Interview Design

In order to conduct a well-constructed professional interview, a sequential process should be followed, which includes: preparing for the interview, constructing effective research questions and implementation of the interview (Creston, 2007, as cited in Turner, 2010). The preparation is a crucial step of the interview process, where the researcher defines the purpose of the interview, select the participants and decide the interview format (Gall, Gall, & Borg, 2003).

This study will use "key informant interviews", in which data is collected from participants who have extensive knowledge or crucial perspectives on the information to be obtained (Gall, Gall, & Borg, 2003).

Participants

The purpose of the study is to understand, from the people who experience the process, what is the current situation in OTIF management. To select the participants for the interview, the study uses *'Maximum Variation'* as a sampling strategy. (Creswell, 2007) describes this approach as deciding in advance some criteria that differentiate the interviewees and then selecting the ones that are found to be different in the same criteria; in consequence, the chances of finding different perspectives or information are maximized. The criteria selected for the interview were: location (VHV, USA, TWN), type of position (team management, LSM, Jr. LSM or OSC) and the teams where they belong (mechatronics, mechanics, optics, etc.). All of the participants had previous experience in the required process.

A total of 21 participants were interviewed, the *'Maximum Variation'* was partially achieved, since it was possible to obtain interviews with participants from all locations, from all types of positions, but not from all teams. The distribution of the interviews could be seen in Figure 11.

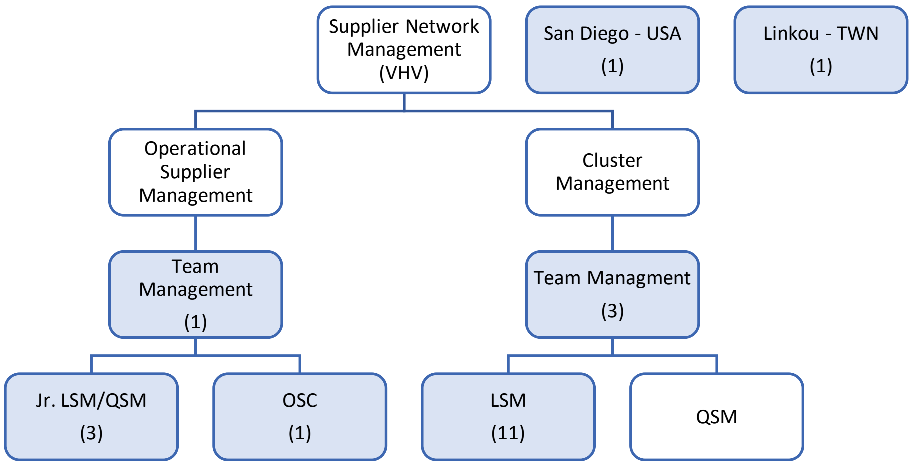

Figure 11. Count and distribution of interviews in the organizational chart.

Format

In order to obtain rich and useful data, several forms of interview designs can be developed utilizing an investigational perspective (Creswell, 2007). (Gall, Gall, & Borg, 2003) presents three formats of qualitative interview design based on the degree of structure: structured interview, semi-structured interview and unstructured interview. According to (Turner, 2010) the semi-structured interview is likely the most popular form of interviewing used in research studies; here, the participants are asked a series of structured questions worded in a way that the responses are open-ended, giving room to more detailed answers and the liberty of the interviewer to follow-up if needed. This approach was selected because of its advantage -over a structured interview- of providing more in-depth answers and reasonable standard data across interviewees (Gall, Gall, & Borg, 2003).

Research Questions

The objective of the interview is to gain insight into the OTIF management procedure. With this in mind, the creation of effective research questions for the interview process is a crucial component in the interview design. Each of these questions should allow us to explore the experiences and/or knowledge of the participants in order to gain maximum data (Turner, 2010). The topics to investigate through the interview process, to have a clearer vision of the current state are:

a) Way of working
   - Frequency of meetings (ASML, ASML – Supplier)
   - Distribution of suppliers through teams
   - People/roles involved

b) Information exchanged (ASML, ASML – Supplier)
   - E-mails

  - Databases
  - Frequency

c) Tooling used
  - Root cause analysis
  - KPI tracking
  - Improvement plans

Therefore, the following questions were asked, with follow-up questions depending on the answer of the interviewee:

1. What is the procedure you follow to address OTIF hits?
2. What information do you send to the supplier, and the frequency?
   - How do you receive feedback from the supplier?
   - Is the feedback you received standardized?
3. Which tools do you use to keep track of root cause analysis of OTIF hits?
   - Where do you store this information?
4. How do you keep track of improvement plans?

Procedure

Given that the sampling method chosen for the interviews was *'Maximum Variation'*, one-on-one meetings were held with the participants to obtain the desired information. According to (Creswell, 2007), for one-on-one interviewing, the researcher must organize an environment in which the participants do not hesitate to speak and share their ideas. In addition, to ensure the readiness for idea sharing, the interviewer should communicate the purpose of the study, the amount of time it will take to complete the interview and how the information will be used. As a first approach, the participants were contacted and the purpose of the project was communicated to them through "Microsoft Teams"; later they were asked if they were willing to answer some questions about the investigation and a meeting was planned. Each meeting lasted approximately 30 minutes.

3.2 Results of the Interview

After completing the round of interviews, all the data and answers from the interviewees were tabulated and summarized to reflect the current status of the OTIF KPI and RCA management.

3.2.1 Information Shared with the suppliers

The company has set up a process where the suppliers receive a daily email with information generated by the Business Analytics Team. These dashboards are created with a combination of sources and are sent out according to the requirements of each account owner. Its goal is to communicate operational hits (issues) to the supplier, create performance awareness, and initiate the hit investigation and resolution process. The dashboard includes a detailed spreadsheet with PO/line data and a summary in the body of the email with the hits categorized as follows:

Past dues: Order lines with a confirmed delivery date in the past. It is expected from the supplier to deliver on time, or proactively communicate a new delivery date to ASML.

Future deliveries: Deliveries confirmed (or unconfirmed by the supplier) in the next 21 days. It also serves as a confirmation cross-check for short term horizon.

Unconfirmed: Order lines not confirmed within the target. For 'New-buy' orders, confirmation should occur within 2 weeks; for 'Repair' orders, within 3 weeks.

VURO: Vendor Unwanted Reschedule Out, it refers to the reschedule at a later date of the confirmed delivery date made by the supplier. Suppliers are required to make realistic supply confirmations. Unwanted reschedule outs by the supplier need to be prevented since a VURO could lead to an OTIF hit.

OTIF: Every Tuesday, the OTIF performance from the previous week is shared with the suppliers. All received goods are scored with an 'On-Time', 'In Full' and 'OTIF' score. An Excel file is sent with all order lines and the dates associated with the KPI calculation.

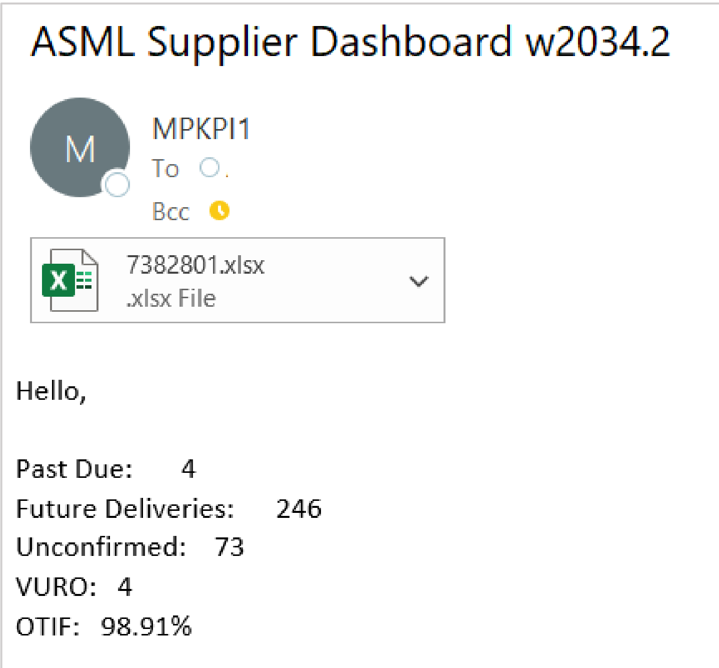

Figure 12. Example of daily dashboard sent to the supplier.

OTIF prediction report: This report is available for the entire department and contains data from the "Regular" and "ROP (Reorder Point)" open orders. The report compares the last confirmation date by the supplier (if it has one) and the required demand date at ASML, in order to 'predict' if an order can become a hit. The logic classifies each order line into the following categories: 'On Time', 'Too Early', 'Too Late', 'Unconfirmed <= 2 weeks' and 'Unconfirmed > 2 weeks'. The information contained in the report is not shared with the supplier as a standard procedure; only a small number of people share it by mail every week.

It is worth mentioning that several teams have already started using this report for internal analysis.

Figure 13. OTIF prediction report.

3.2.2 Roles

ASML has divided SNM into two branches to manage suppliers, Operational Supplier Management (OSM) and Cluster Management. Both branches manage suppliers of different size and importance, and each role has its responsibilities and activities related to OTIF management. Figure 14 shows a simplified view of the structure of the department and each of them will be explained below.

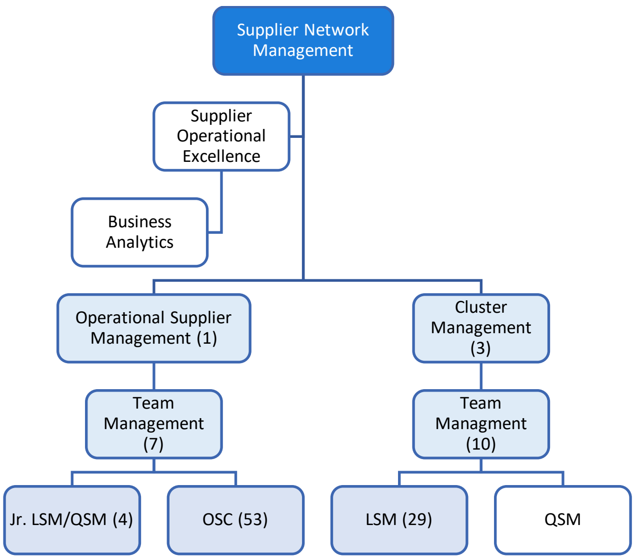

Figure 14. SNM simplified organizational chart

OSC

Operational Supplier Coordinators (OSCs) are part of the Operational Supplier Management (OSM) branch. A group of approximately 50 people distributed in 7 different teams, who constitute the first point of contact for both the supplier and the demand parties. They are responsible for the operational inbound supply towards the different demand parties of ASML. Their mission is to ensure material availability, resolve shortages, drive material escalations, execute inventory management and minimize all related costs. Every OSC is responsible for one or more suppliers, depending on how big they are and the extent of management they need. Their activities include resolving shortages, analyzing trends of the supplier, creating structural improvement plans targeting weak spots, follow up on them and increase the efficiency of the suppliers while maintaining quality.

Jr. LSM

Junior Logistic Supplier Managers (Jr. LSMs) are part of the Operational Supplier Management (OSM) branch, distributed in 3 of the 7 teams of OSM. They are responsible for securing timely material availability with the required quality, plus escalation management and stakeholder management & alignment. Furthermore, Jr. LSMs are also in charge of introducing the ASML way of working to new suppliers, develop structural improvement plans and keep track of their progress.

LSM

Logistic Supplier Managers (LSMs) are distributed in 3 clusters, each cluster with its own team lead. They manage the operational performance of **SAT suppliers,** accounts that require experienced personnel with vast business knowledge. Similarly to the OSCs and Jr. LSMs, they are responsible for securing timely material availability, stakeholder and escalation management. Additionally, LSMs drive supplier capability development, actively participating in improvement processes and projects at suppliers. Other responsibilities include the management of Complex Supply Chain (CSC), identifying risks in n-tier supply chains and develop actions to mitigate. LSMs also give and receive support to OSCs and Jr. LSMs when required.

3.2.3 Jobs Responsibilities

When talking about OTIF management, OSCs are accountable for the operational performance of **medium suppliers** and **suppliers with incidental deliveries** in which they intervene only if necessary. While the Jr. LSMs -in the teams where they are present- manage the operational performance of **key suppliers**, gather relevant information from the OSCs managed suppliers and give support if needed. LSMs, as the employees with more experience and responsibilities, manage operational performance of **SAT suppliers**, also supported by OSCs.

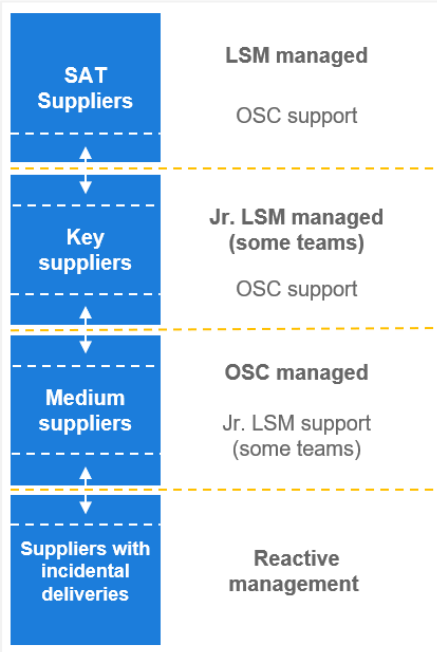

Figure 15. Suppliers distribution per role

The interaction between OSC, LSM and Jr. LSM varies from team to team, depending on the complexity of each supplier and prior agreements within the department. Both LSM and Jr. LSM, as account managers of relevant suppliers, are responsible for meeting performance targets by addressing main root causes on both supplier and ASML side, and developing improvement plans in a combined effort with OSCs. OSCs drive correct OTIF registration at the supplier, supporting Jr. LSM/LSM on an operational level while validating analyses and hits investigations at a deeper level. However, each OSC is also responsible for driving OTIF and improvement plans in their medium accounts.

On both branches of SNM, team managers are accountable for KPI performance, improvements and allocation of resources. They are responsible for facilitating a smooth resolution issue process and remove roadblocks addressed by the team. In addition, they ensure joint collaboration between OSM/LSM and other parties within ASML to drive and improve performance.

3.2.4 Meetings Structure

According to (Allen, Beck, Scott, & Rogelberg, 2014), meetings serve the purpose of accomplishing goals as problem-solving, information sharing and decision making. These meetings could also be classified by who is attending, e.g., staff members, operational employees, suppliers or a combination of different roles. In OTIF management, meetings are primarily used to discuss performance, to identify problems and propose solutions, follow-up on improvement plans (IP) and discuss the next steps to achieve future objectives. Based on the interviews, the interactions between ASML and the supplier are highly dependent on how actively the company decides to manage the supplier due to the importance of its performance. Consequently, every role (LSM, Jr. LSM and OSCs) has its cadence for each supplier; however, there are fixed meetings where ASML periodically reviews performance and IP. As the differences in practices between teams vary greatly, in Table 2. could be seen the frequency and the topics commonly reviewed per type of meeting.

Table 2. Frequency of meetings and topics discussed.

		Performance	IPs
Weekly	Within ASML - Top X	X	
	With Supplier	X	
	OTIF Intervention	X	X
Monthly	Within ASML	X	X
	With Supplier	X	X
Quarterly	With Supplier	X	X

As mentioned before, the weekly meetings generally review performance at a high level, where the KPI scores are reviewed and the causes of OTIF hits are discussed with the supplier. Additionally, there is an "OTIF Intervention" mode –in some teams- in which emphasis is placed on critical suppliers that need continuous monitoring, revision of target and improvement plans. Every month, all the information collected is summarized and together with the supplier, performance is revised and improvement plans are prepared and/or followed up. This information is shared and discussed later within the department with the different internal stakeholders. Lastly, every three months the supplier is in charge to lead a performance review where KPIs and improvement plans are discussed.

3.2.5 Root Cause Analysis and Categorization

When the supplier dashboard is sent on Tuesdays with all the order lines scored OTIF '1' or '0' respectively, the supplier is expected to respond with feedback on the root causes of each hit and a clear explanation of why. This process is carried out by the supplier together with the OSCs and Jr. LSMs, where the OTIF registration falls under their responsibility. This exchange of information does not always occur in the same week, in some cases, the feedback accumulates over the weeks and is discussed when there are enough hits to hold a relevant meeting. There is a constant interaction between the supplier and ASML that occur when clarification of a certain hit is needed. This interaction and feedback between ASML and the supplier are mainly done through calls, emails and stored in spreadsheets, where all the hits are registered and labeled based on previously agreed categories. As a consequence of the labeling of each hit, based on the agreements between the planner (OSC or Jr. LSM) and the supplier, there were not found common categories between clusters, teams, or even the suppliers managed by the same OSC. Figure 16 depicts the information flow of OTIF hits.

Figure 16. Root Cause Analysis information flow.

After gathering information from the interviewees and other department members who contributed with feedback, approximately 360 different categories were found on OTIF hits labeling. Many of them had similar meaning but were expressed in different words and levels of detail, e.g., 'Quality' and 'Quality issues'. Moreover, the feedback was separated into what could be considered 'Levels' of the root cause. 'Level 1' refers to the owner of the root cause, and 'Level 2' as the details of the hit. The labels per hit could also include a remark for clarification.

Table 3. An example of feedback received included 'Levels' labeling.

Cause Owner - Level 1	Category - Level 2	Remark/Comments
Supplier	Lost/damaged	Transportation issue

The information was classified by cluster, team, supplier and cause owner. Table 4 and Table 5 show the distribution of the findings per cluster or cause owner.

Table 4. Distribution of unique OTIF hit categories per cluster.

Cluster	Unique Categories
M&E	149
Metrology	85
Optics	65
OSM	59
Total	**358**

Table 5. Distribution of unique OTIF hit categories per cause owner.

Cause Owner	Unique Categories
Supplier	183
ASML	120
Not defined	28
ASML/Supplier	13
Second Tier	6
3PL (Third-party logistics)	5
Other	3
Total	**358**

This variation in the way OTIF hits are labeled means that the department is unable to collect or aggregate hits to common categories and focus effort on common problems even on the same team. Therefore, each planner seeks to solve problems with their supplier in a dispersed manner, ignoring that the same problem may be happening at the same time with another supplier.

RCA method at the suppliers

When the interviewees were asked about the RCA method performed at the supplier to provide feedback, the most common answer was that in most cases it depends on the type of supplier. Many of these suppliers are a very small company that does not have enough knowledge or manpower to perform a structured RCA. In other cases, the actions are quick and small and do not require deep analysis.

3.2.6 Tooling

Once ASML and the supplier have agreed on the labeling of the hits, and all the feedback is consolidated; several tools are used to show performance, track progress of improvement plans and rank OTIF hits categories.

Pareto Chart

A Pareto chart is a graphic tool for ranking causes from the most significant to the least significant, based on the 80/20 rule that suggests that 80% of effects come from 20% of the possible causes (Imai, 2012). Figure 17 depicts a fictional chart based on the previously mentioned categories, generally done weekly or over a long period to gather enough data (e.g. from Oct-2019 to Apr-2020) to draw a relevant action plan.

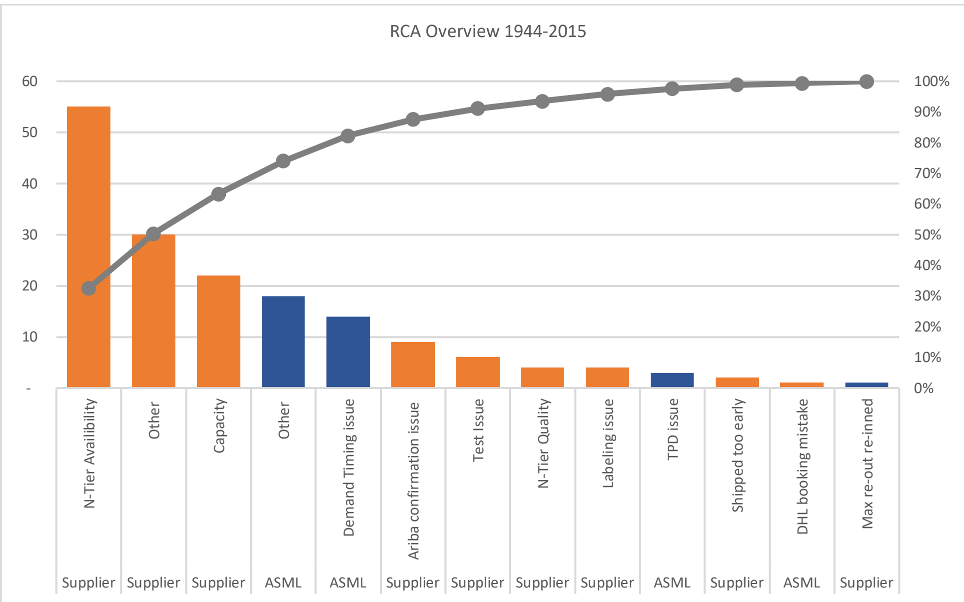

Figure 17. Fictional Pareto chart used to rank categories for further analysis.

4C Method

4C (**C**oncern, **C**ause, **C**ountermeasure, **C**heck) is a basic problem-solving tool widely used in ASML. This tool is meant to be used for 'small' problems with non-obvious solutions. The problem-solving team is composed of just a few persons, and it is expected to be done in less than 4 weeks (the first 3 steps).

1. **Concern:** Step where the problem is described. Here the nature of the problem, relevance, and scope are identified. Generally, it states the current situation, the desired situation, the gap and the trend in performance. Popular tools used to collect information about the problem are the Pareto chart, histogram, flowchart, scatterplot and heatmap.

2. **Cause:** In this step, the root cause of the problem is analyzed. As the first phase, potential root causes are identified via Ishikawa/fishbone, 5-Why's, Gemba or any other known methods. Then, the root cause is verified by a confirmation experiment to show that the found root cause can switch on/off the effect (this verification is not always possible). After the identification of the root cause, it should be analyzed from different perspectives: why did it occur? why not detected? and why not predicted?.

3. **Countermeasure:** In this step, the result from the root cause analysis is used as input to develop countermeasures. Brainstorming, solution mapping, mind mapping are some of the tools used for developing countermeasures. These resulting ideas should be rated/evaluated in an Impact-Effort matrix or based on any other criteria (e.g. feasibility, difficulty, urgency, resource availability, time consumption, etc.). This evaluation is used to select the solutions to implement and plan in time for its execution.

4. **Check:** This step verifies the effectiveness of the implemented countermeasures, establishing how the team will check if the plan worked correctly and the root cause was resolved. Defines the action plan: What, Who, When, and Status of the proposed countermeasure. Additionally, check standards or training to ensure the success is sustainable.

