Supporting Performance Management in an Off-Site Manufacturing Company through a BI Solution

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Abstract

The current complexity and dynamics of the business context have increased the importance of making effective and fact-based decisions to succeed. The integration of Performance Management (PM) and Business Intelligence (BI) principles provides a means of addressing these needs, particularly through the development of practical solutions such as performance dashboards.

In the present dissertation, a BI-based performance dashboard was developed to be used by the plant manager of an off-site manufacturing company dedicated to the prefabrication of chilled water piping systems for data centers. The purpose of this tool is to provide an alternative to existing procedures, in which decisions were primarily based on intuition.

To this end, the project was structured into three phases. The first focused on selecting the performance measures to be included in the tool, starting from the company's three main strategic goals and the critical aspects required to achieve them. From these, performance measures were selected and specified through key attributes such as formula, data source, and actions to address the results.

The second phase involved the collection and preparation of data. To achieve this, Power Query was used to extract the data, transform it into a suitable format, and load it into Power BI. The resulting tables were then connected through relationships to construct the data model.

The third phase concerned the creation of the dashboard displays within the same platform, considering the defined performance measures, the prepared data, user requirements, and visualization best practices.

At the end, these phases culminated in the creation of a performance dashboard comprising a top-level display for monitoring the main performance measures — including a set of indicators aligned with the company's strategy and covering different perspectives such as operations, quality, safety, environment, customer, and financial — and eight additional pages designed for more detailed analysis. Regarding display characteristics, the positioning of the performance measures was intended to emphasize their linkage to strategic goals, while giving prominence to those measures requiring more frequent analysis. As for the types of visual elements adopted, tables, matrices, and charts were used. In addition, interactive features such as filters, slicers, tooltips, and bookmarks were incorporated.

Once the solution was completed, feedback was gathered regarding its development. Overall, the assessed questions received average ratings above 4.3 out of 5. As a result, the project achieved its objective by delivering a BI-based solution that not only enhances the monitoring and analysis of the company's performance but also does so in alignment with its strategy, thereby strengthening the effectiveness of decision-making through its use.

Resumo

A atual complexidade e dinâmica do contexto empresarial têm aumentado a importância de tomar decisões eficazes e baseadas em factos, como condições para o sucesso. A integração dos princípios de *Performance Management* (PM) e *Business Intelligence* (BI) constitui um meio para responder a estas necessidades, em particular através do desenvolvimento de soluções práticas, como os *performance dashboards*.

Na presente dissertação, foi desenvolvido um *performance dashboard* baseado em BI para ser utilizado pelo gestor de fábrica de uma empresa de *off-site manufacturing* dedicada à pré-fabricação de sistemas de tubagens de água refrigerada para *data centers*. O objetivo desta solução é oferecer uma alternativa aos procedimentos existentes, nos quais as decisões se baseavam sobretudo na intuição.

Para tal, o projeto foi estruturado em três fases. A primeira centrou-se na seleção das medidas de desempenho a incluir na ferramenta, partindo dos três principais objetivos estratégicos da empresa e dos aspetos críticos necessários para os alcançar. A partir destes, foram selecionadas as medidas de desempenho, posteriormente definidas através de atributos-chave como a fórmula, a fonte de dados e as ações para explorar os resultados.

A segunda fase envolveu a recolha e preparação dos dados. Para o efeito, recorreu-se ao Power Query para extrair os dados, transformá-los num formato adequado e carregá-los no Power BI. As tabelas resultantes foram depois associadas por meio de relações, com o objetivo de estruturar o modelo de dados.

A terceira fase incidiu na criação dos *displays* do *dashboard* na mesma plataforma, considerando as medidas de desempenho definidas, os dados tratados, os requisitos dos utilizadores e as boas práticas de visualização.

No final, estas fases culminaram no desenvolvimento de um *performance dashboard* composto por um *display* principal, destinado à monitorização das medidas de desempenho mais relevantes — incluindo um conjunto de indicadores alinhados com a estratégia da empresa e cobrindo diferentes perspetivas como operações, qualidade, segurança, ambiente, cliente e financeira — e oito páginas adicionais concebidas para uma análise mais detalhada. Relativamente às características dos *displays*, a disposição das medidas de desempenho procurou salientar a ligação entre estas e os objetivos estratégicos, atribuindo maior destaque às que requerem uma análise mais frequente. Quanto aos tipos de elementos visuais adotados, foram utilizadas tabelas, matrizes e gráficos. Adicionalmente, foram incorporadas funcionalidades interativas como filtros, segmentação de dados, marcadores e *tooltips*.