This method is used as a standard procedure to track improvement plans and verify their proper implementations. It is embedded in a PowerPoint slide that most of the accounts use; it also serves as a supplier management record. The slide (Figure 18) shows the OTIF score along weeks/months, a Pareto of the root causes of hits, and the 4C steps for the improvement plans defined with the supplier (Concern/Opportunity, Cause, Countermeasure, Check, Who, Impact, When).

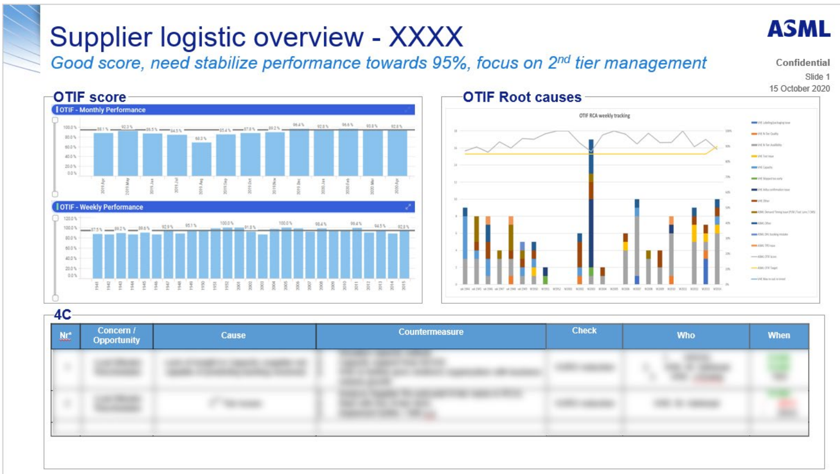

Figure 18. Example of a 4C slide to follow supplier improvement plans and performance.

Although this method is widely used, some account owners still manage their improvement plans in Microsoft Excel, Microsoft Word, or they keep the progress solely in emails.

Other Methods

The company also uses other methods for problem-solving when the issue requires more attention or more than one sector is involved. If an issue can be easily solved and the root cause is known, only the action is taken and the process ends there. However, when the issue needs a more thorough analysis and the stakeholders are constantly monitoring its progress, the 4C method is applied. If the problem presented is complex and it is cross-functional, an A3 method is applied. The A3 method seeks to solve the problem following 10 steps in a structured way; contains more detailed steps to ensure the sustainability of the solution. The following figure presents the flow chart for choosing the problem-solving method used in ASML.

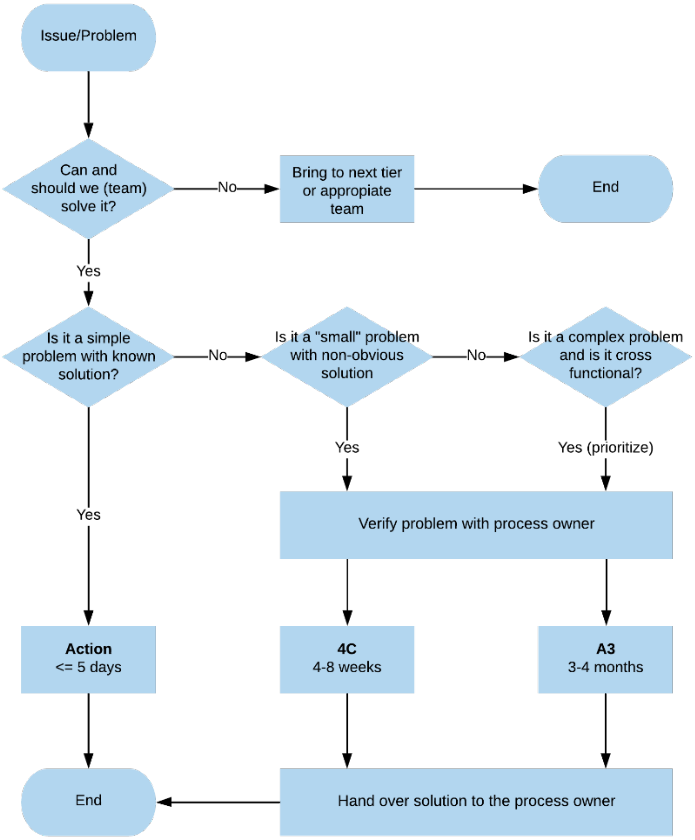

Figure 19. ASML's flowchart for choosing a problem-solving method.

3.2.7 Improvement Plans

As mentioned before, the improvement plans are followed up and stored in Excel spreadsheets, slides, emails and Word Files. These files are used as input for the various performance checking meetings held within ASML or the supplier.

Another tool used in the company to improve supplier performance is the '*Supplier Profile 10' (SP10)*, in which the supplier is evaluated with:

- **Supplier Performance Dashboard**: Used for performance reviews and to measure current KPIs score against predefined targets.

- **QLTCS** (**Q**uality, **L**ogistics, **T**echnology, Total **C**ost and **S**ustainability) Supplier capabilities self-assessment: Used to drive continuous improvement of supplier processes to meet ASML's required standards.

- **Risk Report**: Used to assess critical risks internally (e.g. disruption of supply, financial turndown, etc.)

If a gap is identified, ASML initiates together with the supplier the necessary improvement plans in order to meet the required performance or capabilities. One specific part of this SP10 is a dashboard where the improvement plans are recorded, and their status is registered. The status of the plans can be: 'Aborted', 'In Process', 'Draft;Overdue', 'Implement;Off

Track/Overdue', 'Implement;On Track', 'Draft;On Track' and Completed. This list contains the necessary data to show ownership of the improvement plan from ASML and supplier perspective, including the 'InitiationDate', 'InitialDueDate' and 'RevisionDate'. However, these plans are only being tracked and registered for improvements aimed at closing gaps in supplier's capabilities, raised through self-assessment surveys and audits; in other words, for more complex and structural improvements. These initiatives not always include all key or medium suppliers. Therefore, the improvement plans from the rest of the department are not benefitted from the use of this tool and the high-level view that it provides to the management.

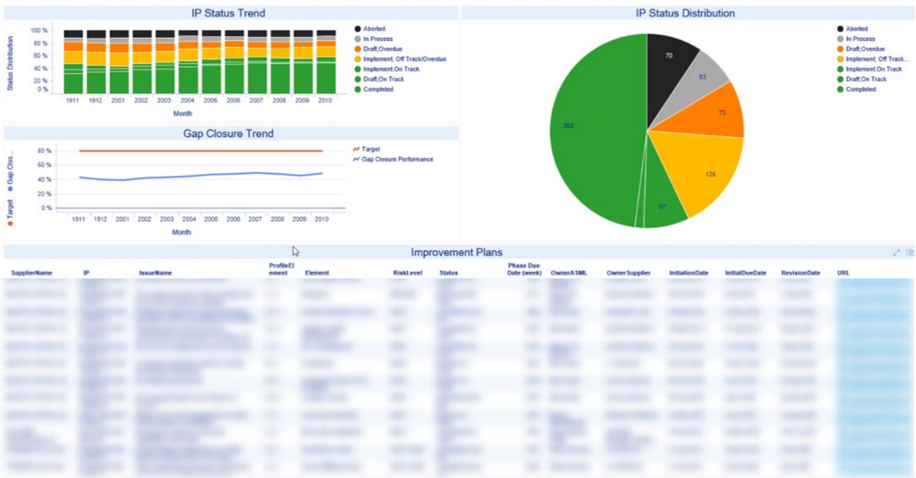

Figure 20. Supplier Profile 10 Deployment Dashboard for Improvement Plans

3.2.8 Expectations and concerns

The standardization of the feedback received by the supplier raised concerns regarding the consistency of information and usability. First, it was mentioned by a few employees that every supplier is unique in its way of working or core business, and therefore having a standard established for feedback might not be a feasible option or would bring much value when compared with other teams/clusters. When the organization adopted the KPI, several rules were shared and among them, a set of standard categories was included in the design of the performance indicator; however, these were not adopted by the department as their definition was not clear enough and they were not communicated to everyone. Moreover, there is a concern that the task of assigning a standard category to a hit will become a debatable and extensive task in itself, adding extra work to the organization and the supplier. The interviews also showed interest from the participants when asked about RCA categories and the standard way of working in the organization.

3.3 Summary

Various aspects were evaluated in the assessment, the 'way of working' of the department, the exchange of information in ASML-supplier interaction, and the tools used to perform RCA and follow-up of the improvement plans. There are clear commonalities between the teams in terms of the types of meetings and the frequency with which they occur; however, some teams have specialized meetings to address supplier issues more frequently than others. Responsibilities are well known to each team, but interaction and accountability are not fully structured.

The information exchange between the company and the supplier has a fixed set of reports that are sent to the suppliers on a weekly basis; however, some account owners share more information with the suppliers to provide them a better overview of what the company has on its records. A clear example of this practice is the 'OTIF prediction report', in which ASML informs the supplier -based on the information stored in the system- what could be a potential hit in the coming weeks. In this way, the supplier is up-to-date on any records that may have been overlooked.

The RCA of OTIF hits is the responsibility of the supplier in most cases, as their feedback is required every week after they receive the record of late -or too early- deliveries. This feedback in some cases is stored within ASML and in other cases, the supplier is the one in charge of the consolidation. This RCA procedure consists of putting a label on each hit, to further analyze it in a Pareto chart within the company or with the supplier. The labels assigned to the hits are not standardized; therefore, it is not possible to perform analysis at higher levels (i.e. team or cluster). For this reason, efforts to solve common issues among teams are scattered due to isolated information. On the other hand, improvement plans are being tracked in 4C templates as separate files per supplier, where account owners do not use a central reporting tool to generate a quick overview. Although a tool to track improvement plans is available in the company, it's only used for medium to long-term plans.

In conclusion, the RCA process in ASML has visible differences such as meetings frequency and purpose, the information shared with the supplier, how the RCA feedback is collected, stored and analyzed, and the way the improvement plans are handled. These differences create room for improvements and process standardization, which will give the department more tools to drive and improve performance. Figure 21 shows a summary of the activities per frequency of occurrence pertinent to Jr. LSM, as an example of the mapped activities in the study.

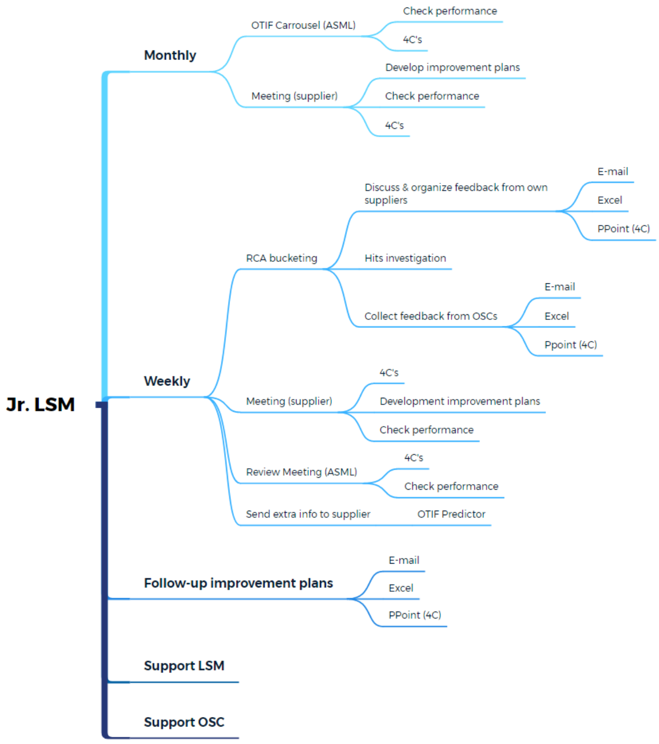

Figure 21. Jr. LSM summary of activities.

4 Solution Design

The study of the current situation showed that the process has some common practices within the department, but does not follow a standard; in addition, there are several differences between how the OTIF process is handled and root cause analysis is performed. Therefore, what is aimed in this chapter is to develop a framework where the best practices could be applied in order to bring value and create an environment for continuous improvement.

First, the justification of standardization and its benefits is presented, and how standardization becomes an enabler for continuous improvement. Then, the methodology on how to create a standard is developed and each step is described for better understanding. Next to this, a problem-solving methodology is used to develop a framework where the opportunities from the previous chapter are analyzed and proposals are made. Finally, an implementation plan is presented based on company standards and developed for the mentioned proposals.

4.1 Justification

4.1.1 Why do we need standards?

Many companies around the world are investing time and money to standardize their business processes to increase their business opportunities and performance. (Münstermann & Weitzel, 2008). According to (Shay & Scherer, 2019), process standardization can be defined as "the improvement of operational performance, cost reduction through decreased process errors, facilitation of communication, profiting from expert knowledge, and providing flexibility without sacrificing organizational controls". These organizations develop standard operating procedures as a product of legislation adherence, ethics, industry best practices, policies and evidence-based procedures (Shay & Scherer, 2019).

Standards are an effective instrument to resolve conflicts and ensure consensus, they are commonly associated with better communication. Specifically, because they include common definitions of metrics, languages that maintain the integrity of business rules, process logic, data, and flexibility; in this way, dissimilar goals and actions can be re-aligned to solve day-to-day problems (Wüllenweber, Beimborn, Weitzel, & König, 2008). In this particular case, ASML could benefit from the positive effect on communication that applies to business processes beyond the boundaries of the company, where the supplier could learn the specifics of the business or its best practices. Both parties could understand the process easily and therefore, facilitate the communication about process execution, changes and improvements (Wüllenweber, Beimborn, Weitzel, & König, 2008)

Besides the communication, process standardization is also associated with consensus, since using process standards could reduce complexity and therefore allows better coordination. Where parties can refer to standards for mutual understanding and agree on how to proceed to increase productivity (Wüllenweber, Beimborn, Weitzel, & König, 2008). Therefore, having a standard procedure on how to perform the RCA could allow for a smoother interaction between ASML and the supplier because, by sharing a common language, a consistent result could be expected.

4.1.2 Benefits

The objective of process standardization is to make process activities transparent and achieve uniformity throughout the value chain and across the company boundaries, which also has a positive effect on communication and coordination between the parties (Wüllenweber, Beimborn, Weitzel, & König, 2008). Many benefits could be listed as a result of process standardization, as there is a significant impact on process performance in general and on process time, cost, and quality in particular (Münstermann, Eckhardt, & Weitzel, 2010)

(Münstermann & Weitzel, 2008) summarize the potential benefits of process standardization as shown in Table 6.

Table 6. Potential benefits of process standardization. Based on (Münstermann, Eckhardt, & Weitzel, 2010)

Value driver	Description
Improved process performance	Reduced end-to-end time (cycle time)
	Reduced process costs
	Improved process quality
Enhanced readiness	To outsourcing business processes
	To merge with or buy other companies
	To react to regulatory changes
	To react to changing compliance needs
	To react to market and external change and trends by increased process flexibility
Enhanced technical interchangeability	Standardizing processes, step by step detaches the processes from continuous tweaking and support from IT departments. Thereby, enables the use of standard hard- and software solutions.
Improved customer confidence	Standardized processes reduce the probability of process-driven mistakes.
	Standardized processes allow coping with continuously increasing process complexity. Consequently, the overall quality and thereby customer confidence improves.
Simplified and increased communication/transparency/measurability	Make process activities transparent
	Allow for benchmarking due to common key performance indicators
	Employees can move more easily from one location to another or one product to another due to standardized processes
	Simplified communication among departments and locations within organizations

There are other aspects -in addition to the already mentioned- from which ASML could benefit from process standardization, such as the ease of problem identification, in addition to the fact that deviations and improvements can be consistently measured against targets. Furthermore, it could prevent over-processing and serve as a basis for onboarding new employees, training, preservation of knowledge, etc. Particularly, standardization has a positive effect on process performance and, therefore, on its potential as an approach to continuous improvement (Münstermann, Eckhardt, & Weitzel, 2010).

4.1.3 Standardization is an enabler for improvements

Before results can be improved, processes must be improved, unlike the result-oriented approach where results are the only thing that counts. At first, any work process is unstable; every time an abnormality occurs in the current process, the following questions arise:

- *Did it happen because we did not have a standard?*
- *Did it happen because the standard was not followed?*
- *Did it happen because the standard was not adequate?*

consequently, any current process must be stabilized with a method often referred to as the S*tandardize – Do – Check – Act (SDCA) cycle, b*efore starting work on a process improvement phase called *Plan – Do – Check – Act (PDCA)* (Imai, 2012, p. 5)

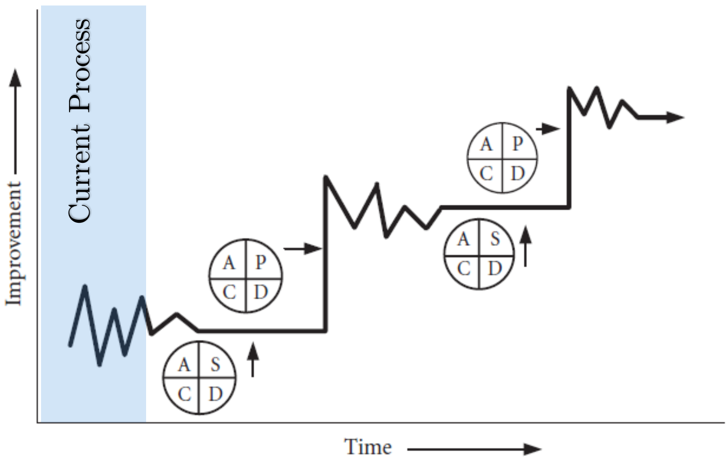

Figure 22. Process movement in time, from SDCA to PDCA cycles (Imai, 2012)

Only after a standard has been established, followed, and employees are doing their jobs according to those standards with no anomalies, the process is considered as under control (SDCA). Then the next step is to adjust the created status-quo and raise standards to a higher -enhanced- level (PDCA) (Imai, 2012, p. 51). Thus, the SDCA cycle standardizes and stabilizes the current processes, while the PDCA cycle improves them, as can be seen in Figure 22. It is also important to realize that the final stage of both cycles —Act— refers to standardizing and stabilizing the job, making standardization an inseparable part of everyone's job. (Imai, 2012, p. 5).

Considering that in ASML there is no standard procedure in place on how to carry out RCA with respect to OTIF management, the first step to complete is to standardize the process and then use it as a stepping stone for continuous process improvement. Figure 23 illustrates how continuous improvement relies on a standard to increase quality consciousness.

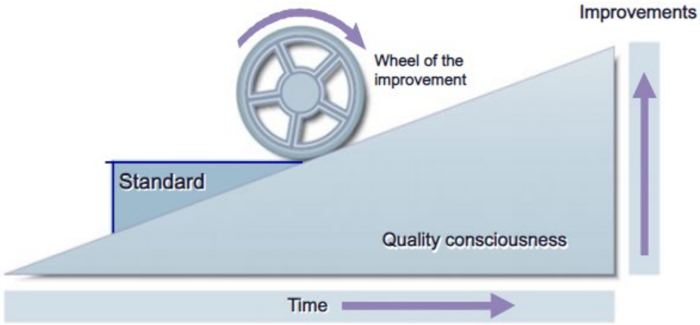

Figure 23. Wheel of improvement (Kaizen Institute Consulting Group, 2015)

4.2 How to create a standard

The previous section described the purpose of having a standard, how it can benefit the organization, and how it can be used to support continuous improvement. The next step is to create the standard based on a proven methodology; for this study, the company has provided a three-step method that is currently in use.

4.2.1 Methodology

ASML currently uses a method composed of three steps to create a standard, where it first makes visible the processes or activities that need to be standardized. Then it prioritizes what needs to be done to finally create the standard based on the SDCA cycle. Figure 24. shows the sequence to follow and the recommended tools for each of the steps. The three stages will be explained in more detail below.

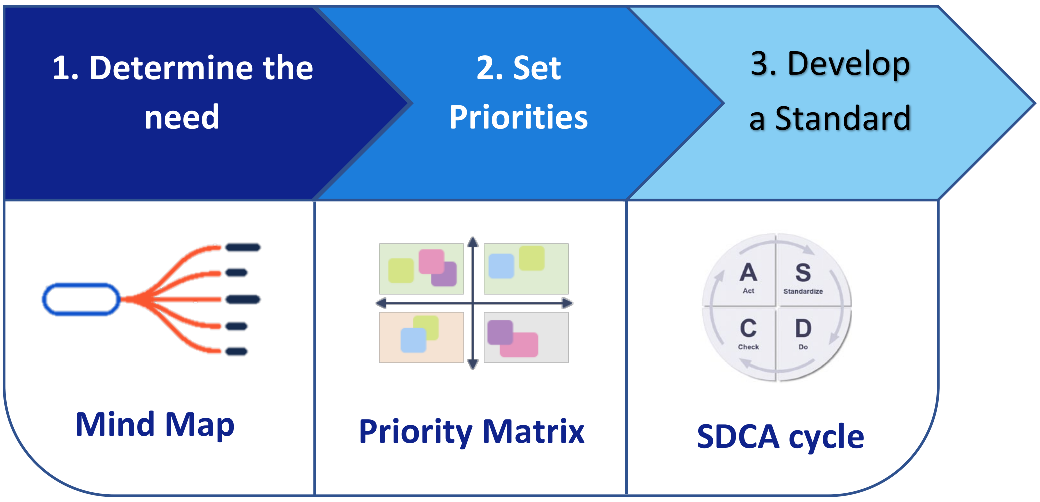

Figure 24. How to create a standard (ASML method)

4.2.2 Determine the need

Before starting the entire standardization process, efforts must be focused and oriented to cover the most critical processes or tasks that can contribute the most to improve. For this reason, the company uses a 3-step approach to narrow the scope of the standardization:

1. Identify the processes performed by the team.
2. Select process to be standardized (e.g. critical to performance)
3. Map tasks within the process

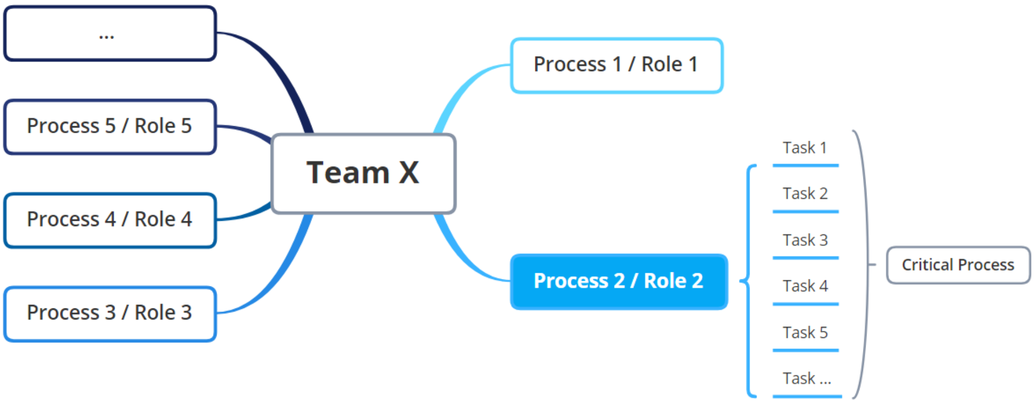

Figure 25. Mind map detailing: team, processes and activities before standardization.