Após a conclusão da solução, foi recolhido *feedback* relativamente ao seu desenvolvimento. De forma global, as questões avaliadas obtiveram classificações médias superiores a 4,3 em 5. Como resultado, o projeto alcançou o seu objetivo ao disponibilizar uma solução baseada em BI que não só reforça a monitorização e análise do desempenho da empresa, como também o faz em alinhamento com a sua estratégia, apoiando uma tomada de decisão mais eficaz.

Acknowledgments

The last five years have been a complete rollercoaster, full of loops that at times felt never-ending. But now that I can almost see the end of the track approaching, it feels like the right moment to express my gratitude to those who stood by me, whether on the peaks, celebrating my victories, or in the valleys, offering support to help me keep going and stay focused on the next climb.

Firstly, I want to thank my family for being my main source of support. To my parents, thank you for always believing in my dreams, often even more than I did. I am sure you gave me the best you could to support both my education and my growth as a person. Thank you for your patience in dealing with my moods and for always being there. A special thanks also to my sister, who, although young, has given constant encouragement and strength, helping me reach the highest peaks. You were undoubtedly a bright light in my journey. Moreover, I will always be grateful to my grandparents. Even when the path I chose felt distant from your reality, you were always by my side and proud of my achievements. And to the rest of my family, thank you as well, even in the background, your presence, care, and joy helped make many moments along the way lighter and happier.

Secondly, to my colleagues and friends, both those I met along this journey and those who have been present since the beginning, thank you for sharing these moments with me and for showing that everything becomes easier with mutual support and joyful moments.

Moreover, to FEUP and its professors, I would like to express my gratitude for helping me grow. It was not an easy stage. At times, it was too demanding but I am certain that, in the end, it contributed to shaping me as a person and helped prepare me to become a good professional. In particular, I am especially grateful to Professor Telmo Matos for the support during this final stage. Your patience, humanity, valuable input and feedback, were fundamental to the completion of this project.

Finally, I would like to thank Mecwide for giving me the opportunity to conclude this journey with the company, as well as all the Mecwiders who were available to teach me about its activities and did their best to answer my many questions. A special word of thanks goes to my supervisors, Adriana Santos and Tiago Novais, for sharing your knowledge with me and providing constant support during our weekly meetings. It was essential that you believed in this project from the beginning, giving me the freedom to think big while also helping me maintain a practical approach to achieve the final result. Last but not least, I would like to acknowledge the IT Software team, who not only helped me grow technically but also created an environment of respect, collaboration, and many enjoyable moments. I truly hope to find more teams like this in the future.

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To my grandmother, Rosa

Contents

Acronyms and Symbols

API	Application Programming Interface
BI	Business Intelligence
BOM	Bill of Materials
BPM	Business Performance Management
BSC	Balanced Scorecard
CPM	Corporate Performance Management
CSF	Critical Success Factor
DAX	Data Analysis Expressions
DSS	Decision Support System
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EPC	Engineering, Procurement, Construction
EPM	Enterprise Performance Management
ERP	Enterprise Resource Planning
ETL	Extract, Transform, Load
HR	Human Resources
IMS	Integrated Management System
IT	Information Technology
KPI	Key Performance Indicator
KRI	Key Result Indicator
LTFR	Lost Time Frequency Rate
LTI	Lost Time Injury
LTIFR	Lost Time Injury Frequency Rate
LYTD	Last-Year-to-Date
MES	Manufacturing Execution System
MTD	Month-to-Date
ODS	Operational Data Store
OLAP	Online Analytical Processing
OTIF	On-Time, In-Full
PI	Performance Indicator
P&L	Profit and Loss
PM	Performance Management
QCPC	Quality Control Process Charting
RI	Result Indicator
ROI	Return on Investment
SHE	Safety, Health, Environment
SR	Severity Rate
TRIF	Total Recordable Injury Frequency
TRIR	Total Recordable Incident Rate

TRS	Time Report System
YTD	Year-to-Date

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Chapter 1

Introduction

The present study, developed as part of the curricular dissertation project of the Master's in Industrial Engineering and Management of the Faculty of Engineering of the University of Porto, was carried out within the corporate environment of Mecwide S.A.