This mind map could be done differently depending on the type of team:

1. **Functional team:** every member does the same activity
   a. Split the team by processes.
   b. List the tasks for each process.

2. **Multifunctional team:** team members have different roles
   a. Split the team according to the roles/responsibilities.
   b. List all the tasks performed by each team member.

In ASML case, the department involves different roles in the same process (i.e. OSC, Jr. LSM and LSM). Therefore, it is classified as a multifunctional team and based on the information collected three mind maps where built (one for each role), including:

- Frequency of the activities
  - Quarterly
  - Monthly
  - Weekly
  - Continuous
- Types of meetings
  - Within ASML
  - With supplier
- Activities involved in the meetings

  - Check performance
  - Develop of improvement plans
  - 4C analysis
- Root Cause Analysis
  - Hits investigation
  - Collect and consolidate hits
- Information sent to the supplier
  - OTIF hits
  - OTIF predictor
- Activities related to the role
  - Follow-up improvement plans
  - Support other roles
- Resources used
  - Microsoft Excel
  - Microsoft Power Point
  - Microsoft Word
  - Email
- Frequency of occurrence
  - Supplier specific – green
  - Done by one or a few - yellow)

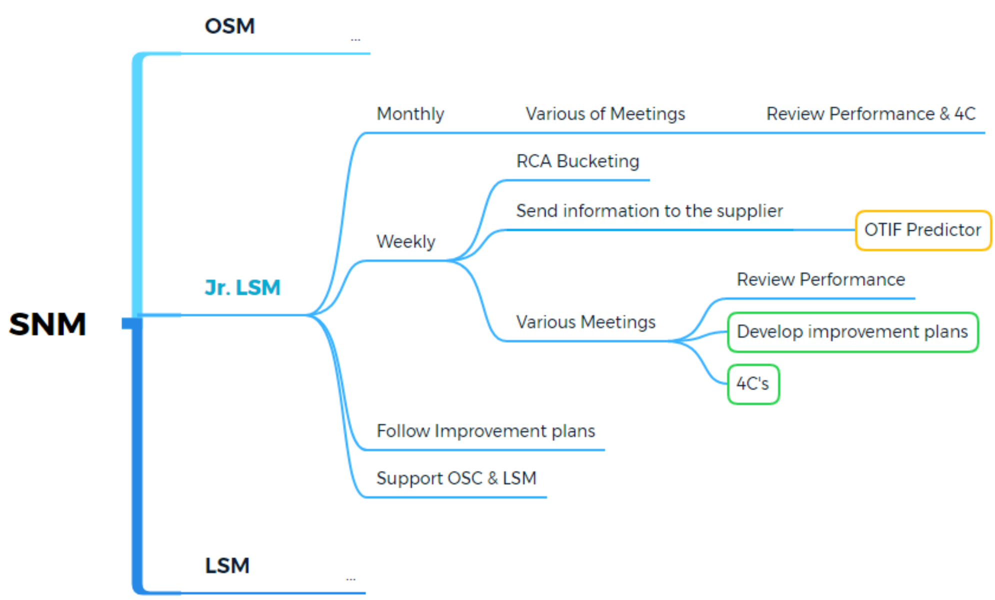

Figure 26. Schematic of Mind maps per role with a summary of described activities.

The mind maps for each role are included in Appendix B. A schematic summarizing the characteristics of the described mind maps is shown in Figure 26.

4.2.3 Set priorities

After having defined the activities performed by each role in the selected process, it is important to establish priorities for the activities that will be standardized. The activities most commonly chosen for the standardization process have the following characteristics:

- Performed by several workers in different ways
- Low-frequency tasks and where information is not easily accessible
- Tasks done by only one employee (‘the irreplaceable’)
- Recently improved
- Critical to Quality

The selected activities based on the criteria -and relevant to OTIF management and RCA- are:

1. **Responsibilities:** In some teams, some activities are performed by the supplier; while in others, ASML employees are responsible and accountable.
2. **Information sent to the supplier:** Sending the OTIF prediction to the supplier is an activity that has brought improvements in ASML-supplier communication. However, sharing this information is not a common practice in the department.
3. **OTIF hits categories:** For each supplier, categories have been defined to receive feedback on OTIF hits. With these, Pareto charts are built to address the most repeated causes and develop improvement plans. This lack of standardization has not allowed ASML to aggregate causes on a team/cluster level to have a better picture of the current status of the KPI and tackle problems not specific to a single supplier.
4. **Improvement plans tracking**: After defining an improvement plan, there is no consensus on how to track the improvement plans. Tools and templates are available for this purpose, but not all employees are making use of these resources.

Once these activities have been identified, the next step is to place them in a **priority matrix**, where *Impact* and *Ease of Standardization* are evaluated. Next, the following criteria is applied to locate these activities in each quadrant of the matrix:

Table 7. Impact and Ease of standardization criteria

Impact	Ease of Standardization
Current Performance: Is the task meeting the required output (quality, volume)?	**Complexity of the task:** The greater the complexity of the task, the more effort is needed to standardize it.
Process Capability: Is the task consistently meeting the customer requirements?	**Recently changed:** Has the process been introduced/changed/improved not long ago?
Frequency: Is the tasks performed several times, where the chance of errors is higher.	**Stakeholders involved:** Are the activities crossing the boundaries of the company?
Potential experience loss: Likely loss of experienced staff in the short term.	**Customization of the task**: Is the task tailored for each customer?

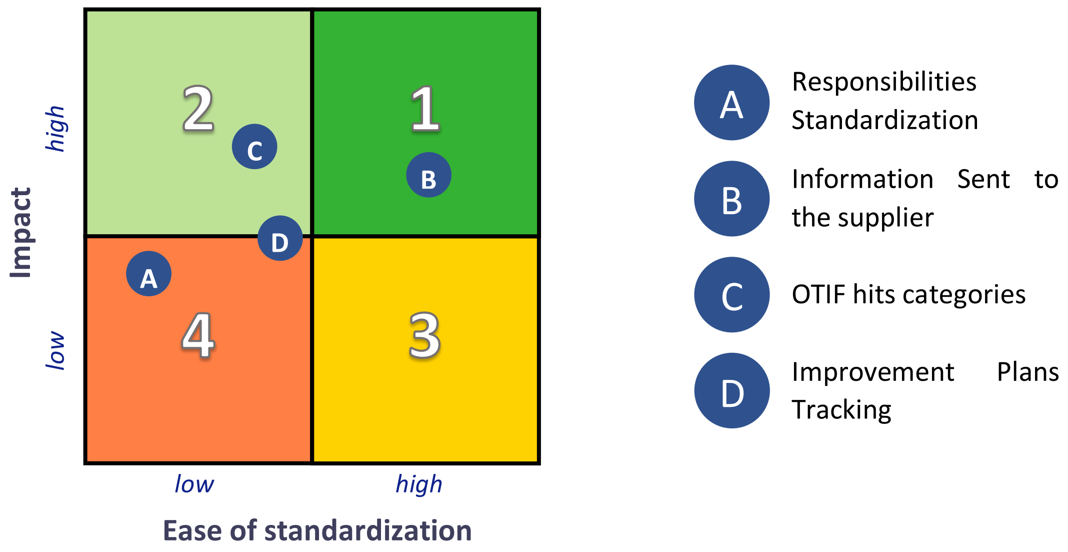

Figure 27. Priority Matrix

The selected activities are placed in the matrix, based on the criteria detailed in Table 8. As a result of this evaluation, 'Information Sent to the supplier' and 'OTIF hits categories' are the top priorities and possibly could bring the most benefit to the organization. However, 'Improvement Plans Tracking' and 'Responsibilities Standardization' could also benefit the organization to a lesser extent with a not so easy implementation.

Table 8. Impact and ease of standardization - ASML case

Activity	Impact	Ease of Standardization
A	Defining standardized responsibilities, and which level of the hierarchy is responsible and accountable for the performance of its team could improve the performance and stability of the process.	Each team and supplier has their own way of working and it is tailored based on experience and specific capabilities of the parties, therefore changing the interaction completely can be challenging.
B	Increasing the visibility of orders and their status at the supplier has shown an improvement in communication and awareness of the KPI behavior.	There is a report that is updated weekly with the OTIF prediction. Performance information is already sent weekly to the supplier (OTIF hits); the knowledge to adapt this process to the current practice is within the department.
C	Having standard categories among the teams and suppliers could bring to light issues that are not a priority now but could be affecting the department as a whole.	Each supplier is different and has its own set of issues. All the information is already labeled and analyzed with 'old' categories. There is not a tool to collect all the 'standardized' feedback.
D	Management could benefit from having a clear overview of the status of improvement plans and how effective the planning and execution are.	Employees are already keeping track of improvement plans, and creating more administrative workload may not be the best approach.

4.2.4 Develop a standard

The activities selected to be standardized now have to go through the SDCA cycle. As the first step, the current situation is described, and based on practical knowledge and industry best practices the new standard is defined. Then these 'new' standards have to be validated and tested by specialists/end-users of the process. After validation and testing, these standards have to be adjusted to have a finalized standard. Finally, these new practices have to be shared with the users involved, and any necessary training must be provided; ensuring sustainability and continuous improvement.

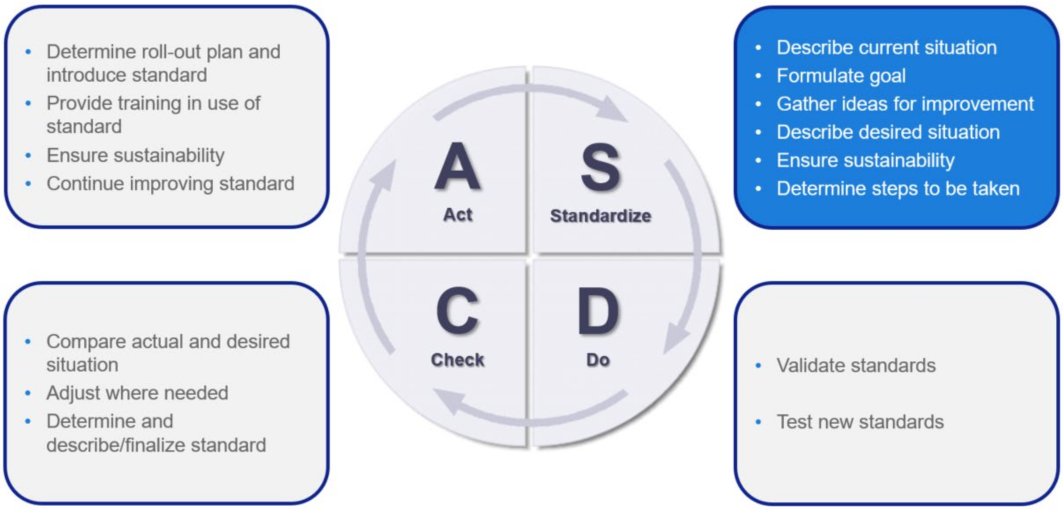

Figure 28. SDCA cycle

The required four steps of the SDCA (Figure 28) cycle will be described in detail in the following sections, taking into account that the testing and validation will not be studied in detail due to the nature of this project. However, the roll-out (act) plan will still be described as a suggestion for implementation.

4.3 Standardize

A process standardization can only be a success when the knowledge that is captured in the standard is available for the direct users, and used (in the right way) within the company. Thus, the potential users must be willing to use the standard and be capable of understanding and using it. To accomplish this, the standard should be user-friendly and include experience and practical knowledge into the development of the standard (Vries & Slob, 2006). For this reason, one way to provide the users with a known way of working and familiar steps to follow in their day-to-day work routine is to provide a model that gives them sufficient details about the discrete mental activities required (Okes, 2019).

A widely known method used in the industry for problem-solving is the **"A3"**, an A3 report was conceived as series of boxes/steps in a template or sheet of paper that aims to turn routine managing into cumulative learning for the whole organization; while the thinking behind follows a common logic, most organizations adapt the report to fit their needs (Wright, 2009). The A3 method also serves as a mechanism to guide others in RCA and scientific thinking, align parties' interests, encourage dialogue and mutual learning (Shook, 2009). The general steps to follow are: (1) establish the business context and importance of a specific problem or issue; (2) describe the current conditions of the problem; (3) identify the desired outcome; (4) analyze the situation to establish causality; (5) propose countermeasures; (6) prescribe an action plan for getting it done; and (7) map out the follow-up process.

ASML uses its own extended version of A3, which consists of 9 steps where there is an added focus on monitoring and learning from the problem. The goal of applying this method as a template to define a standard process is to cover end-to-end structural thinking. In particular, a process where roles and responsibilities are defined, the problem is summarized, the root causes are visible, solutions are tested, and performance monitoring is measurable.

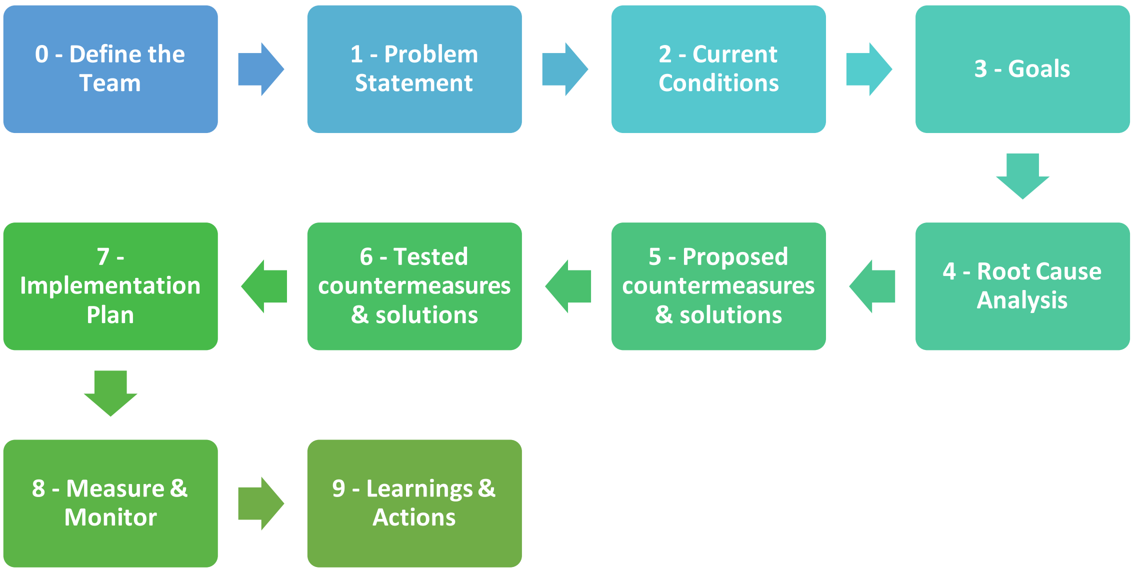

Figure 29. ASML's A3 problem-solving steps.

All steps outlined will be covered with ASML best practices; but in addition, the stages in which the -previously defined- activities to be standardized are framed will be explained in more detail.

4.3.1 0 - Define the Team

First, the team that will work on the issue must be defined. A team should be comprised of a champion/sponsor, a team leader, a problem-solving expert and a subject matter expert. All roles and responsibilities should be defined in advance, to allow employees to focus on their tasks and maintain accountability. To do this, a model will be used to determine tasks ownership; the most commonly used model in business and IT is the RACI model (**R**esponsible, **A**ccountable, **C**onsulted, and **I**nformed) (Costello, 2012). RACI matrixes represent the responsibility assignment of the members of an organization; they are used to associate activities with (human) resources, usually by using organizational roles (e.g. LSM, Jr. LSM, OSC) (Cabanillas, Resinas, & Ruiz-Cortés, 2012).

There are some rules that apply to using the matrix, where each activity (row) is assigned a letter for each role (column), where it applies. Only one person/role could be 'Accountable' for a given task, they will respond for the completion of the task; the 'Responsible', will be the person/role that performs the task. ASML uses 'Contributes' instead of 'Consulted', for person/roles who contribute to the work by providing information or resources to the 'Responsible'. Finally, the 'Informed' is the person/role who is kept updated about the progress of an activity or the result of the work, usually by the 'Responsible'.

For this case, frequency of occurrence and the selected activities were used as *rows* in the RACI matrix; the roles were used as *columns*. Each role is responsible for a specific type of supplier; therefore, a set of symbols (* → SAT suppliers, + → key suppliers, No symbol → medium suppliers) was used to represent the type of accounts related to each role. Some activities are general to all the accounts and have been highlighted for better understanding. The full matrix is found in Appendix C.

Table 9. RACI matrix

	Task / Functions	Bussiness Analytics	SNM			OSM				Supplier
			Cluster Manager	Team Manager	LSM	OSM Manager	Team Manager	Jr. LSM	OSC	
Weekly	Send OTIF Dashboard	A/R			I*			I+	I	I
	Update OTIF KPI	A/R								
	Send OTIF Feedback to ASML				A*/I*			A+/I+	A/I	R
	Validate OTIF Feedback from supplier				A*/I*			A+/R+	A/R/R*	C
	Consolidate OTIF hits feedback				A*/R*			A+/R+	A/R	R/C
	Meeting within ASML - DK Only Top X - Drive OTIF			I*	R*/A*		I+/I	R+/A+	C*/R/A	
	Meeting with Supplier - Drive OTIF			I*	R*/A*		I+/I	R+/A+	C*/R/A	C
	OTIF Intervention - Only Top 3 - SNM Staff DK		A*	R*	C*	A+/A	R+/R	C+	C/C*	
Monthly	ORM within SNM - Only Top 5 - Drive OTIF		I	I*	R*/A*		I+/I	R+/A+	C*/R/A	
	OTIF Carrousel - OSM					I+/I	A+/A	R+/R	C	
	Meeting with Supplier - Drive OTIF			A*	R*			R+/A+	C*/R/A	C
Quarterly	ORM meeting with Supplier		I*	A*	R*					C
Supplier specific	Drive and follow-up improvement plans to the root causes			I*	R*/A*		I+/I	A+/R+	A/R/C*	C
Ad-hoc	Revise OTIF categories (First, 3 months; later, every 6 months)		A	R	C		R	C	C	

All accounts (highlighted) * = SAT suppliers
+ = Key suppliers
No symbol = Medium suppliers

The matrix was developed with input from users of the three main roles (OSC, Jr. LSM, LSM). As an example, for the weekly activity 'Validate OTIF Feedback from supplier', the OSC role is **A**ccountable and **R**esponsible for medium suppliers; moreover, it is also **R**esponsible for SAT accounts (A/R/R*). The Jr. LSM is **A**ccountable and **R**esponsible for Key suppliers (A+/R+), while the LSM is **A**ccountable and **I**nformed for SAT suppliers (A*/I*). The supplier serves as a **C**ontributor in all the accounts.

4.3.2 1 - Problem Statement

In this step, the problem has to be defined and described properly in order to be clear on what should be solved. First, the symptoms (what is visible from the problem) should be described. Next, the facts should be collected through: the customer, interviews, logs, records, data analysis or process statistics. A powerful method to clarify the problem is the use of '5W1H', where several questions should be answered to identify the specifics of the incident:

- **W**hat is the problem?
- **W**hy is it a problem?
- **W**here is it a problem?
- **W**hen is it a problem?
- **W**ho is it a problem for?
- **H**ow much of a problem is it?

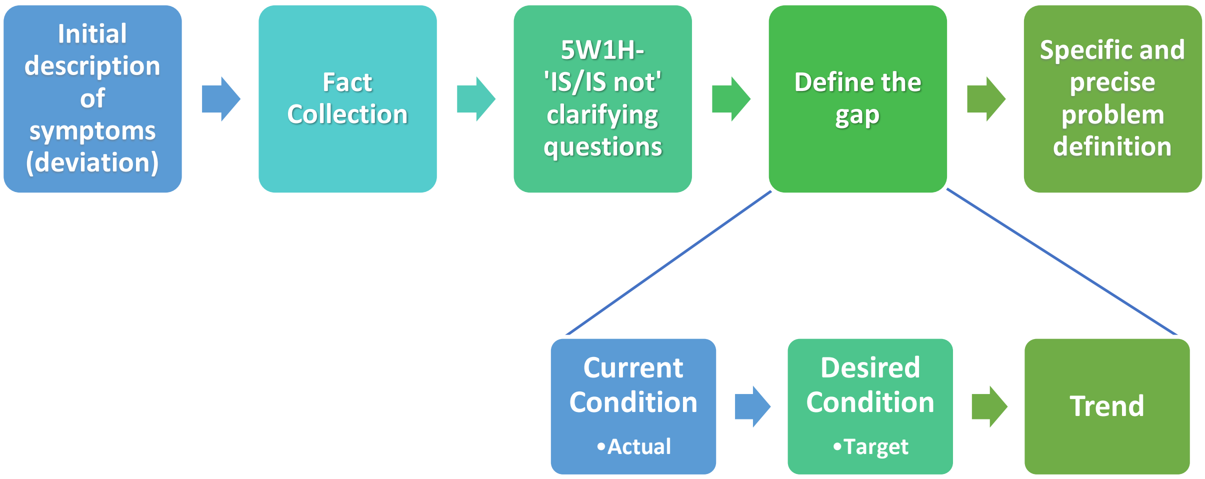

Figure 30. Problem Definition process

After identifying the specifics of the incident, the next step is to describe the actual state (current condition), the target (desired condition), the gap (difference between actual and target) and a trend (is the problem getting worse in terms of time?). With all these considerations, the problem statement is defined, clear and understood; paving the way for the next steps. Figure 30 depicts the process to follow to form a precise 'problem definition'.

4.3.3 2 - Current conditions

For this stage, the current conditions (performance) have to be described, to quantify the initial state as much as possible; more specifically, the existing data available to assess the current performance. Measuring the current state of the KPI is a good indicator of performance, also aiming to include historic data to take into account the trend. Several tools could be used for this purpose, such as tally sheets, scatter diagrams, graphs, value stream mapping (VSM), control charts, histogram or Pareto charts.

The company already uses a weekly updated performance report, shared with the whole department; where OTIF scores -per supplier- and order line details are available for analysis, including historic data up until 24 months in the past. This report reflects the information shared with the supplier regarding weekly OTIF hits.

Figure 31. OTIF dashboard

As mentioned in section 3.2.1 [Information Shared with the suppliers], the 'OTIF prediction report' is also updated weekly with order lines information about their propensity to become an OTIF hit. This report is already being used by some teams for internal analysis and as a source to evaluate current conditions. However, a successful use-case showed that sharing data from the 'OTIF prediction report' led to an increase in OTIF performance due to the increased visibility of orders status perceived by the supplier. Therefore, a proposal to share OTIF prediction will be elaborated in the next section.

4.3.3.1 OTIF Prediction report

The 'OTIF prediction report' was created with the goal of showing a complete overview of the order's current status, and offer an 'estimated' OTIF score based on the match between the supplier confirmation date and the demand date at ASML. As the OTIF KPI only reports when a late or early delivery arrives at ASML's facilities, improvement plans can only occur reactively and not proactively (before the hit occurs). Moreover, due to multiple rescheduling messages or changes in the date required by ASML, there have been times where the supplier is unable to track the order status; which could lead to an OTIF hit that could have been 'prevented'.

According to (Won Lee, Kwon, & Severance, 2007), supplier linkage is a key indicator of performance reliability and overall performance. Therefore, as a tactic to increase the visibility of orders status at the supplier, sharing the data behind the 'OTIF prediction report' on a weekly basis would allow the supplier to have up-to-date order data and trigger proactive actions. The 'OTIF Prediction' data could be shared along with the OTIF weekly report, as a means to give the supplier a detailed list of the goods received and the goods soon to be received (and their status). In this way, the supplier could check their records and make the necessary adjustments to ensure high performance.

The data to share per order line should include:

- Last confirmed date by the supplier
- Required demand date by ASML
- Delivery Delta (in case there is a difference between the dates)
- Status: 'On Time', 'Too Early', 'Too Late', 'Unconfirmed <= 2 weeks' and 'Unconfirmed > 2 weeks'

4.3.4 3 – Setting Goals

Improvement is the desired result of A3 methodology; hence, goals should be set to evaluate this result. This may include a percentage of improvement in process throughput (or KPI), a reduction of defects per unit or processing time (Quality-One, 2020). These goals could be designed using the SMART approach (**S**pecific, **M**easurable, **A**mbitious, **R**ealistic, **T**imely) and structured with the following fields for precise documentation:

Table 10. Goal statement structure

Verb indicating a change	Metric indicating the gap (problem)	From current state	To future state	By a date
Increase or Reduce	…	…	…	…

4.3.5 4 - Root Cause Analysis

Root cause analysis should not be viewed solely as a single tool or strategy, but rather as a series of tools used in combination. RCA is considered as a structured investigation that aims to determine the true cause of a problem and the factors that may influence it (Andersen & Fagerhaug, 2006). This investigation must be based and verified on the problem definition, taking into account previous research and lessons learned.

The objective of RCA is to identify and verify the cause of the problem, the cause of occurrence, the cause of non-detection, and the systemic causes. Afterward, corrective and preventive actions are proposed based on an effective RCA.

The RCA process can be divided into 5 sections:

1. **Collect input**

All the data collected to identify and define the problem must be used. The data from **'5W1H'** could be useful to search for clues or leads to the root cause. Other sources of knowledge for this step are databases with previous RCA investigations, lessons learned or any other problem-solving tools where the problem is related.

2. Identify Root cause

With all the information and knowledge collected in previous steps, the root cause analysis process can start. The purpose now is to delve deeper into the possible causes and zoom in on the root cause of the event. Several tools and techniques could be used for this goal, sometimes these tools have to be used several times to enable drilling down to the real root cause (Andersen & Fagerhaug, 2006). Some of the tools available for the identification process are:

- 5 Why's
- Gemba
- Fishbone
- Statistical Engineering Breakdown
- 3x5Why
- Standard Checks
- **Pareto analysis**
- Design of Experiments (DOE)
- Value Stream Mapping (VSM)
- Histograms
- Scatter Charts
- Cause-and-effect-chart
- Dirty Dozen

In the next section [4.3.5.1 Categories Standardization], the approach to standardize the *Pareto Analysis* will be explained in detail.

3. Verify Root cause

When the root cause is found, it has to be verified to confirm its influence on the problem. This could be done by reversing the 5 Why's and using the word "therefore" to check if the found cause is the real cause. Another method applied is to perform a confirmation experiment, to show that the found root cause can switch on/off the effect or improve the current performance.

4. **Identify why the problem was not detected and predicted**

The problem may have more than one contributing cause; therefore, the 5 why's progression could lead sometimes to form more than one path (Quality-One, 2020). The 3x5 why's method is used in this stage to find the underlying causes of the identified root cause. This method performs individual 5 why's in three different types of failure-causes: (1) cause of occurrence, (2) cause of non-detection, and (3) the systemic causes of non-prediction of occurrence and detection. The following questions are asked to start each 5 why's branch of the analysis.

- Why the problem occurred?
- Why was the problem not detected?
- Why was the problem not predicted?

(Gangidi, 2019) proposes another approach where it performs the 5 why's in three different aspects that may be overlooked: (1) cause of occurrence, (2) human factor, and (3) System factor (method, material, environment).

5. Create output

Once all the previous steps are finished, the root cause has been verified. These analyses will serve as input for corrective, preventive and predictive actions.

4.3.5.1 Categories Standardization

The categorization of OTIF hits used to document the supplier feedback [3.2.5], allows the construction of a Pareto chart [3.2.6] to rank the categories with the most hits. This chart turns the focus on the causes with the highest impact; and indirectly, makes the user to document the reason for every hit. This Pareto chart differs for each supplier, team or cluster; since each supplier has its own labeling defined according to its needs. Having these differences in the labeling has not allowed information consolidation for further and deeper analysis. For this reason, to satisfy the standardization need a proposal is made to homogenize these categories.

Methodology

The feedback from participants was consolidated into one large set of two levels of categories, and some methods were evaluated to use the data gathered. An individual request to key users was sent, where they had to choose between four approaches for a new design of categories: (1) Feedback ASML (2) OTIF-roll out categories (3) SP10 and (4) Own proposal.

Highligth instructions

Please highlight the buckets according to the level of category you think would work best for ASML root cause analysis of OTIF Hits.

XXXXX	1st level (Owner)
XXXXX	2nd level (Cause)
XXXXX	3rd level (Subcause)

Proposals

1. Feedback ASML	Based on feedback from LSM, OSM, Jr LSM/OSM.
2. OTIF roll-out categories	
3. SP10	
4. Own proposal (new tab)	Please fill in with your customized proposal

ID	Owner	Level 1	Level 2
1	**Supplier**		-
2			Availability
3			Capacity
4			Delay
5			Direct SERV Parts packaging
6		2nd Tier / N-Tier	Holiday closure
7			Incident
8			Management

Figure 32. Request for information sent to key users.

After receiving feedback from each user, no consensus was reached between the approach to use or the relevant categories to include in the final proposal. Because of this, a focus group was formed to address the task. According to (Creswell, 2007), focus groups are beneficial when the participants are similar and cooperative with each other, and their interaction is likely to produce the best outcome. The focus group consisted of Jr. LSM, LSM and OSC. The task was divided into two sessions, where the number of levels, the nature of the proposal -as a standard or suggested- and the possible implementation approach were discussed.

Categories

A problem is usually the result of multiple causes at different levels; in other words, some causes influence other causes that, in turn, create the visible problem (Andersen & Fagerhaug, 2006). It is beneficial to think about how the visible cause can be contrasted with the deeper underlying cause. The *Symptoms* of a problem are not actual causes, but signs of existing underlying problems. *First-level causes* and *Higher-level causes* form links in the chain of cause and effect that ultimately create the problem. Figure 33 illustrates how the sequence of causes behaves to eventually become a visible problem.

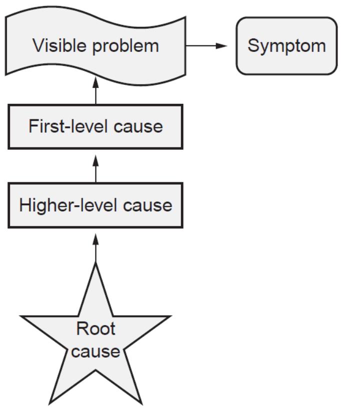

Figure 33. Different levels of causes of a problem (Andersen & Fagerhaug, 2006).

The focus group aimed to develop a set of categories with relevant labels that would allow for further analysis. Three levels were defined:

- **Level 2:** Defined as a combination of categories that are already in use and other additions, to address *symptoms* or *visible problems.*
- **Level 1:** Umbrella labels containing level 2 categories with a common topic.
- **Owner:** ASML and supplier were chosen as the primary owners of the hits, leaving out neither the warehousing company nor 2nd Tier as cause owners.

An explanation of each category was included to avoid any confusion in ASML or the supplier. Additionally, to take into account important categories not covered in the proposal, a level 2 'Other' category was included for hits without a standard label. Figure 34 shows the hierarchy and examples of the proposed categories.

Figure 34. Schematic of defined Category levels

ASML

Categories for ASML include, but are not limited to, the warehousing company as level 1. Also, specific level 2 labels related to the ERP and PO administration are listed.

Table 11. ASML standard categories

Level 1	Level 2	Explanation
Planning	NC to volume planning NOK	OTIF mismatch carried over from NPI (NC flagged) planning
	Ordering above agreed MR	
	Ordering within OLT	
	Partial Delivery Re-inned	Order split on request of ASML to expedite partial delivery
	Priority Request (outside SAP)	Expedition of order requested without requested date becoming visible in Ariba
	Other	Only use if the issue really doesn't fit in the regular buckets
3PL (third-party logistics)	Late booking	
	Lost	Material lost at 3PL warehouse. POD available
	Wrong PO item	Incoming material booked on wrong line item of PO
	Other	Only use if the issue really doesn't fit in the regular buckets
Administration	Ariba bug	OTIF hit due to ASML acknowledged Ariba bug
	Early intake not processed correctly	OTIF date not adjusted after an approved early delivery
	Pending PO/Change PO - Normal	Delivery either delayed or stagnated at ASML warehouse due to pending PO change
	Pending PO/Change PO - Return 4 Re-use	Delivery either delayed or stagnated at ASML warehouse due to pending PO change
	Pending PO/Change PO - Repair	Delivery either delayed or stagnated at ASML warehouse due to pending PO change
	Other	Only use if the issue really doesn't fit in the regular buckets
RTM	Occupied RTMs at ASML	No RTM available for pending delivery due to high stock levels
	Pool leakage	Actual RTM pool size level lower than pool size set-up (e.g. RTMs lost in field)
	Pool size setup incorrect	RTM pool size calculation not in line with actual need
	Other	Only use if the issue really doesn't fit in the regular buckets
Transport (FCA)	Availability	Not enough transport available
	Customs	Shipment held up at customs
	Delay	Planned transport not performed according to schedule
	Other	Only use if the issue really doesn't fit in the regular buckets

Supplier

Supplier categories are less specific, to cover the variety of issues that may arise and to avoid the creation of extra labels to detail supplier-specific issues.

Table 12. Supplier standard categories

Level 1	Level 2	Explanation
Capacity	Cleaning	Not enough capacity on inhouse cleaning services, either in- or outbound, or during the process
	Cleanroom	Not enough cleanroom floor space available
	Machinery, tooling	
	Manpower/Personnel	
	Other	Only use if the issue really doesn't fit in the regular buckets
Planning	Administrative Error	Planning issues stemming from manual errors such as typo's
	Incorrect holiday planning	Not enough planned capacity due to holidays
	Order process issues	OLT mismatch, wrong ERP settings, etc.
	Shop floor control issues	Insufficient insight in order status
	Other	Only use if the issue really doesn't fit in the regular buckets
Warehouse & Transport	Capacity of transport	Insufficient transport possibilities
	Damaged	Finished material damaged in transport from supplier to ASML
	Incorrect documentation and registration causing stagnations	
	Lost	Finished material lost in transport from supplier to ASML
	Other	Only use if the issue really doesn't fit in the regular buckets
2nd Tier / N-Tier	Capacity	See level 2 capacity descriptions
	Planning	See level 2 planning descriptions
	Quality	See level 2 quality descriptions
	Warehouse & Transport	See level 2 warehouse & transport descriptions
	Other	Only use if the issue really doesn't fit in the regular buckets
Quality	BID Label	Incorrect or missing BID labels
	Design	Delay in production due to design-related issues (e.g. TPD unclarities)
	Missing/incorrect PRR	Problem Resolution Report not attached to a shipment or incorrectly filled
	Missing/incorrect ZQSOLUT	Missing repair conclusion in the Q-Portal
	Workmanship	Human error
	Yield	Yield-% insufficient to fulfill entire demand
	Other	Only use if the issue really doesn't fit in the regular buckets
RTM	RTM availability due to repairs	Repair/maintenance not performed in time leading to RTM unavailability
	Other	Only use if the issue really doesn't fit in the regular buckets

Expected Results

With all the categories in place, and the suppliers together with ASML using the proposed labels, it is expected that analysis could be performed using combinations such as: Owner-Level 1-Current Week, Owner-Level 1-Week history, Owner-Week history, Owner-Level 2-Current Week. The use of standard categories throughout the department will allow the construction of the same analysis, by team, cluster or any other classification that may be needed in the future. With this in mind, if the feedback comes from the supplier in the agreed form on a weekly basis, this analysis (Figure 35) would be possible for each performance review meeting.

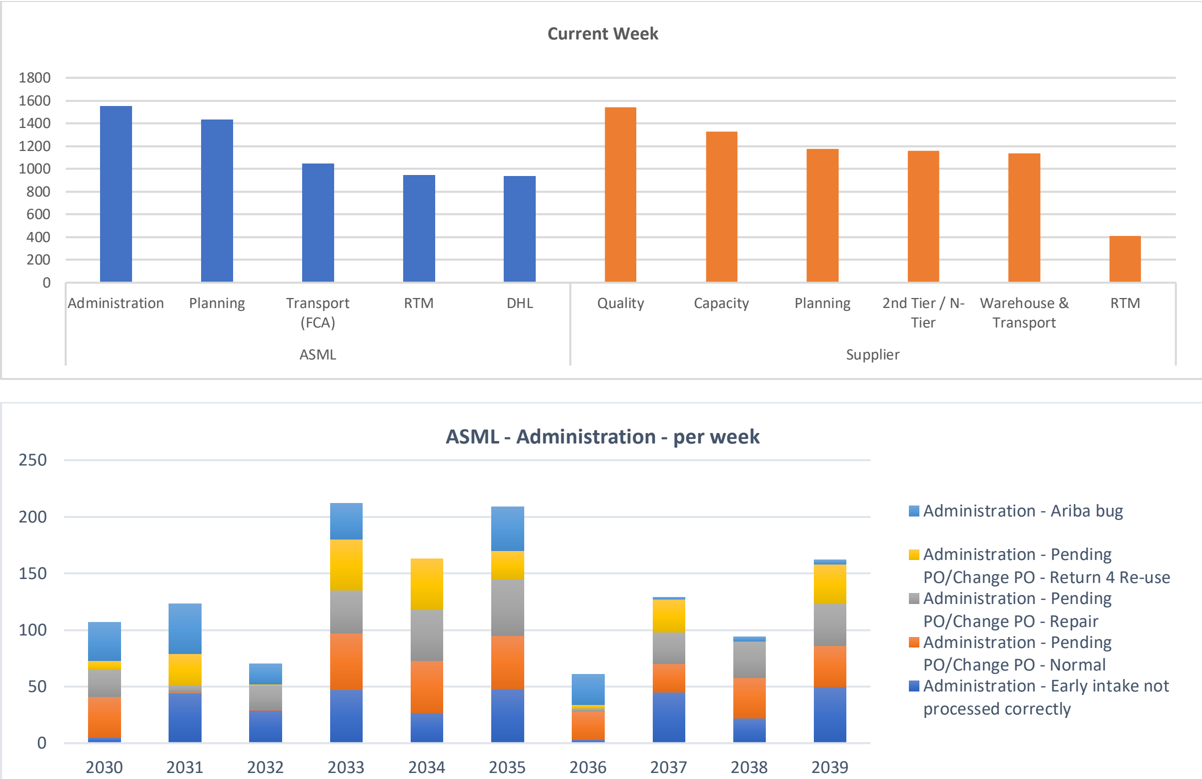

Figure 35. Expected charts from new categories implementation (fictional)

4.3.6 5 - Proposed Countermeasures & Solutions

After finding the root cause(s) of the problem, the next step is to determine what actions should be initiated to ensure that the process is controlled.

The process to propose possible countermeasures and select them can be divided into 3 steps:

1. **Identify possible countermeasures for each root cause**

In other words, identify potential solutions to achieve the desired results. There are many tools available to propose countermeasure ideas, such as: brainstorming, solution mapping, mind mapping, making comparisons, challenge assumptions and six thinking hats. Technical, organizational or behavioral actions could be applied to solve the problem. In Figure 36, a mind map is used to show two ramification levels of proposed countermeasures for a single root cause.

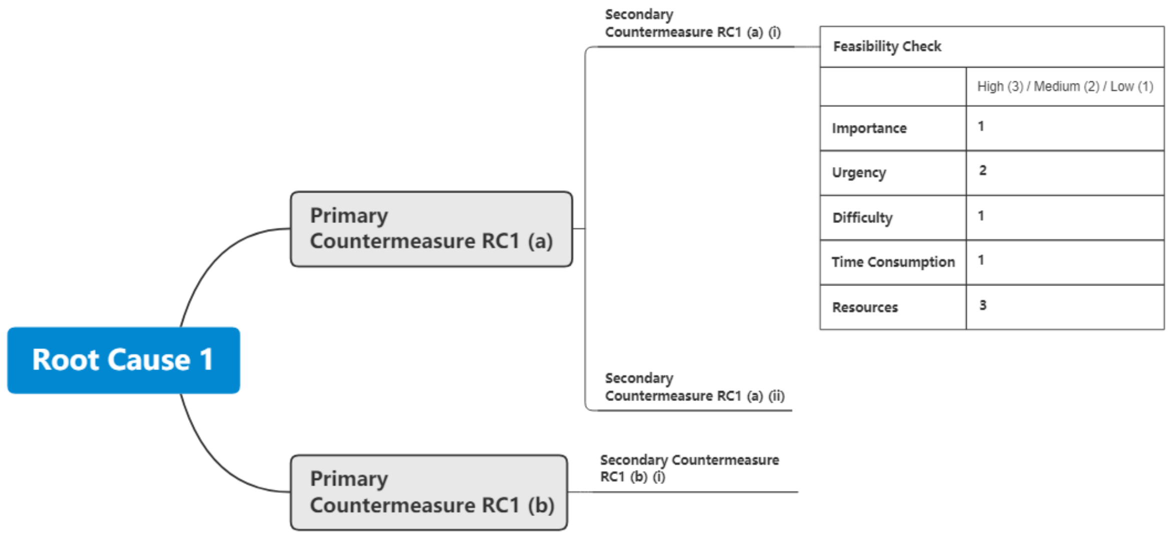

Figure 36. Mind mapping of proposed solutions and rating.

2. List SMART decision criteria and weight

The proposed countermeasures must be clearly defined, achievable by the person in charge and have a due date to avoid continuous postponements (Quality-One, 2020). Using the SMART criteria will provide enough factors to evaluate a countermeasure. These factors must be weighted and then scored for each proposal. Other common criteria for evaluation are: Impact on solving the root cause, risk to disturb the ongoing operation and meeting internal customer requirements. Figure 36 (right side) illustrates the matrix where the countermeasures must be evaluated. After scoring the ideas, several options could be chosen to solve the problem.

3. Challenge the solutions on reliability

The proposed countermeasures can be tested against the 'Countermeasures ladder' (Figure 37), to check how effective the countermeasure could be to eliminate the problem. The higher up the ladder, the more reliable the implemented countermeasure will be.

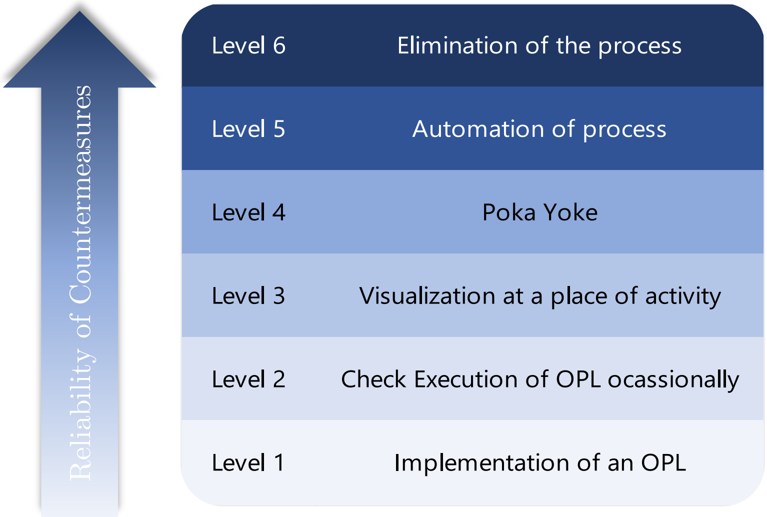

Figure 37. Countermeasures Ladder

4.3.7 6 - Test countermeasures & solutions

Testing the countermeasures ensure that they will be efficient in solving the problem and bring the expected result. Once these countermeasures have been selected based on the previous criteria, they must be prioritized before starting to create an action plan. For this purpose, a priority matrix could be used with 'Impact on solving the root cause' and 'Effort' as axes (as exemplified in Figure 27). Then, a pilot test can be used to test whether the countermeasures have the expected effect on the root cause. This pilot can be small but must be also representative, in order to optimize resources and decide whether it is worth moving forward with implementation or deployment.

4.3.8 7 - Implementation Plan

Once the countermeasures are tested, implementation is the next step to take. An implementation plan should be developed to define what, who, when, and the status of the change. The plan should include the team, time and resources necessary to complete the task; in some cases, external resources or facilities may be required. Moreover, the corresponding management levels must also be aware and informed throughout the process, to guarantee that adequate resources are available for the implementation of corrective actions (Quality-One, 2020). Additionally, stakeholders should be involved if any of the changes are affecting them. The implementation should include a risk assessment and a plan for what to do if there is reoccurrence of the issue. Above all, standardization, metrics, and training are key to making change sustainable and avoiding the same problem in the future.

4.3.9 8 - Measure & Monitor

This step reviews if the **results** are being obtained with the implemented countermeasures. First, the level of process implementation must be followed, to ensure that the due date and the implementation stages are on track. In addition, the elimination of the root cause (step 4) should also be checked to monitor for any possible reoccurrence. A data collection plan should be created to verify if the results are being achieved according to the goals defined (step 3). Finally, to verify if the output meets the target, it is recommended the use of visual-management tools to track performance or any KPI related to the problem. This verification of results should be done with an agreed frequency or during team meetings to maintain accountability.