This first chapter begins with an overview of the general context in which the project is framed. It then narrows to a more specific level by presenting the companies under analysis, followed by the project's motivation, main objective, and related research questions. The chapter concludes with a brief outline of the adopted methodology and the overall structure of the report.

1.1 Contextualization

In the 21st century, business environments have become increasingly complex and dynamic, driven by factors such as globalization, volatile markets, and rapid technological progress (Kemper et al., 2013). Whereas in the past trends could be assessed on a quarterly basis, today they often shift on a weekly or even daily scale. These scenarios highlight the limitations of management approaches based on instinct and intuition, which were commonly adopted by organizations in the 20th century. To succeed in the current context, it is essential that decision-makers across all organizational levels are empowered to make effective and informed decisions (Cokins, 2004).

The combined application of the principles of Performance Management (PM) and Business Intelligence (BI) provides solutions to address these needs (Kemper et al., 2013). In practice, the PM process encourages executives to translate organizational strategy into a shared understanding, motivating managers and teams to move collectively in a value-creating direction (Cokins, 2004). To ensure progress, PM also promotes the definition of performance measures to assess whether strategic objectives are being achieved. The outcomes of these measures, in turn, help identify when actions are required to improve performance or when opportunities can be leveraged for further growth, thereby providing guidance for decision-making. BI complements this closed-loop process by supplying the technical foundation required to deliver the necessary information, covering the collection, integration, transformation, and visualization of data (Eckerson, 2011; Frolick and Ariyachandra, 2006).

A practical solution that can combine the principles of both fields is the performance dashboard. When effectively integrated, these tools enable timely monitoring and analysis of performance in alignment with strategy, offering insights that support decision-making and drive progress toward defined goals. The recognized value of these solutions has contributed to the widespread adoption in the business context. Nonetheless, their actual impact depends on how properly they are designed, developed, and used within organizations (Eckerson, 2011).

The present study explores the development of a BI-based performance dashboard solution and its underlying principles within the context of an off-site manufacturing company, which will be presented in the following section.

1.2 Company Presentation

Founded in 2008 in Barcelos, Mecwide, S.A., hereafter referred to as Mecwide, is an engineering services company operating in the metalworking industry. Although it is a relatively young company, Mecwide has established itself as an international reference for integrated Engineering, Procurement and Construction (EPC) solutions in the fields of technical assistance, oil and gas, mining and cement, modular systems, industry and energy, electricity and instrumentation, data centers, painting and isolation.

In 2024, the company's turnover was approximately 170 million euros, reflecting significant growth of over 50% compared to the previous year. This success is the result of the completion of more than 2,000 projects since its foundation, the efforts of a workforce of around 1,600 employees, and the operation of eight manufacturing units.

With a mission to develop efficient, sustainable, and innovative industrial solutions, ensure customer satisfaction, and promote the continuous development of its teams, Mecwide is guided by the values of determination, excellence, ambition, commitment, and passion. Moreover, the company is committed to quality, safety, and environmental responsibility.

1.2.1 Expanding into Off-Site Manufacturing for Data Center Construction

The data centers business unit is one of the newest divisions of the Mecwide group, which started operations in January 2023 in Norway. This expansion aligns with Mecwide's strategy to enter this growing sector, characterized by high demand and limited supply, driven by the increasing need for data storage.

In the beginning, among the activities of this division was the mechanical assembly and installation of the data center's chilled water piping systems. This work was initially executed entirely on-site. However, the method proved to be inefficient. As a result, in 2024, a company (hereafter referred to as Company X) was established as a strategic joint venture between Mecwide and two other partners (Partner A and B), dedicated to the prefabrication of piping systems for data centers, leaving only the final installation to be performed locally.

The establishment of this company, managed by Mecwide, is aligned with a growing trend in the construction sector, commonly referred to as off-site manufacturing. This approach introduces an innovative method of construction in which components and units are produced in a controlled factory environment and subsequently transported for installation on-site (Alhawamdeh and Lee, 2025). In this context, off-site manufacturing can take different forms, encompassing the production of products with varying levels of complexity, such as components and subassemblies (e.g., windows), non-volumetric pre-assemblies (as in the case of Company X), volumetric pre-assemblies (e.g., bathroom pods), and even complete modular buildings (e.g., prefabricated houses) (Gibb and Isack, 2003).

The adoption of this method has been shown to improve construction projects considerably in terms of time, cost, and quality, but also in reducing health, safety risks, and environmental impacts when compared with the on-site construction (Blismas et al., 2005; Zhang et al., 2021). However, adopting industrialized processes also has its constraints, particularly the complexity and dynamism of supply chains that involve highly interdependent processes such as design, manufacturing, transportation, storage, and installation (Zhang et al., 2021). In addition, synchronizing factory production with on-site construction schedules is challenging, especially under short timelines and when it is not possible to freeze the design and specifications at an early stage (Alhawamdeh and Lee, 2025; Blismas et al., 2005; Peiris et al., 2023).

1.3 Project Motivation, Main Objective and Research Questions

Company X has been experiencing growth in its operations, having already surpassed, in June 2025, the production volumes achieved in the previous year. The increasing level of activity consequently introduced additional needs and challenges, such as those outlined in the previous section, which demand greater rigor in management decisions.

Before the start of this project, the plant manager's decisions relied mainly on their experience and intuition, complemented only by manual analyses when necessary, which was becoming limited in scope and time-consuming. Based on that, it was identified, for example, the absence of a comparison between the progress of work and the schedule, which made it difficult to anticipate potential delivery constraints. Likewise, there was no systematic assessment of the differences between the estimated and the actual resources consumed, both financial and non-financial. These limitations were further reinforced by expectations at the executive level, which emphasized the need for more detailed insights to be presented during meetings by the plant manager and also to use them as support for decision-making.

As a consequence, the need emerged for a solution that would provide closer monitoring and analysis of the company's activities and, consequently, more informed decisions. Following an initial analysis of the company context, the development of a BI-based performance dashboard solution to support the plant manager of Company X was defined as the main objective of this project.

To provide guidance and ensure alignment with both the company's needs and academic rigor in achieving this goal, this dissertation is structured around the following main research questions:

- **Question 1:** How should performance measures be selected and defined for assessing the company's performance?
- **Question 2:** How can the necessary data be collected and prepared for use?
- **Question 3:** In what ways can appropriate dashboard displays be created to monitor and analyze the organizational results?

1.4 Methodology

To answer the research questions and achieve the objective set above, it was essential to select a methodology that guided the project's development. Given the characteristics of this study, Action Research was selected. This strategy is designed to create practical solutions to real organizational problems through a participatory and collaborative approach that combines different forms of knowledge, including theoretical understanding, participants' experiences, and knowledge acquired through practice. In addition, it is characterized by a continuous cycle of problem identification, action planning, implementation, and evaluation. Beyond research and action, participation is crucial to the success of this process, since organizational members are more likely to adopt and sustain changes when they have actively contributed to their development (Saunders et al., 2012).

In terms of timeline, the project was divided into the main phases presented in the Gantt chart in Figure 1.1. Accordingly, the project began with an introductory phase aimed at understanding the organizational context of Mecwide. It should be noted that, although the project was dedicated to creating a solution for Company X, its development was carried out within Mecwide, specifically with the BI team of the Information Technology (IT) Software Department, as Mecwide is responsible for managing the joint venture and providing the necessary support.

A subsequent phase was dedicated to understanding the reality of Company X, particularly its stakeholders, processes, and the main problems addressed in this project. Moreover, the Manufacturing Execution System (MES) used by the company to support the production process was analyzed. Before moving forward with the creation of the performance dashboard, the conditions for creating such solutions in the given context were examined. This step made it possible to understand both how Mecwide conducts similar projects and the BI architecture it has implemented.

After this, the project focused on the development of the solution, which was structured around three main phases. The first involved the selection of performance measures aligned with the company's strategy, followed by their definition through the specification of corresponding attributes. Based on these choices, the required data were collected and prepared using a BI platform. Subsequently, the dashboard displays were designed and then implemented in the same platform, combining the visual and interactive elements with the defined performance measures and the processed data.

The last phase of the project focused on presenting the developed tool and collecting feedback and suggestions for its improvement, as well as on the development of a manual to support the use and ongoing maintenance of the proposed solution.

These phases, in addition to incorporating the collaborative input of the organization's members as well as the experiential knowledge gained through practice, were accompanied by a review of the literature on the main subjects, with the purpose of improving the quality of the delivered solution.