4.3.9.1 Improvement Plans Tracking

To track operational improvement plans and the level of process implementation of the countermeasures, a standard has to be in place to avoid variability in execution and allow further consolidation. The tool already in place for SP10 could serve as a format template, adding extra fields to allow more control and visibility. Fields to be registered for every improvement plan are:

- Cluster
- Team
- Supplier Name/Code
- Concern/Opportunity/Issue
- Root Cause(s)
- Countermeasure
- IP/KPI affected
- Start Date/Week
- End Date/Week
- Closing Date/Week
- Total duration
- Status
  - On track
  - On Hold
  - Overdue
  - Closed
  - Aborted
- Responsible
- Improvement Category
  - Owner - Level 1 Categories [4.3.5.1]

This database will allow the consolidation and an overview of the current status of improvement plans, or any other initiative focused on improving OTIF performance. The database includes dates and duration of tasks to allow various analyses such as: Number of plans closed/aborted per month, average duration of the closed plans, number of improvement plans per OTIF category and the status of all improvement plans for each supplier/team/cluster. Figure 38 shows the expected result and managerial insights to be gained by consolidating information in one place.

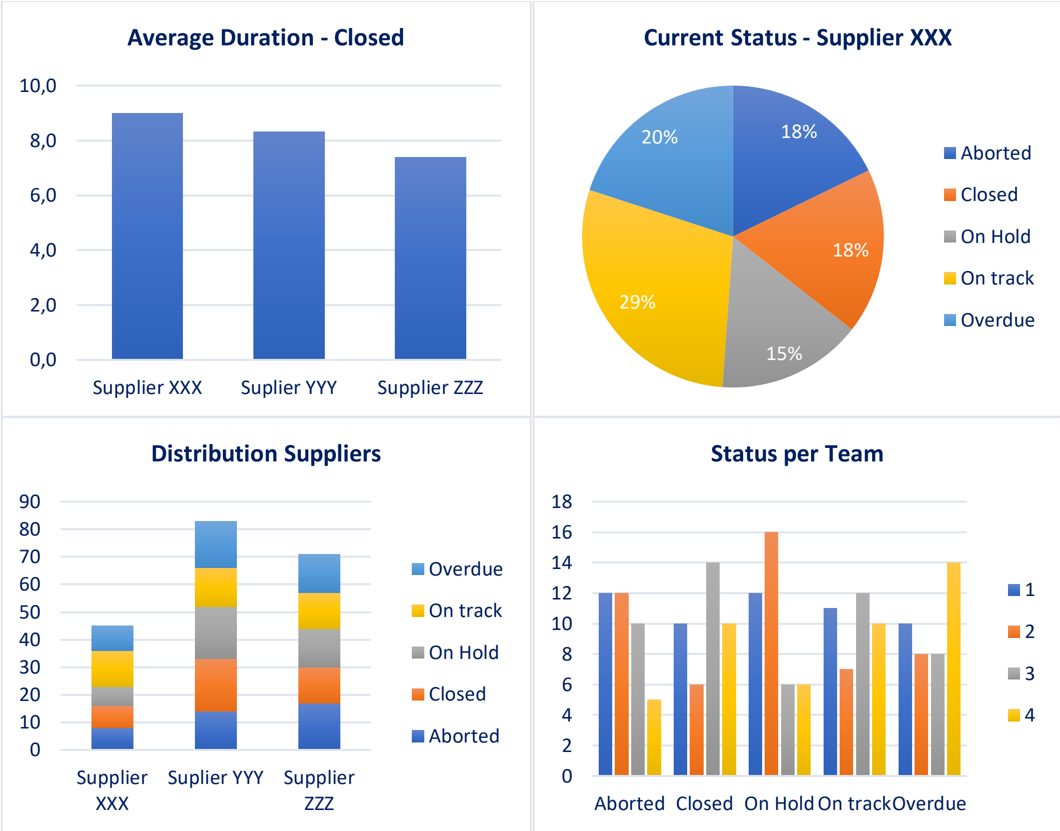

Figure 38. Expected charts from improvement plans database implementation (fictional)

4.3.109 - Learning & Actions

The last phase of the process is intended to capture the lessons learned throughout the previous steps, as well as to develop and secure standards to ensure the sustainability of the countermeasures taken. The team must take actions to standardize the process changes or improvements; updating work instructions, process control plans, or any other factor that needs to be secured to prevent the problem from happening again.

Moreover, it is recommended to share the learnings of the process; what went well and what could use improvement. Sharing these learnings also promotes continuous improvement in the organization (Quality-One, 2020).

ASML already has a standard procedure to *'Start, approve and close 4C & A3s initiatives'*, where if an improvement action is decided to follow a 4C or A3 path, it must go through a series of structured steps. This path begins with the 'initiative' creation, alignment, execution, documentation update, approval, until it is registered in a 'List of initiatives' and finally shared on an internal platform of 'Shared Success'.

4.3.10.14C and A3 Categorization

As mentioned, currently there is already a procedure to record and share 4C and A3 initiatives. Documents and databases are populated with useful information classified by team/cluster or owner. However, as each registry has its own 'Initiative Name', it is not an easy task to go through the whole database to look for success stories in a specific topic or category. Therefore, it is recommended to add to each line of next registries, an "Owner - Level 1" Categories [4.3.5.1], which will serve as keywords to facilitate the search and allow employees to look up for success stories in a desired domain.

4.4 Do & Check

Once the standard has been defined, validation with the interested parties must be performed. Users must be satisfied with the standard; therefore, user feedback to those who have decided to make the standard, as well as the people who developed it, is essential (Vries & Slob, 2006). The validation is done to correct any misalignment or details that may have been overlooked when the standard was designed (Do). If the validation of the new procedure is approved, the new standard has to be tested. The current status of the operation or process has to be compared with the desired one, and the necessary adjustments have to be made. Lastly, the standard can be determined, described and finalized (Check).

It has not been possible to test the proposed measures given the nature of the project; however, a description of the change plan for the proposals will be provided in the next section.

4.5 Act - Change plan

The next step towards progress after a standard has been established, is that the standards become accessible to intended users and for them to be aware of their existence. During this introduction process, potential users should also be informed about how these new practices can fit into their way of working. The more and better the standard is known, the greater the likelihood that the users will use it, and perform as intended by the developers of the standard (Vries & Slob, 2006). Therefore, an ASML's standard procedure could be applied: *"Create and Control Process Documentation"*. This guideline ensures that the documentation corresponding to the procedure is up-to-date, under change control and is centrally accessible in the shared documentation portal to all users.

The steps in the procedure are the following:

1. Reviewing the process and defining the scope of the document
2. Create/update document
3. Review of documents
4. Approval of documents
5. Publishing the document in the document portal
6. **Roll-out process** & audit process
7. Retention and disposition of documents

It is also important to start with the introduction and promotion of the standard already during its development. With the aim of sharing an initial approach and collect feedback from other stakeholders that could be affected/benefitted. Throughout the development of this project, meetings have been held and time has been allocated to share the status of the project with ASML stakeholders; also, the collected feedback was implemented in the presented proposals. Furthermore, after a period of time, the standard may be revised for improvements; therefore, the distribution process is defined in such a way as to ensure that that the user always works with the correct version of the standard (Vries & Slob, 2006).

Roll-out Plan

For the standard to be available to the direct users, a distribution process should be established. This process should ensure the standards reach the direct user in a fast and easy way, including the necessary training (Vries & Slob, 2006). For this purpose, ASML uses a standard procedure: *"Process Deployment (Roll-out)", to en*sure the processes are deployed after their release in a shared documentation portal. It also contains the steps to be performed after the standard is approved and published, and all applicable users are trained/informed about the updates.

The steps in the procedure include:

1. Confirm if training is needed
2. Publish documentation in the portal and send an announcement
3. Inform about changes via Quality, Logistics and/or Operational recurrent meetings
4. Prepare training material, organize and perform training sessions
5. Follow-up on deployment
6. Complete sign-off in the tracker
7. Report out completion progress to management

The new standard process success relies heavily on how the process is shared with the interested parties. *Ease of use of new ways of working, correct assessment of training requirements* and *follow-up of the deployment* will define if the desired outcome is achieved at the end of the day. For this reason, guidelines for the implementation of the proposals will be described; some of them can be implemented with current resources, but others would need more time and resources for their completion.

4.5.1 OTIF Prediction Report

The 'OTIF Prediction' report was originally built to be another tool for ASML employees to analyze the status of their orders according to the confirmed dates by the supplier. To implement this exchange of reports with suppliers on a weekly basis, the following procedure is recommended:

1. Select appropriate suppliers to run a pilot for a few weeks to test the behavior of report and supplier response.
2. In the weekly report (Excel), include the 'OTIF Prediction' dataset as another tab next to 'OTIF'.

3. After acceptance of deployment based on added business value, create a list of all suppliers and ask the account owners to decide whether or not they want to share the 'OTIF Prediction' with their accounts.
4. Send a communication package to suppliers to inform the upcoming change in the weekly report and the meaning of the new data incorporation.
5. Run the report every week.

Table 13 includes the fields to be sent to the supplier per order line:

Table 13. Fields included in 'OTIF Prediction' report.

Fields	
PO	Vendor
PO Item	Vendor description
OTIF Order Type	Last confirmed date
Plant	On Time Date
Material	Delivery Delta
Material description	Predicted On Time Bucket

During the course of the project, 'OTIF Prediction' was implemented successfully by the Business Analytics team in collaboration with the SNM department. After asking the account owners to decide whether their supplier will receive the report, approximately 50% (44% OTIF and Predictive OTIF + 6% Only Predictive OTIF) of the suppliers were included in the first roll-out. This number could increase if more account owners verify the added value and see a potential increase in the OTIF score on their accounts. Figure 39 shows the distribution of the type of information that the supplier will receive weekly.

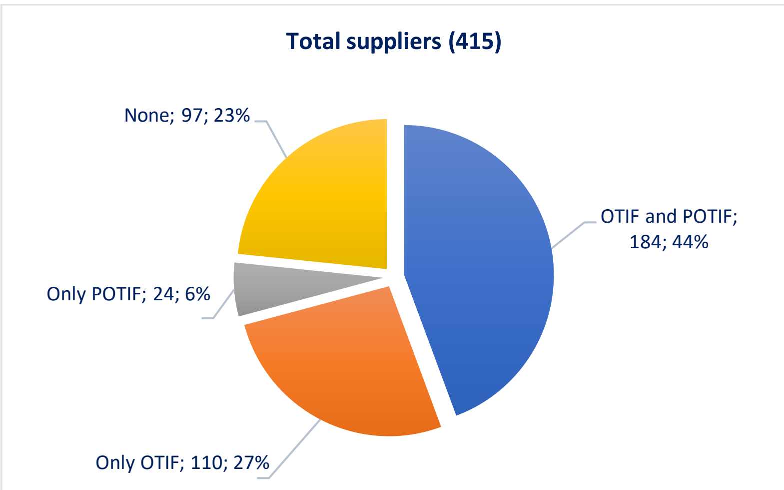

Figure 39. Distribution of accounts where ' OTIF Prediction' will be shared.

4.5.2 Categories Standardization

With the categories defined for both the supplier and ASML to label OTIF hits, the next step is to determine how they will be shared and used among their users to facilitate analysis. The recommended steps to follow for implementation are:

1. Choose a supplier or OSM team (multiple suppliers involved) to start a pilot plan.
2. Transform OTIF hits database into the new categories or decide to start a new analysis from scratch.
3. Share and train the supplier(s) into the new categories and their meaning to avoid misclassification.
4. Hold a review meeting to evaluate the usability of the new categories
    a. Adjust/Rename/Add new buckets if necessary
5. After success, deploy to a larger group of suppliers (repeat steps 2,3,4).

This process will enable a feedback loop to improve the usability of the buckets and define which categories are more relevant and should be highlighted or divided into more buckets.

As an additional observation, during the course of the project, a supplier has already started using the proposed set of categories.

4.5.2.1 Tooling

To ensure the success of the plan, suitable tooling must be defined to allow labeling of the OTIF hits. The company has the opportunity to implement this labeling in a variety of ways, depending on the level of investment of time and resources.

The first alternative uses current resources and could be implemented in a short period. It requires modifying the weekly e-mail containing the OTIF hits per supplier, adding 4 extra columns to the 'OTIF' tab. These columns -*Owner, Level 1 RC, Level 2 RC, Description*- should be used by the supplier to fill in the previously described categories for each level, including one last column to describe the hit in detail. For clarity, another tab with the standard categories could be added to serve as a reference for the person labeling the hits.

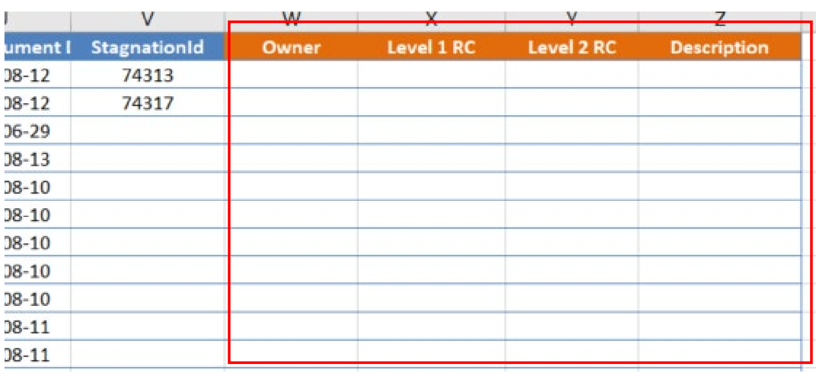

Figure 40. Example of weekly OTIF hits e-mail with 4 extra columns.

After receiving the weekly feedback from the supplier, this data should be stored in a database. Microsoft Excel is currently used for this purpose; this allows the creation of a summary (pivot table), with a suitable format to be used in other spreadsheets destined for higher levels of analysis (teams/clusters/department). Figure 41 shows an example table from a single supplier (supplier 'A'); if a *team level* analysis were to be constructed, this table should be consolidated with all the information from the rest of the team's suppliers. The same procedure should apply for a *cluster-level* analysis (group of teams). All these spreadsheets should be stored and saved in a shared location so that they are accessible at all times by each member of the department; Microsoft SharePoint is currently used as a company standard.

Sum of Hits Supplier	Week	Owner	Level 1 RC	Level 2 RC	Total
A	2030	ASML	RTM	Occupied RTMs at ASML	35
A	2030	ASML	RTM	Other	24
A	2030	ASML	Planning	Ordering above agreed MR	34
A	2030	ASML	Planning	Priority Request (outside SAP)	12
A	2030	ASML	Administration	Ariba bug	34
A	2030	ASML	Administration	Pending PO/Change PO - Return 4 Re-use	8
A	2030	ASML	DHL	Lost	30
A	2030	ASML	Transport (FCA)	Delay	6
A	2030	Supplier	2nd Tier / N-Tier	Capacity	31
A	2030	Supplier	2nd Tier / N-Tier	Warehouse & Transport	45
A	2030	Supplier	Capacity	Cleaning	27
A	2030	Supplier	Capacity	Manpower/Personnel	40
A	2030	Supplier	Quality	Design	43
A	2030	Supplier	Quality	Workmanship	23
A	2030	Supplier	RTM	RTM availability due to repairs	46
A	2030	Supplier	Warehouse & Transport	Incorrect documentation and registration causi	27
A	2030	Supplier	Planning	Incorrect holiday planning	6
A	2030	Supplier	Planning	Other	20
A	2031	ASML	Administration	Early intake not processed correctly	44
A	2031	ASML	Administration	Pending PO/Change PO - Repair	6
A	2031	ASML	Planning	Ordering within OLT	10
A	2031	ASML	Planning	Other	23
A	2031	ASML	RTM	Pool leakage	29

Figure 41. Summary table of hits per week and levels of RC (fictional data)

A second alternative involves the development of a tailored tool, using a team of developers allocated to relevant projects within the department. This group, together with the management, assesses the feasibility and importance of the project, allocates resources and defines the governance. After approval and resource allocation, the development of the tool could take approximately 5 months before it can be deployed. The aim of this tool is to allow the supplier, through an ERP environment (SAP-Fiori), to access their weekly hits and select the OTIF hits categories from a list of options. More importantly, using a centralized tool with a single data source would avoid manual work by both parties and continuous maintenance by the company; enabling this information to be used with any Business Intelligence software for further analysis and presentation. Figure 42 shows how the user must enter data for consolidation purposes in the developed application.

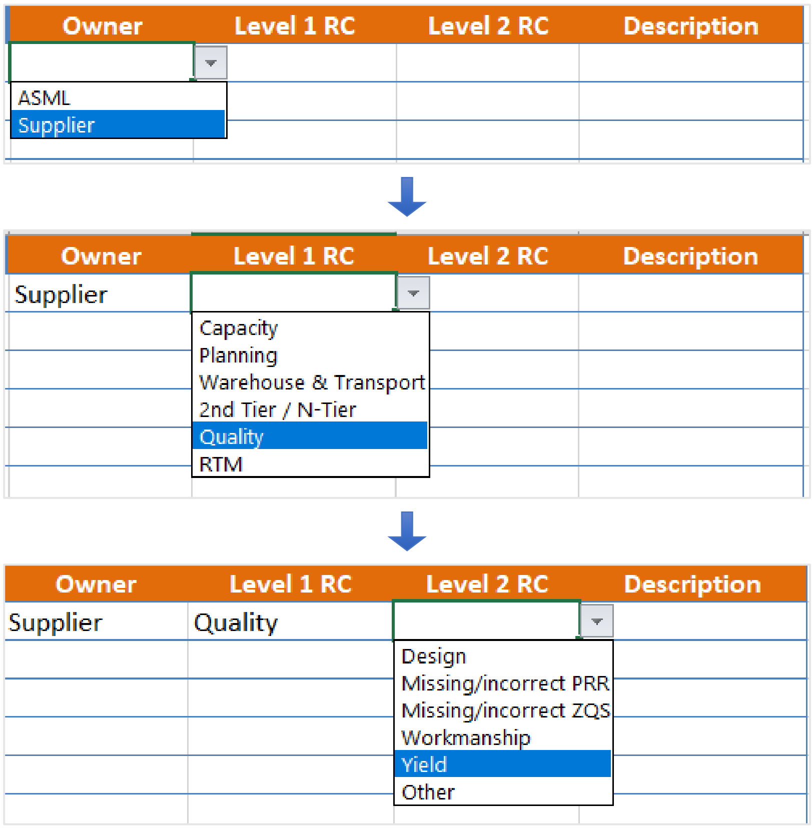

Figure 42. Usability example allowed by the development of a tailored tool.

In either of the two alternatives, it is important to also measure how much feedback is obtained from the supplier, or ultimately by ASML. A *Response Rate* could be calculated to have information about the accuracy of the analyzed categories after consolidation. Moreover, the *Response Rate* could also serve as a metric to measure the extent to which suppliers are addressing their logistic gaps.

$$Response\ Rate: \frac{Number\ of\ OTIF\ hits\ labeled}{Number\ of\ OTIF\ hits\ sent}\ x\ 100$$

To summarize, both alternatives share the same purpose of allowing interaction between the supplier and ASML; enabling the categorization and consolidation of OTIF hits to then trigger the creation of improvement plans and drive performance improvement. However, each alternative requires a different level of effort and has its own advantages over the other.

4.5.3 Improvement plans tracking

As not all the operational plans are being tracked in the currently available tools, adjustments have to be made to offer familiar and useful tooling to follow-up on the progress of the improvement plans. As a first alternative, a shared file must be created with the fields mentioned in the section [4.3.9.1], to allow the users to register all the initiatives meant to drive OTIF performance improvement. These fields will not only allow supplier/team/cluster-level analysis, but also serve as a tool for continuous performance reviews and as a template for presentations. Nevertheless, this database could lead to duplicate workload and information, as the 4C & A3 initiatives have their own database.

Therefore, as a second alternative, the platform that stores the 4C & A3 initiatives could serve as a centralized place where the operational plans could be consolidated. However, some fields have to be added to offer the capability of the templates already in use:

- Cluster
- Supplier Name
- Root Cause (s)
- Countermeasure
- Total Duration
- Improvement Category

This will allow to have a complete picture of all the initiatives taken (open and closed) in the department for improvement; not only for OTIF, but also for other relevant KPIs without duplicating the information.

4.6 Summary

The assessment of the current situation highlighted various aspects in which practices could be improved, such as: OTIF hits categorization, type of information shared with the supplier and how the improvement plans are registered. These differences in the way of working and tooling, opened space for standardization and the application of a problem-solving method to design an effective framework. In particular, process standardization offers benefits of transparency and uniformity throughout the value chain; while also having a positive effect on performance, communication and coordination between the supplier and the company. Therefore, a standardization of the process was proposed, which also serves as a basis for future improvements.

An ASML standard methodology was used to develop the standard. Firstly, the need for the standard must be defined and all the tasks related to the chosen process have to be mapped. Mind maps were the tool used to list the activities performed per role and define their differences. Then, a priority matrix was used to choose which activities would be most important when developing a standard, while also listing their pros and cons. Lastly, the standard was created using the SDCA (Standardize, Do, Check, Act) cycle. For the 'Standardize' step, the A3 method was used as it is an effective tool for driving improvement and promoting a problem-solving way of thinking. Each step of the A3 was reviewed and specific proposals were included and elaborated in each step based on the input of chapter [3]. First, roles and responsibilities were defined through a RACI matrix, standard categories were proposed to label OTIF hits, the 'OTIF prediction report' was proposed to be shared with all suppliers, and a method for improvement plans tracking was also elaborated. Finally, in order to implement these proposals, a change plan was described with several alternatives depending on the level of complexity and resource requirements. These proposals make use of the current knowledge in the company and the developers available to create environments to interact with the suppliers.

In conclusion, standardizing the process and applying a problem-solving methodology could bring benefits to the way the company manages the OTIF KPI. Following the process of problem identification, root cause analysis, corrective actions and monitoring improvement or performance; ensures the development of critical thinking and encourages sustainable practices. Moreover, most of the above proposals can be implemented with current resources; however, to automate or enable interactive environments, more resources would be required.

5 Contributing Factors to OTIF hits

The main reasons for low logistic KPIs are sometimes hidden in the complex environment of the manufacturing industry. Common approaches may lead to wrong interpretations because the underlying root causes are not known. Understanding logistics interactions across all processes of the internal supply chain of an organization could provide the basis for KPIs improvement. Therefore, structural analysis must be applied in order to determine potential causes of issues (Schmid, Maier, & Lasse-Härte, 2020).

The OTIF KPI is the main logistic KPI in the department; where the average number of PO lines per week in 2020 was ≈3700, 'On Time' hits corresponded to ≈17% and 'In Full' hits ≈2.5% (Figure 43). Making 'On Time' the most critical section of the KPI and where further improvement could potentially be achieved.

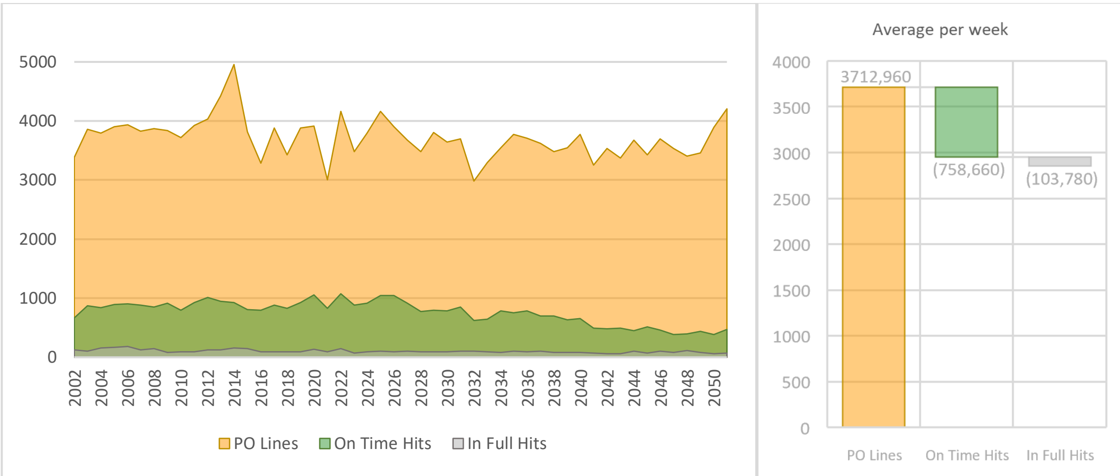

Figure 43. Number of PO lines, 'On Time' and 'In Full' hits (2020)

The present chapter revises the steps followed to perform structural analysis of the main root causes of OTIF hits. The applied methodology will be detailed and, based on the results, initiatives will be proposed to counteract these variables.

5.1 Methodology

In the case of unsatisfactory logistic KPIs, it is important to identify the root causes before attempting to correct the situation. (Schmid, Maier, & Lasse-Härte, 2020) propose a methodology to identify these root causes, where universal cause-effect-relationships are identified to construct cause-effect relation trees for the studied KPI. The possible causes or influencers are then structured at different levels until defining factors are discovered. Lower levels split the main influencers into palpable data suitable for analysis; therefore, enabling the discovery of underlying factors that could possibly influence the behavior of the KPI. These same factors could have incidence on other KPIs, making this an appropriate analysis to study interrelationships and connections between various KPIs. The cause-effect tree will be divided into 'On Time' and 'In Full' sections for a more detailed analysis.

After having defined the variables to be analyzed with the cause-effect tree, Classification and Regression Tree (CART) will be used to identify the critical input. CART modeling has been used to identify influencing variables in large datasets consisting of a combination of continuous/categorical values, including outliers (Sarkar, Mukhopadhyay, & Ghosh, 2013). More specifically, *'Gain Ratio'* will be used to rank their influence on the 'On Time' section of the KPI. The most important variables will be then compared with the 'On Time' score to analyze their behavior and draw conclusions. For the 'In Full' section, Pareto charts will be constructed to rank the most significant factors, since the root causes of these hits are already labeled. Based on the results, counteractive actions will be proposed to address the negative influence on the score.

5.2 Cause-effect tree

The cause-effect tree for OTIF is built with its two main components separated into different branches, 'On Time' and 'In Full'. Each of the branches has its own influence and different actors that trigger certain behavior on the KPI. The tree was built based on the original conception of the OTIF KPI (ASML, 2019). It includes *'Master Data Management'*, where the lead-time for each supplier is set; *'Material Availability on time'*, where the production of the plant is taken into account for its influence on demand changes and inventory settings (buffers and decoupling strategy). Additional ramifications, such as: '*Purchase-to-Pay Process'*, and *'Order Expediting'* (Re-in, Re-out-VURO) were added, as they are considered important for the perspective of the process as a whole. The full-size cause-effect tree can be found in Appendix D.

After having the cause-effect tree in place (Figure 44), the next step is to gather information on these factors to begin analyzing their relationship to the KPI performance.

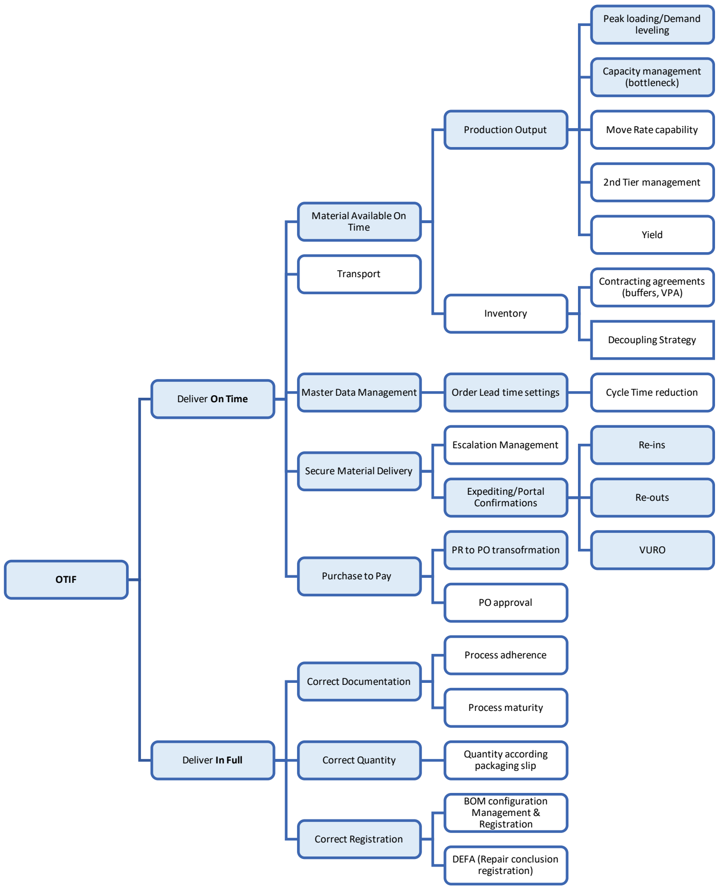

Figure 44. Influencing factors for OTIF KPI.

5.3 On Time

The main concentration of the analysis will be done in the 'On Time' section of the KPI, as it represents on average ≈17% of OTIF hits from the last 6 months. The information collected for the analysis comes from different sources and some other variables have been calculated to provide a deeper understanding of their influence. Not all the variables from the cause-effect tree could be obtained due to the availability of information.

Variables

The data collected for the analysis correspond to the branches highlighted in Figure 44. Where *'Net Price', 'Quantity' and 'PlannedDeliveryTime'* were included from 'Master Data Management' to check if the characteristics of the order have influence in performance. *'Demand_freq'* and *'Demand_quantity'* were included from 'Production Output' to investigate the relationship of the demand patterns in the KPI. Additionally, expediting behavior was also included with: *'in_count_PO', 'out_count_PO', 'weeks_in_system_PO', 'in_days_avg_PO', 'out_days_avg_PO', 'rescheduling_freq_PO', 'PO_VURO_count', 'PO_VURO_days_avg'* to study the impact of rescheduling requests from ASML and supplier side. Finally, *'PR_PO_On Time'*, was also included in the dataset to verify whether the 'Purchase-to-Pay' process influences performance. Table 14 shows a list of the variables, with their type and an extended explanation.

Table 14. Variables to analyze in 'On Time' database.

Data Base Name	Detail	Type
Net_price	Net price per part in EUR	Continuous
Quantity	Quantity per Purchase-Order-Item	Discrete
PlannedDeliveryTime	Planned Delivery Time in days	Continuous
in_count_PO	Number of Reschedule-in (re-in) requests per PO-Item	Discrete
out_count_PO	Number of Reschedule-out (re-out) requests per PO-Item	Discrete
weeks_in_system_PO	Number of weeks a PO-Item has status "Open"	Discrete
in_days_avg_PO	If a PO-Item has re-in requests, number of days on average of all the requests.	Continuous
out_days_avg_PO	If a PO-Item has re-out requests, number of days on average of all the requests.	Continuous
rescheduling_freq_PO	Number of rescheduling messages (in+out) / number of weeks in system.	Continuous
PO_VURO_count	Number of VURO for a PO-item requested by the supplier	Continuous
PO_VURO_days_avg	If a PO has VURO requests for a PO-item, number of days on average of all the requests.	Continuous
open_days	Difference between PO-creation day and confirmation day	Continuous
demand_freq	Number of weeks per year where positive demand is placed for the material in PO-Item	Discrete
demand_quantity	Sum of all the demand quantities placed for the material in PO-Item	Discrete
PR_PO_On Time	Indicator of timely Purchase Requisition (PR) to Purchase Order transformation. On Time: 1, Late: 0	Categorical [0,1]
On_time	Indicator of 'On Time' delivery. On Time: 1, Late: 0	Categorical [0,1]

All these variables were merged in a dataset where each Purchase-Order-Item line had its corresponding 'On Time' -1 or 0- score. The data analyzed belongs to the period from February-2019 to July-2020.

Prioritization of Variables

Decision tree learning is one of the most commonly used and practical tools that can be used for classification or regression predictive modeling problems. By having more than one attribute that could possibly affect our variable of interest, it is important to evaluate the relevance and importance of each attribute, thus placing the most relevant ones at the root node and applying the same criteria when splitting the nodes down. As moving down the tree, the level of impurity or uncertainty decreases, leading to a better split or classification at each node. To perform this, splitting measures such as *Information Gain* is used (Tahsildar, 2019). *Information gain* is used to determine which attribute gives the maximum information about a class. However, a natural bias in information gain is that it favors attributes with many values, thus decreasing its performance. One way to overcome this bias is to penalize these attributes with many values by incorporating a term called *Split Information*, hence creating the ***Gain Ratio*** measure (Wang & Jiang, 2007)

With the given dataset, *Orange Data Mining Toolbox in Python* (Demsar, et al., 2013) was used to obtain the *Gain Ratio* for each of the presented variables, using 'On Time' as the target variable.

Table 15. Gain ratios for studied variables

Variable	Gain ratio
PO_VURO_count	0.120
PO_VURO_days_avg	0.115
in_count_PO	0.021
PR_PO_On Time	0.014
weeks_in_system_PO	0.006
open_days	0.005
rescheduling_freq_PO	0.005
in_days_avg_PO	0.004
Net_price	0.002
demand_quantity	0.001
Quantity	0.001
demand_freq	0.001
out_days_avg_PO	0.000
PlannedDeliveryTime	0.000
out_count_PO	0.000

From Table 15, it can be seen that the variables which provide the most information on 'On Time' are*, 'PO_ VURO_ count', 'PO_ VURO_ days_ avg', 'in_ count_ PO'* and *'PR_ PO_ On Time'*. Therefore, they will be analyzed in the next section.

Rescheduling and VURO

Every week the MRP updates the requirement dates for the Purchase Orders, and due to changes and uncertainties in the operation, mismatches happen in supply and demand in the planning system, triggering rescheduling messages towards the supplier. A rescheduling message can be of three types:

- Reschedule-in: suggestion to pull-in/bring the date forward
- Reschedule-out: suggestion to push-out/delay the date
- Cancel: suggestion to cancel the existing order

When a reschedule-out comes from the supplier side, a Vendor Unwanted Reschedule-out (VURO) is created. These messages occur when the supplier notifies ASML that the delivery date cannot be met and has to be postponed to a later date. Two variables of VUROs, were found to be relevant and were investigated further; the number of VUROs and the Average days of delay requested in all the VUROs per Purchase-Order-Item. Each of the variables was categorized on the x-axis in buckets and compared with its correspondent 'On Time' score (y-axis) of these PO-Items (Figure 45 and Figure 46, left). Additionally, the number of PO-Items per category was plotted on a secondary logarithmic y-axis to show how many records are included in the calculation (Figure 45 and Figure 46, right).

The analysis shows that the 'On Time' score is more likely to increase when PO_VURO_count is 0 than otherwise (i.e. 'On Time' score decreases when the number of VUROs increases). The score excluding the first category (VURO = 0) is ≈46%, which shows a significant difference of ≈43% in performance. Moreover, In Figure 45 (right) it can also be seen that the number of PO-Items per bucket decreases with each increment of the number of VUROs.

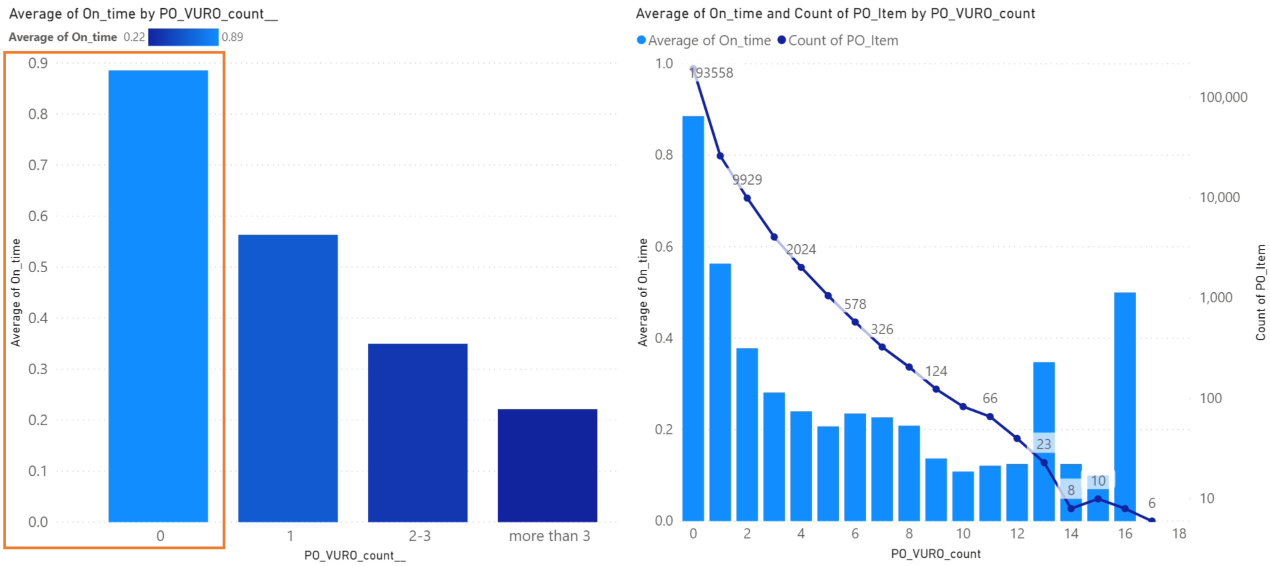

Figure 45. Average 'On Time' score by number of VUROs

This behavior is also visible when comparing the average of VURO days (PO_VURO_days_avg) under the same parameters (Figure 46). The 'On Time' score is more likely to increase when PO_VURO_days_avg is 2 or less than otherwise. The score excluding the first category is ≈41%. However, there is a minor increase in the score when the average VURO days goes beyond 30.

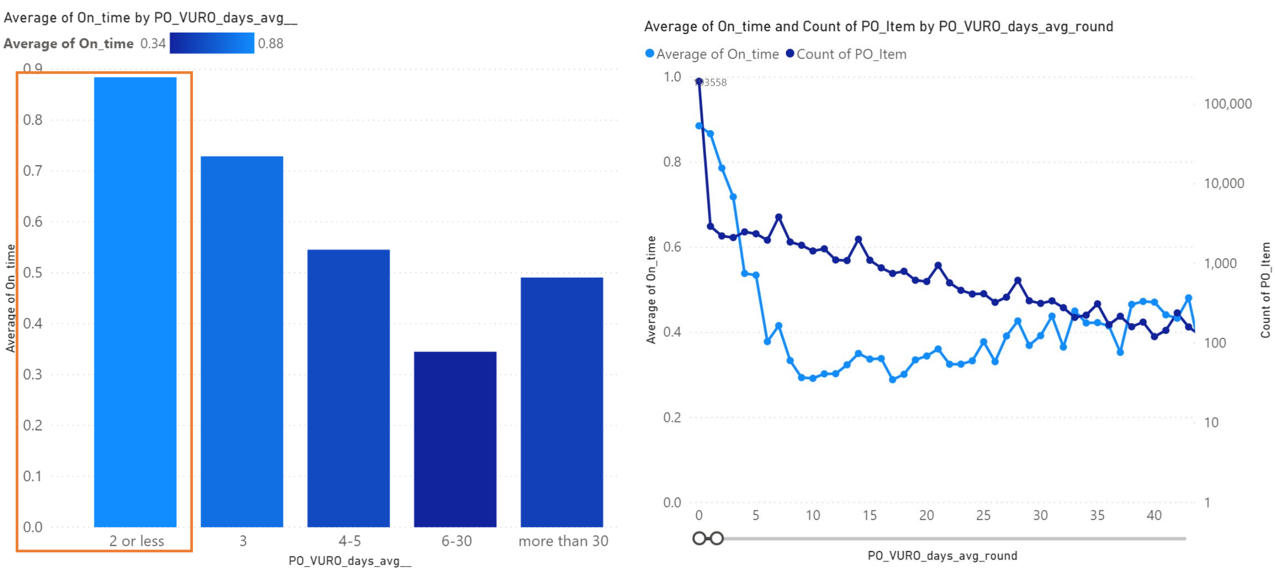

Figure 46. Average 'On Time' score by average VURO days.

For the reschedule-ins, although they also have to be confirmed by the supplier, the number of re-ins also influences the behavior of the orders. The 'On Time' score is more likely to increase when in_count_PO is 1 or less than otherwise (Figure 47). The score excluding in_count_PO = 1 or less is ≈73%. The ≈14% difference in performance -from 87% to 73%- is not as prominent as in the previous cases, but it is still an important fact to consider.

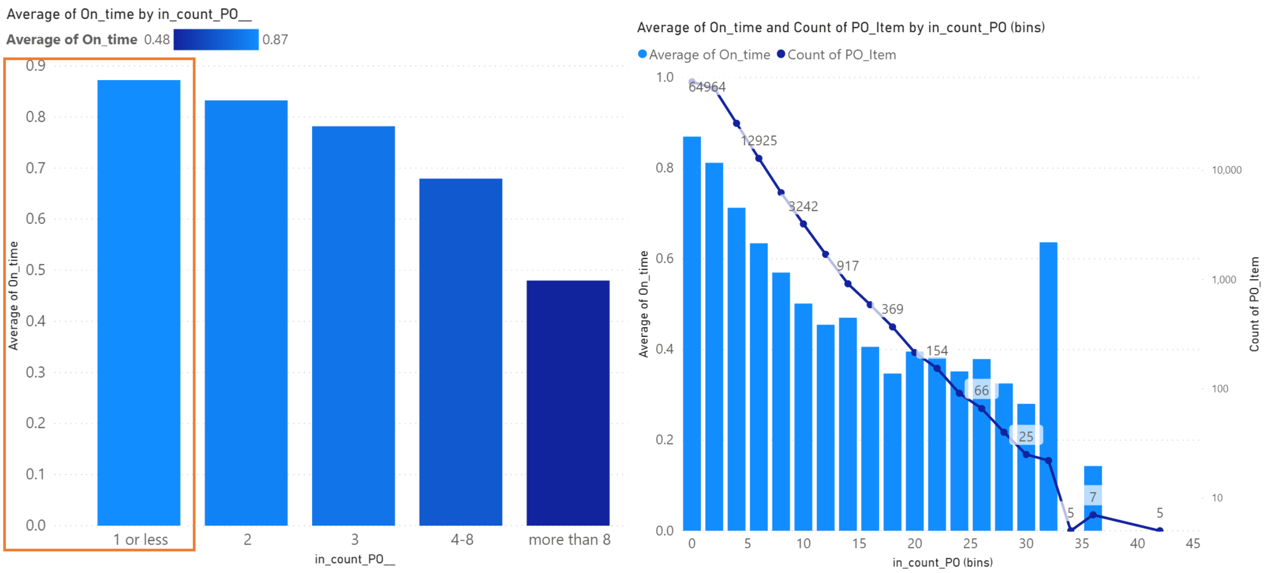

Figure 47. Average 'On Time' score by number of reschedule-in.

Purchase Requisition to Purchase Order Transformation

From the weekly MRP run, an order moment is calculated and the *Procurement Department* has two weeks (14 days) to convert a Purchase Requisition (PR) into a Purchase Order (PO). From the analysis (Figure 48), it can be seen that purchase orders with a longer PR-PO transformation (>14 days), on average score ≈67% 'On Time', compared with ≈82% of purchase orders transformed in 14 days or less. Purchase orders with a timely transformation correspond to ≈95% of the studied cases. There is also an automated process that allows PR-PO transformation without procurement interaction. Currently, almost 60% of the PRs are automatically transformed through this process.

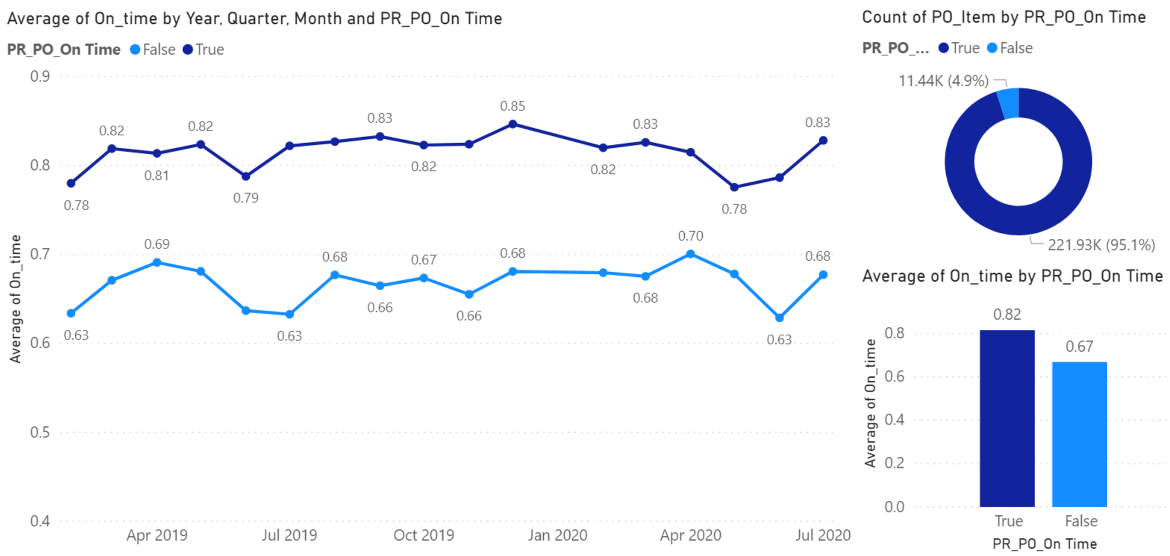

Figure 48. Average 'On Time' score by PR-PO transformation category.

5.4 In Full

Deliveries should adhere to an ASML delivery checklist to avoid issues in the booking process. When these conditions are not met, a 'Stagnation ticket' is created at the ASML warehouse. This stagnation prevents the factory from booking stock and delays the goods receipt (ASML, 2020). The 'In Full' section of the KPI corresponds to the integrity of goods received documentation, registration and correct quantity. In 2020, on average ≈100 hits were registered per week (Figure 49). Unlike the 'On Time' hits, the 'In Full' hits have dedicated categories to label the hits, as only the supplier caused hits are considered in the KPI calculation.

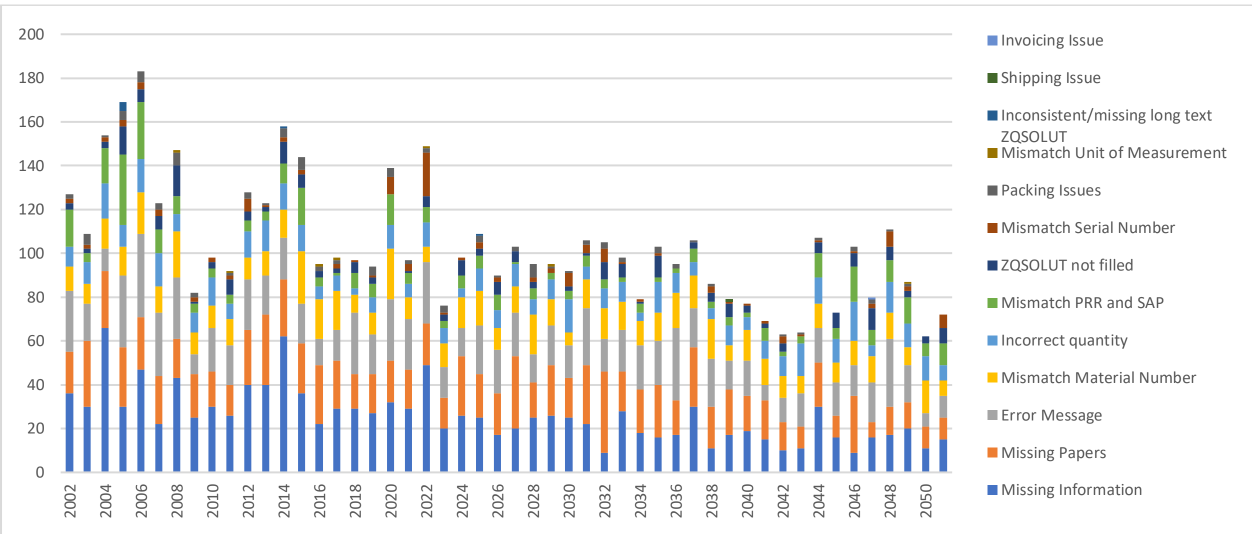

Figure 49. Problem Sheets category per week.

The most relevant categories in the analysis were 'Missing Information', 'Missing Papers', 'Error Message' and 'Mismatch Material Number' (Figure 50); each of them contains sub-categories. A brief explanation of the most frequent cases will be provided (3PL Supply Chain, 2018):

- **Missing information:** Information needed to process the material is missing
    - Line item missing in SAP: One of the line items on the packing list cannot be found in SAP and cannot be booked.
    - No material number or identification on part: There is no material number on the physical part or the packaging
- **Missing Papers:** Papers needed to process the material are missing.
    - Problem Resolution Report
    - Packing list
- **Error Message:** Error message encountered while processing in SAP. Error messages appear when trying to perform goods issue and prevent the warehouse from shipping the delivery.
    - Not in list, see attachments or feedback: Mix of delivery specific issues.
    - Barcode status issues: Error while scanning the barcode. The bar code identification has the incorrect settings in SAP
    - Delivered too early: Shipment has been delivered before the PO is released.
- **Mismatch Material Number:** A discrepancy of the material number and physical shipment.
    - Different material number between order and part.

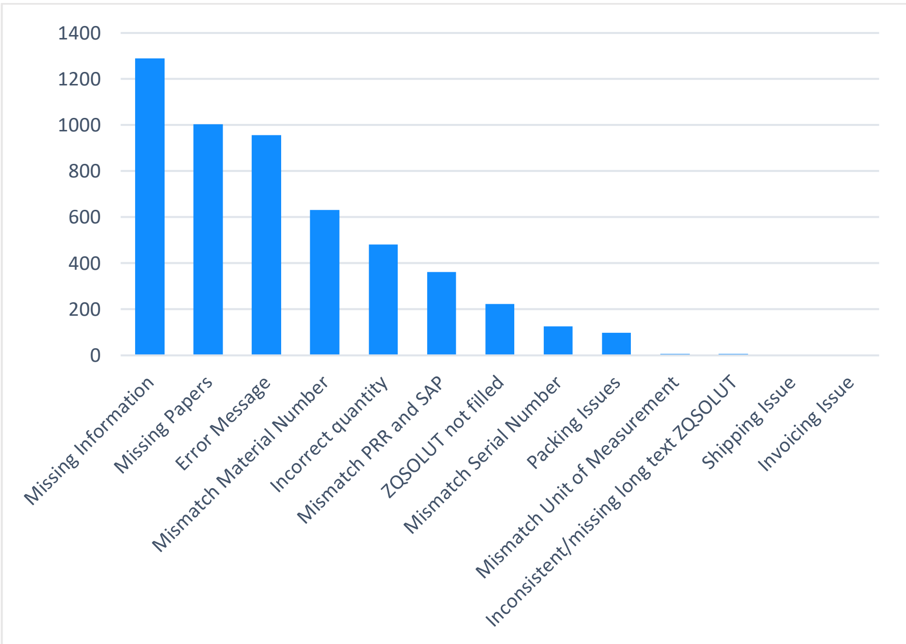

Figure 50. Pareto 'In Full' hits categories.

5.5 Potential Solutions

5.5.1 On Time

Typically, any change in demand or supply leads to rescheduling. Nervousness, or schedule instability, is a consequence of many factors of uncertainty affecting the MRP system. It has been considered an important operational problem associated with MRP systems with serious impacts on the performance (Ho, 2005). The term refers to frequent rescheduling actions, such as expediting (re-ins, re-outs), delaying (VURO) or canceling an order, or to changing the size of an order (Silver, Pyke, & Thomas, 2016). ASML also experiences nervousness due to the high volatility of the semiconductor industry, coupled with forecasted demand over a relatively long horizon -leaving room for changes until the goods are received. Additionally, ASML is not only facing demand for end products, but also service demand, upgrades, and engineering changes that trigger instability in the Bill of Materials (BOM). All of these factors taken together are essentially drivers of nervousness.

It's important to introduce stability into the planning process; for this, there are many possible alternatives in literature to reduce nervousness (Jacobs, Berry, Whybark, & Vollmann, 2011) (Waller, Johnson, & Davis, 1999) (Heisig, 2002) and (Ho, 2005), some of them are already being used in ASML's operation:

- Reduce the incidence of unplanned demands, by incorporating spare parts forecasts into MRP record gross requirements.
- Control the introduction of parameter changes, such as changes in safety stock levels or planned lead times
- Selective use of lot-sizing procedures at different product structure levels
- Using firm planned orders (planned order that the MRP system does not automatically change when conditions change)
- Inventory-oriented buffering:
    - Safety stocks, used when the uncertainty is of the quantity category.
    - Safety lead time, used when uncertainty is of the timing category.
- Control engineering changes
- Eliminate transaction errors
- Minimize supply uncertainty
- Dampening procedures: Incorporate a filter to screen out 'insignificant' rescheduling messages based on different filtering mechanisms.
- Vendor Managed Inventory (VMI)

As a complementary alternative, the visibility of the parameters studied could be increased. That is, make the numbers of re-ins, re-outs, VUROs and average VURO days per Purchase-Order-Line more visible to the planners. So that these specific POs are seen with a higher chance of becoming an 'On Time' hit.

For the Purchase Requisition to Purchase Order Transformation, as currently ≈95% of the orders are being transformed in the stipulated time, the remaining can benefit from an automated transformation process. By the end of 2020, almost 60% of the Purchase

Requisitions are being *automatically* -based on a set of rules- transformed into Purchase Orders; this number has increased steadily from 40% in early 2019 (see Appendix E). Approximately 9% of the 'manual' transformed purchase orders fall into the 'late transformed' category. Highlighting the importance of continuing with this process, including more material codes into the automatic transformation scheme; thus alleviating workload in the procurement department and stabilizing the process.

5.5.2 In Full

In 2017, ASML created a *Work Instruction (WI)* with all the categories and sub-categories of possible causes of stagnations (potential 'In Full' hits), including a description for each and a possible solution (ASML, 2017). The following is an example of '*Missing Papers – Please provide PRR':*

Problem: Please provide PRR (Problem Resolution Report)

Description: When a repair order is delivered, the delivery should include a PRR report. Sometimes this report is lost during transport, not visible on the outside of the packaging (placed inside the box) or just forgotten by the supplier.

Solution: Contact the supplier and ask for the PRR conclusion. When you have it, the next step is informing 3PL so that they can book. If needed, inform the supplier about the correct way of working (structural improvement)

This WI addresses all the possible categories that a stagnation ticket might have. However, this categorization structure changed in 2018, to use 12 categories for 'Stagnations' -previously 7- with an average of 5 sub-categories per category. Most of the 'old' categories have been covered by the new structure, but there are new additions that are not mentioned in the *'Problem-Solution'* WI. For this reason, it is of utmost importance to have an updated document that covers all the issues that may arise, and subsequently inform users (planners) that this document is ready to be used for operational purposes.

In addition, emphasis should be placed on the accuracy of the 'hits' categorization, as inconsistencies were found in the database. For instance, a sub-category that reflects three different categories, making it difficult to track issues and create improvement initiatives. With an accurate categorization in place, a Pareto Chart of 'In Full' categories and sub-categories could be included in the 'Problem Sheets' Weekly Report, increasing visibility and allowing analysis by category and sub-category of hits on a weekly basis.

5.6 Summary

The analysis presented in this chapter aims to identify the main factors that contribute to OTIF hits. A cause-effect tree methodology is used to discover relevant data and visualize relationships in a simplified way. The OTIF tree is built with two main branches, 'On Time' and 'In Full'. Each of the branches is analyzed separately, as they have different behavior and incidence.

For 'On Time', several data sources were collected to analyze the lead-time, net price, order quantity, demand frequency, demand quantity, expediting messages behavior (Re-in, Re-out-VURO) and timely PR-PO transformation. All these variables were consolidated together with the 'On Time' score (1 or 0) per Purchase-Order-Item. Then, the *Gain Ratio* -part of Classification and Regression Tree methodology- was applied to evaluate the importance of all of the available variables. As a result, 'PO_VURO_count', 'PO_VURO_days_avg', 'in_count_PO' and 'PR_PO_On Time' were the variables chosen to be analyzed. The expediting variables revealed that as the *number of VURO*, *average VURO days* or *number of re-ins* increased, the 'On Time' score showed a poorer behavior; confirming the effect of nervousness in the performance of the KPI. For the PR-PO transformation, timely transformation (within 14 days) showed better performance than late transformation. However, since late transformation only accounts for 5% of orders, the incidence in the KPI is not very noticeable.

The 'In Full' section, which has to do with the integrity of goods received documentation, shows a different behavior and impact in the KPI ($\approx$2.5% on average). These 'In Full' hits are already labeled in pre-defined categories and sub-categories. Therefore, a Pareto chart is constructed to rank the causes of the hits. 'Missing information', 'Missing Papers' and 'Error Message' are the categories with the most hits in the last year.

As a result of the analysis, actions can be triggered to reduce the effect of the contributing factors. To deal with nervousness, some alternatives were proposed such as control of parameter/engineering changes, elimination of transaction errors, use of dampening procedures for expediting messages and VMI. All these measures, combined with greater visibility of the variables, would contribute to improving awareness of how these variables affect performance. Moreover, to address late PR-PO transformation, it is important to continue increasing the number of automatically transformed PRs, as it would contribute to avoid late transformations and also ease the workload in the procurement department.

For the 'In Full' hits, it was recommended to focus on the accuracy of stagnations labeling; with the purpose of adding this information in weekly reports to allow supplier, team or cluster analysis. To conclude, this methodology of comparing the studied KPIs with a visual representation of its influencing factors, can also be used to establish permanent control loops and drive constant performance improvement.

6 Conclusion

6.1 Final Conclusion

The main goal of this study was to both gain insights about the current situation of OTIF hits Root Cause Analysis and the influencing factors that might impact the performance. In the course of this project, several aspects were studied, understood and analyzed. First, the current situation was investigated through several interviews with employees in various roles. Product of these interviews, various facets of the process were discovered. The most important components of the process were: the way of working, information shared with the suppliers, RCA categorization and improvement plans management. It was found that common practices were occurring within the department; however, there were also specific activities that were not standardized, adding value to just few teams/suppliers. As a result, process standardization was proposed to bring uniformity, and also because of its ability to improve performance and communication between parties. An ASML methodology was used to standardize the process, along with the 'A3' problem-solving method, in order to obtain a structured way of thinking. All the steps of the methodology were reviewed, placing special emphasis on proposing practices that could fill the gap and add value to day-to-day operations. Along with the proposals, an implementation plan was also suggested. Some of the recommended measures are relatively simple to implement, while others require more resources and company involvement to make them happen.

After discussing the process of how the RCA of OTIF hits is managed, it was also important to investigate the possible causes of these same hits. A cause-effect tree methodology was used to map in a structured way the most important factors that influence the behavior of the KPI. With this visual tool, the 'On Time' and 'In Full' branches of the performance indicator were divided into possible causes of the hits. A dataset with relevant data was built to identify the critical input. Then, the Gain Ratio -a tool used in CART- ranked the influence of the variables on the 'On Time' branch. With this, the variables with the higher score were analyzed against the 'On Time' score to get insights and draw conclusions. Nervousness (re-ins, VUROs) and a part of a Purchase-to-pay process were shown to have a negative impact on performance. Therefore, potential solutions based on literature were proposed to address these issues. For the other branch of the KPI, the analysis showed a wide variety of causes for hits (based on labeled input). Likewise, recommendations were made to provide improved analysis and troubleshooting tools at the operational level. Summarizing, when a gap exists between the desired and current performance, it is important to not only verify the root causes of the hits, but also the process that addresses the hits once they have occurred; using tools and practices that allow the detection, solution and monitoring of the countermeasures.

Hence, considering all the findings and results, it can be concluded that the research questions mentioned in section [1.4] have been adequately answered.

6.2 Limitations

Most of the aspects covered in this report have been clarified through the use of the relevant information obtained from the company. There are, however, some areas in which some limitations were found and where work could be done to improve the results.

As ASML has a strong culture of continuous improvement, processes are continually changing within the department, which can sometimes lead to inconsistencies in the information collected (e.g. meetings structure, information exchange, available platforms). The change occurs not only with respect to processes, but also in the logic of the KPIs. In other words, the logic that applies today to the KPI calculation, was not the same as 6 months ago, which complicates the historical analysis and generates assumptions. Furthermore, as +400 suppliers are working together with ASML in the supplier chain, some of them have developed specific procedures to handle certain processes due to the nature of their operation; which creates exceptions where the proposed countermeasures might not apply or bring benefit.

Unfortunately, the proposed countermeasures were not fully tested across the department, which prevented the research from rich feedback coming from different perspectives. In the same way, the implementation of the proposals was not included in the scope; therefore, effectiveness could not be assessed. As the study was conducted within the company, all the available information came from the ASML, leaving the supplier side out of the analysis. This bias in the sources of information limited the study from having other perspectives.

Finally, some of the information found had errors or inconsistencies due to manual changes; or as mentioned above, changes in the KPI logic.

6.3 Future Research

The following section describes the possible topics that can be addressed for future research, which can add value for academic or practical purposes.

As the research was conducted primarily from ASML perspective, an interesting analysis could be done based on the supplier perspective. For instance, choosing one supplier per cluster, and evaluating from their point of view the factors that influence the most OTIF hits. Furthermore, not all the reported variables could be obtained, but others showed an important influence on the behavior of the KPI. Therefore, predictive models could be constructed for 'On Time', 'In Full' or OTIF as a whole; providing a useful tool for material planners in the company. Nervousness was shown to have influence on the 'On Time' score, an analysis to see how dampening procedures (e.g. suppression of rescheduling messages) might affect performance would also be interesting.

Finally, OTIF is considered a reactive KPI; in other words, a hit is recorded only when the goods are received. It could also be proposed to use another KPI to measure logistics performance before the goods are received, in order to have a more proactive perspective on performance.

References

3PL Supply Chain. (2018). TRS Handbook.

Allen, J. A., Beck, T., Scott, C. W., & Rogelberg, S. G. (2014). Understanding workplace. *Management Research Review, 37*(9), 791-814.

Andersen, B., & Fagerhaug, T. (2006). *Root cause analysis: simplified tools and techniques.* ASQ Quality Press.

Arzu Akyuz, G., & Erman Erkan, T. (2010). Supply chain performance measurement: A literature review. *International Journal of Production Research, 48*(17), 5137-5155.

ASML. (2017). 3PL – Problem sheets and Solutions. *Work Instruction*.

ASML. (2019). On Time In Full: Delivery reliability of our external suppliers. *KPI Poster*.

ASML. (2020). ASML Supplier Handbook.

Balfaqih, H., Nopiah, Z. M., Saibani, N., & Nory, M. A. (2016). Review of supply chain performance measurement systems: 1998-2015. *Computers in Industry, 82*, 135-150.

Beamon, B. M. (1998). Supply chain design and analysis: Models and methods. *International Journal of Production Economics, 55*(3), 281-294.

Cabanillas, C., Resinas, M., & Ruiz-Cortés, A. (2012). Automated resource assignment in BPMN models using RACI matrices. *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"* (pp. 58-59). Springer.

Christopher, M. (2011). *Logistics & Supply Chain Management* (4 ed.). FT Publishing International.

Costello, T. (2012). RACI—Getting Projects "Unstuck". *IT Professional Magazine, 14*(2), 62-64.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches.* Sage publications.

Demsar, J., Curk, T., Erjavec, A., Gorup, C., Hocevar, T., Milutinovic, M., . . . Zupan, B. (2013). Orange: Data Mining Toolbox in Python. *Journal of Machine Learning Research, 14*(Aug), 2349-2353.

Doggett, M. (2005). Root Cause Analysis: A Framework for Tool Selection. *Quality Management Journal, 12*(4), 34-45.

Elrod, C., Murray, S., & Bande, S. (2013). A review of performance metrics for supply chain management. *EMJ - Engineering Management Journal, 25*(3), 39-50.

Farahani, R. Z., Asgari, N., & Davarzani, H. (Eds.). (2009). *Supply chain and logistics in national, international and governmental environment: concepts and models.* Physica-Verlag HD.

Gall, M. D., Gall, J. P., & Borg, W. R. (2003). *Educational research: An introduction.* Pearson Education.

Gangidi, P. (2019). A systematic approach to root cause analysis using 3 × 5 why's technique. *International Journal of Lean Six Sigma*, 295-310.

Gunasekaran, A., Patel, C., & Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management, 21*(1/2), 71-87.

Gurnani, H., Mehrotra, A., & Ray, S. (2012). *Supply chain disruptions: Theory and practice of managing risk.* (H. Gurnani, Ed.) London: Springer.

Heisig, G. (2002). *Planning stability in material requirements planning systems.* (Vol. 515). Springer.

Hendricks, K., & Singhal, V. R. (2005). Supply-Chain Disruptions. *Metal Producing & Processing, 43*(6), 36-36,35.

Ho, C.-J. (2005). Examining dampening effects for alternative dampening procedures to cope with system nervousness. *International Journal of Production Research, 43*(19), 4009-4033.

Hugos, M. (2011). *Essentials of Supply Chain Management* (Vol. 53). John Wiley & Sons, Inc.

Imai, M. (2012). *Gemba Kaizen: A Commonsense Approach to a Continuous Improvement Strategy.* McGraw Hill.

Jacobs, F. R., Berry, W. L., Whybark, D. C., & Vollmann, T. E. (2011). *Manufacturing Planning and Control for Supply Chain Management: APICS/CPIM Certification Edition.* McGraw-Hill Education.

Kaizen Institute Consulting Group. (2015, May 5). *SDCA before you do PDCA*. Retrieved from Kaizen Institute Blog: https://in.kaizen.com/blog/post/2015/05/05/sdca-before-you-do-pdca.html

Leon, A. C. (1998). Descriptive and Inferential Statistics. In A. S. Bellack, & M. Hersen (Eds.), *Comprehensive Clinical Psychology* (Vol. 3, pp. 243-285).

Livingston, A. D., Jackson, G., & Priestley, K. (2001). Root causes analysis: Literature review. *HSE Contract Research Report*.

Martin, J. W. (2014). Root-Cause Analysis Using Six Sigma Tools (with Operations Research Methods). In *Lean Six Sigma for Supply Chain Management: A 10-Step Solution Process* (Second ed.). McGraw-Hill Education.

Münstermann, B., & Weitzel, T. (2008). What is process standardization? *CONF-IRM 2008 Proceedings*, (p. 64).

Münstermann, B., Eckhardt, A., & Weitzel, T. (2010). The performance impact of business process standardization. *Business Process Management Journal, 16*(1), 29-56.

Okes, D. (2019). *Root Cause Analysis: The Core of Problem Solving and Corrective Action.* ASQ Quality Press.

Parker, C. (2000). Performance measurement. *Work Study, 49*(2), 63-66.

Piotrowicz, W., & Cuthbertson, R. (2015). Performance measurement and metrics in supply chains: an exploratory study. *International Journal of Productivity and Performance Management, 64*(8), 1068-1091.

Quality-One. (2020). *5 Why & 5 How*. Retrieved December 8, 2020, from Quality-One International: https://quality-one.com/5-why-5-how/

Quality-One. (2020). *A3 Problem Solving*. Retrieved December 03, 2020, from Quality-One International: https://quality-one.com/a3/#How

Quinlan, J. R. (1986). Induction of decision trees. *Machine learning, 1*(1), 81-106.

Reid, I., & Smyth-Renshaw, J. (2012). Exploring the fundamentals of root cause analysis: are we asking the right questions in defining the problem? *Quality and Reliability Engineering International, 28*(5), 535-545.

Sarkar, S. A., Mukhopadhyay, A. R., & Ghosh, S. K. (2013). Root cause analysis, Lean Six Sigma and test of hypothesis. *The TQM Journal, 25*(2), 170-185.

Schmid, M., Maier, J. T., & Lasse-Härte. (2020). Data based root cause analysis for improving logistic key performance indicators of a company's internal supply chain. *Procedia CIRP*, *86*, pp. 276-281.

Shay, A., & Scherer, M. (2019). Assistive technology techniques, tools, and tips. *Assistive Technology Service Delivery*, 220-221.

Shook, J. (2009). Toyota's Secret: The A3 Report. *MIT Sloan Management Review, 50*(4), 30-33.

Silver, E. A., Pyke, D. F., & Thomas, D. J. (2016). *Inventory and Production Management in Supply Chains* (4th ed.). CRC Press.

Tahsildar, S. (2019). *Gini Index For Decision Trees*. Retrieved Dec 6, 2020, from QuantInsti: https://blog.quantinsti.com/gini-index/

Turner, D. W. (2010). Qualitative interview design: A practical guide for novice investigators. *The Qualitative Report, 15*(3), 754-760. Retrieved from http://nsuworks.nova.edu/tqr/vol15/iss3/19

Vries, H. J., & Slob, F. J. (2006). Best Practice in Company Standardization. *International Journal of IT Standards and Standardization Research (IJITSR), 4*(1).

Waller, M., Johnson, M. E., & Davis, T. (1999). Vendor-managed inventory in the retail supply chain. *Journal of Business Logistics, 20*(1), 183-203.

Wang, D., & Jiang, L. (2007). An Improved Attribute Selection Measure for Decision Tree Induction. *Fourth International Conference on Fuzzy Systems and Knowledge Discovery (FSKD 2007)*, *4*, pp. 654-658.

Williams, P. M. (2001). Techniques for root cause analysis. *Baylor University Medical Center Proceedings, 14*(2).

Won Lee, C., Kwon, I.-W. G., & Severance, D. (2007). Relationship between supply chain performance and degree of linkage among supplier, internal integration, and customer. *Supply Chain Management, 12*(6), 444-452.

Wright, D. (2009). The A3 Management Process. *Security Technology Executive, 19*(2), 20.

Wu, T., Blackhurst, J., & O'grady, P. (2007). Methodology for supply chain disruption analysis. *International journal of production research, 45*(7), 1665-1682.

Wüllenweber, K., Beimborn, D., Weitzel, T., & König, W. (2008). The impact of process standardization on business process outsourcing success. *Information Systems Frontiers*, 211-224.

Ziaei, I., & Amalnick, M. S. (2016). Managing Aerospace Supply Chain Disruptions of "Increased Complexity" and "Single Sourcing". *World Journal of Research and Review (WJRR), 2*(4), 42-45.

Appendix

A. Process Landscape

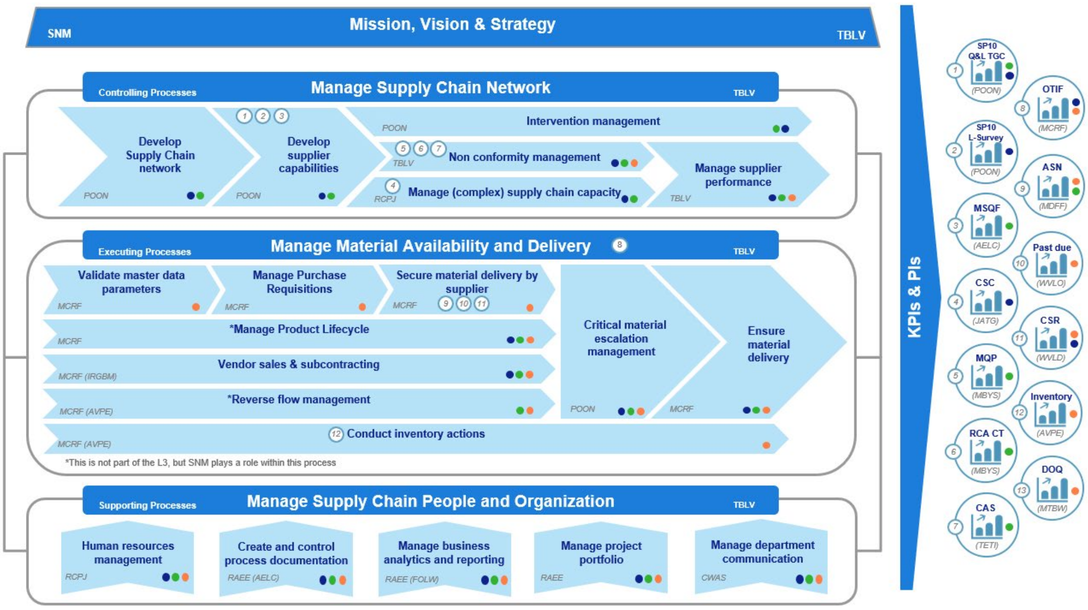

Figure 51. SNM Process Landscape

B. Mind maps per role

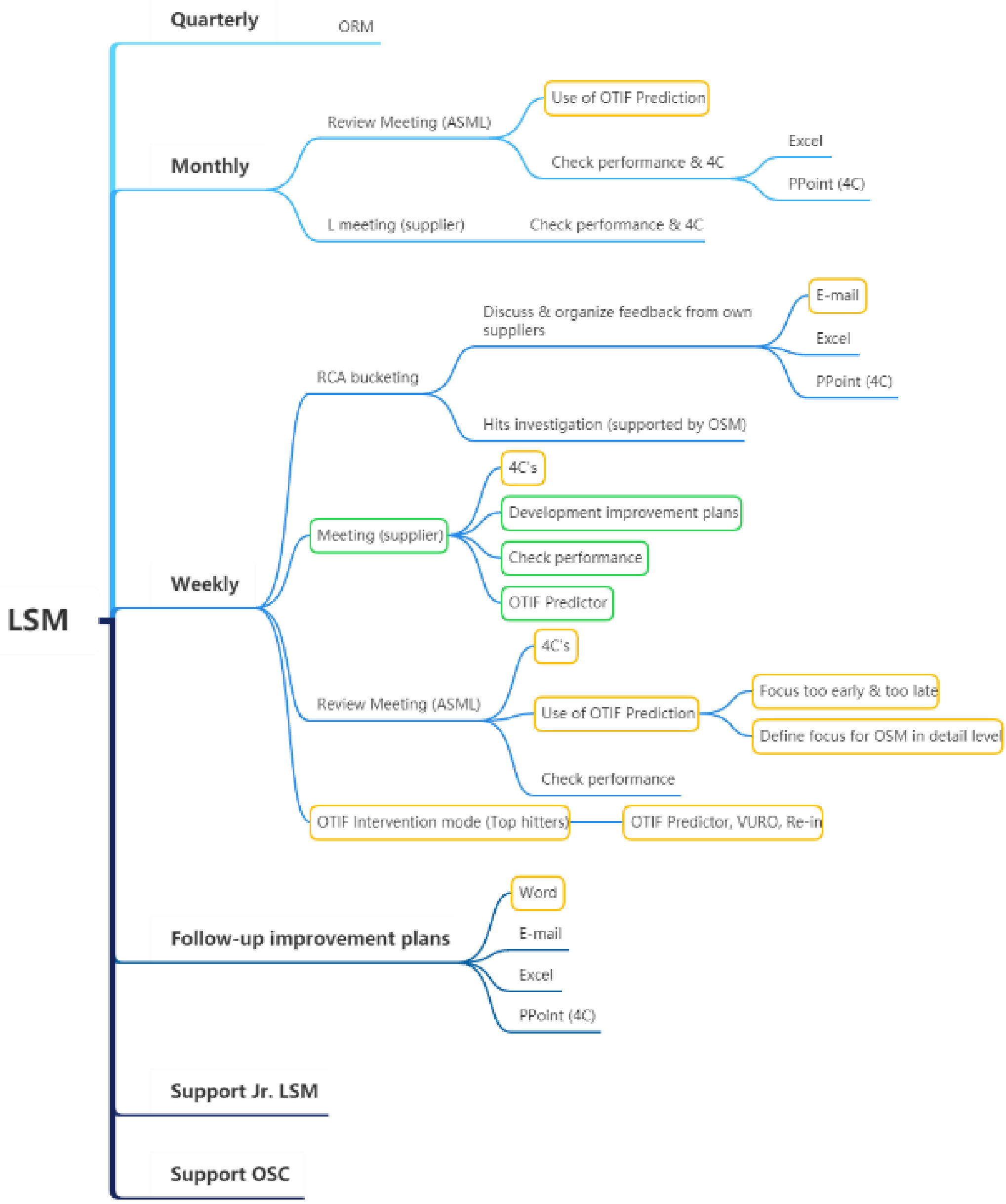

Figure 52. LSM summary of activities.

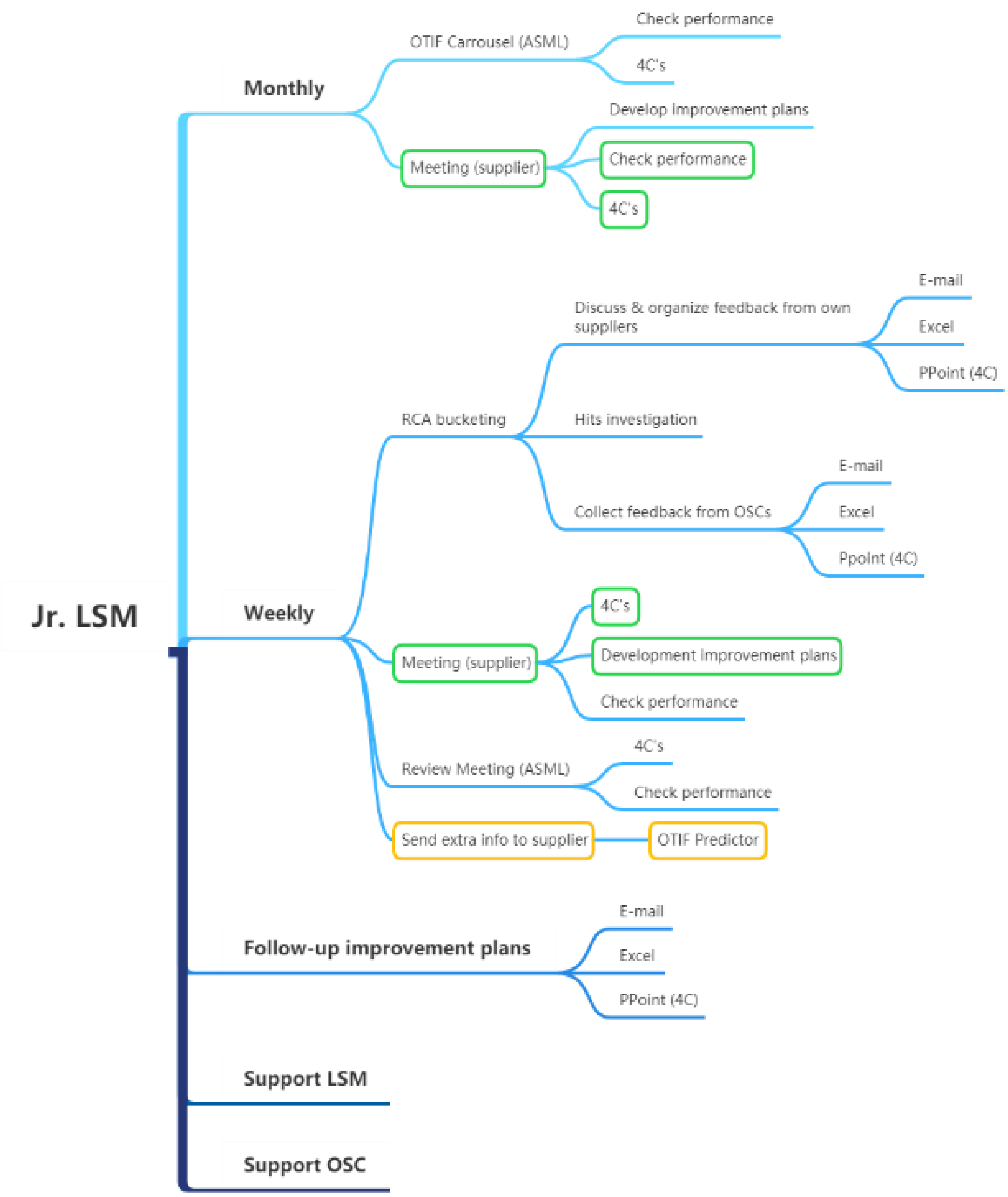

Figure 53. Jr. LSM summary of activities.

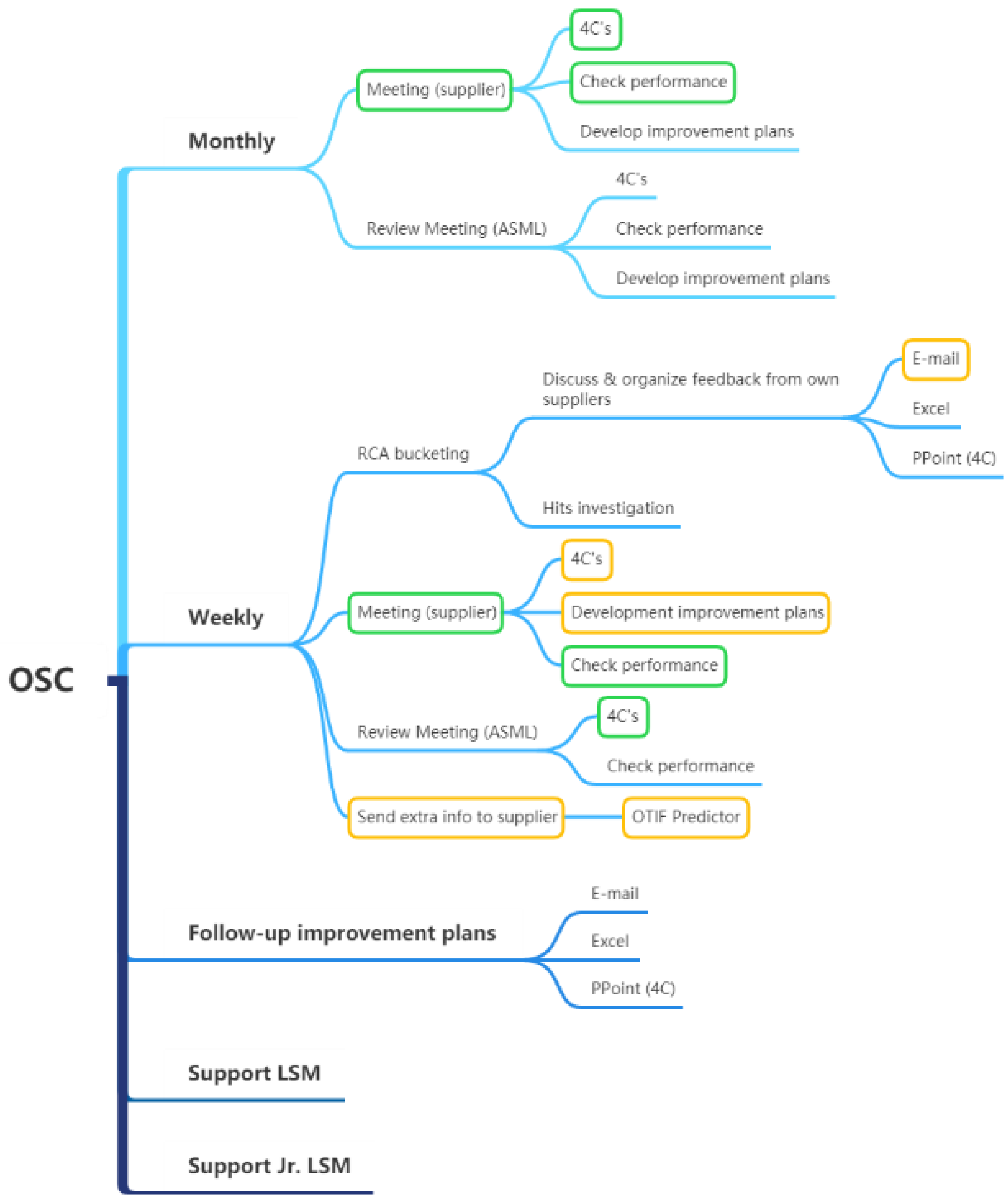

Figure 54. OSC summary of activities.

C. RACI matrix

Table 16. Full-size RACI matrix

	Task / Functions	Bussiness Analytics	SNM			OSM				Supplier	Remarks
			Cluster Manager	Team Manager	LSM	OSM Manager	Team Manager	Jr. LSM	OSC		
Weekly	Send OTIF Dashboard	A/R			I*			I+	I	I	*I and I+ involved in critical suppliers.
	Update OTIF KPI	A/R									
	Send OTIF Feedback to ASML				A*/I*			A+/I+	A/I	R	
	Validate OTIF Feedback from supplier				A*/I*			A+/R+	A/R/R*	C	
	Consolidate OTIF hits feedback				A*/R*			A+/R+	A/R	R/C	Responsibility shared 50/50 between OSCs and Supplier
	Meeting within ASML - DK Only Top X - Drive OTIF			I*	R*/A*		I+/I	R+/A+	C*/R/A		
	Meeting with Supplier - Drive OTIF			I*	R*/A*		I+/I	R+/A+	C*/R/A	C	Team managers only involved in critical suppliers
	OTIF Intervention - Only Top 3 - SNM Staff DK		A*	R*	C*	A+/A	R+/R	C+	C/C*		
Monthly	ORM within SNM - Only Top 5 - Drive OTIF		I	I*	R*/A*		I+/I	R+/A+	C*/R/A		
	OTIF Carrousel - OSM					I+/I	A+/A	R+/R	C		
	Meeting with Supplier - Drive OTIF			A*	R*			R+/A+	C*/R/A	C	
Quarterly	ORM meeting with Supplier		I*	A*	R*					C	
Supplier specific	Drive and follow-up improvement plans to the root causes			I*	R*/A*		I+/I	A+/R+	A/R/C*	C	
Ad-hoc	Revise OTIF categories (First, 3 months; later, every 6 months)		A	R	C		R	C	C		

(blue shading) All accounts
* = SAT suppliers
+ = Key suppliers
No symbol = Medium suppliers

D. OTIF tree

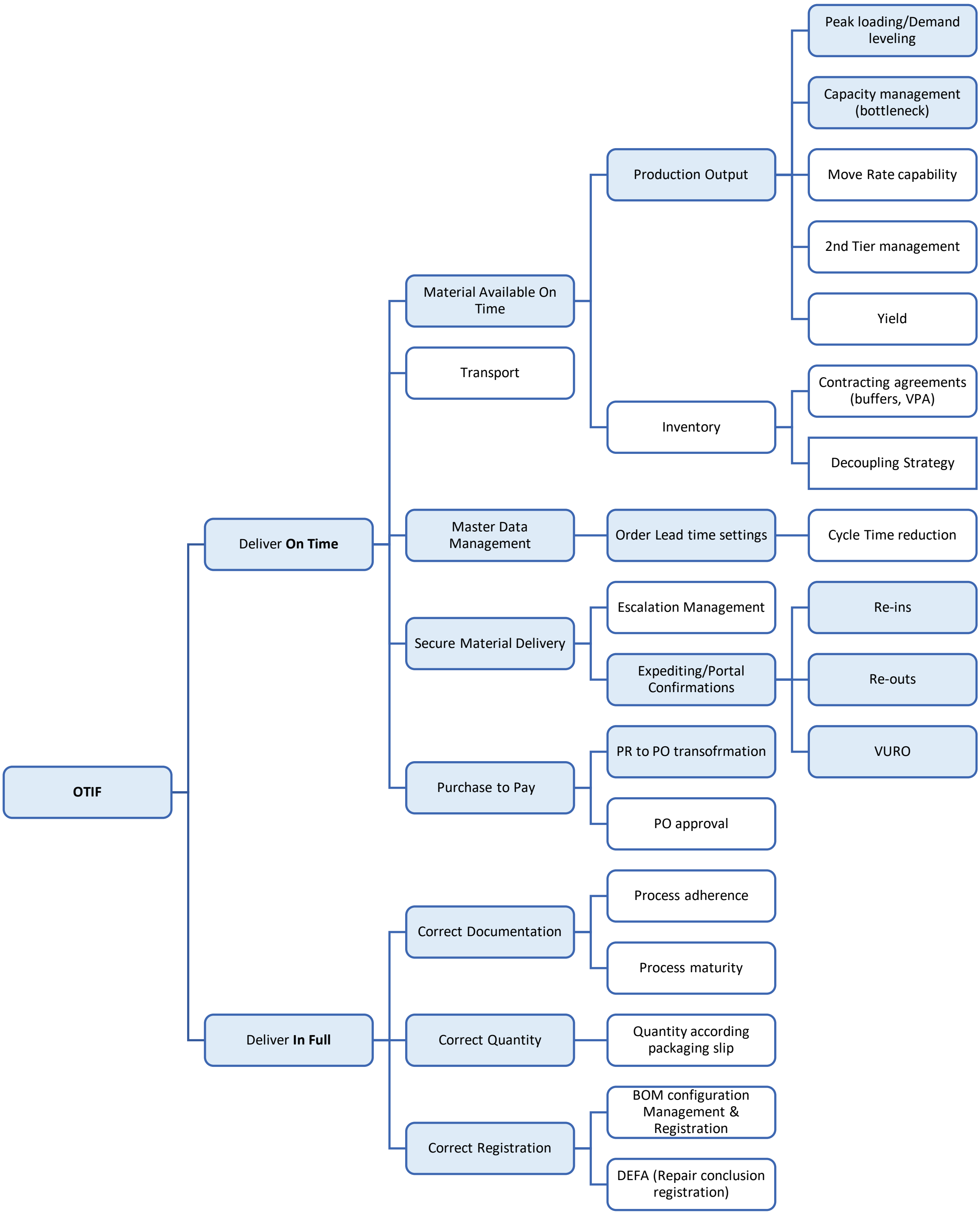

Figure 55. Full-size influencing factors for OTIF KPI

E. Automatic PR-PO transformation

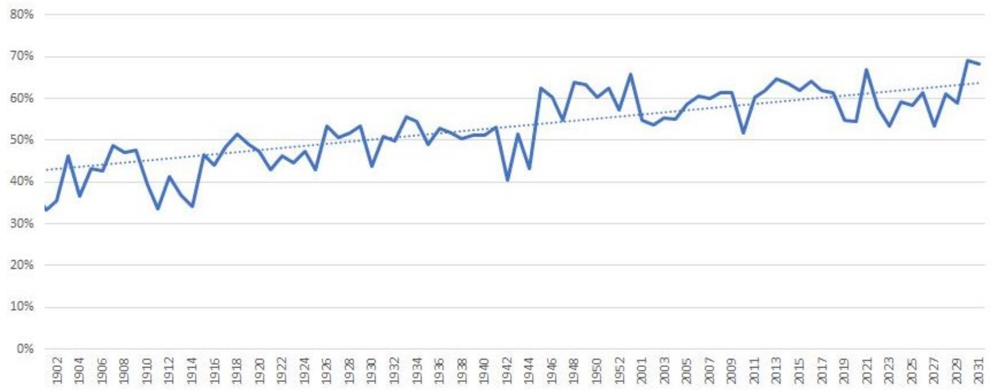

Figure 56. Trend of number of automatic PR-PO transformation.