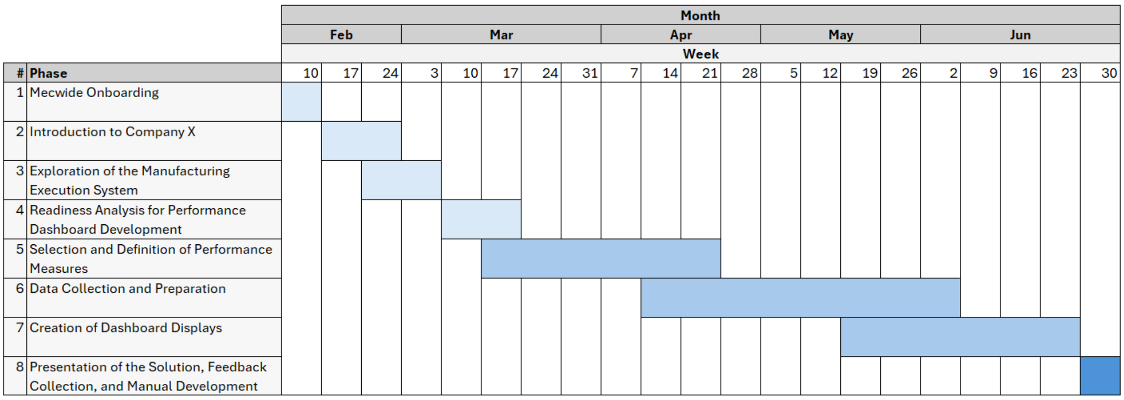

Figure 1.1: Project's Gantt Chart

1.5 Dissertation Structure

To reflect the work carried out during this project, the present dissertation is organized into six chapters. Following this introduction, Chapter 2 provides a review of the state of the art of the main themes addressed in this study, including PM, performance measures, and BI. Chapter 3 then presents a detailed description of the company's operational context, the problems that motivate this study, and potential solution approaches. Subsequently, Chapter 4 is organized into three main parts, which reflect the phases five, six, and seven of the Gantt chart presented in Figure 1.1, and aims to provide a comprehensive description of the execution of the proposed solution. In Chapter 5, the developed tool is presented, together with the corresponding feedback and the suggestions for its improvement. Finally, Chapter 6 summarizes the main conclusions of the study and outlines directions for future work.

Chapter 2

Literature Review

This chapter is divided into three main parts. The first presents a review of the PM field, outlining its evolution from the phase of performance measurement and its integration with the field of BI, which provides the context for the topic of performance dashboards. To clarify the essential aspects for developing this PM tool, the second part focuses on the concept of performance measures and the methodologies associated with their definition, while the final part explores key aspects of BI. Finally, the chapter concludes with a summary highlighting the main findings.

2.1 Performance Management

The field of PM has attracted increasing attention in both academic and practical contexts since the late 20th century, with applications in diverse sectors (Bititci et al., 2012; Cuccurullo et al., 2016; Kemper et al., 2013). To provide a broader understanding of the field, the next two sections outline its evolution. It is important to note, however, that the multidisciplinary nature of PM, with research contributions from different fields, including accounting and human resources, makes it challenging to develop a comprehensive overview (Cuccurullo et al., 2016; Folan and Browne, 2005; Marr and Schiuma, 2003). Therefore, only the most relevant developments for this study are mentioned.

2.1.1 From Performance Measurement to Performance Management

According to Bititci et al. (2012) and Cuccurullo et al. (2016), who provide an overview of this evolution, PM originally focused on performance measurement can be dated back to the 13th century, with the introduction of double entry bookkeeping by Florentine merchants to track capital investments and profitability. During the Industrial Revolution, mass production and labor specialization, along with the transition from piecework payment to the wage system, created a need to measure employee productivity. In the 1950s, as companies expanded through internationalization and adopted divisional structures, performance measurement changed its focus to financial, growth, and risk indicators. From the 1960s to the 1980s, the increasing importance of marketing and customer preferences brought new dimensions to measurement, such as quality, time, customer satisfaction, and flexibility.

As a result of this evolution, performance measurement acquired a multi-dimensional character, which led to the development of more balanced measurement approaches (Bititci et al., 2012). Furthermore, this rendered the previously widely adopted management accounting systems increasingly obsolete. In fact, their exclusive focus on the financial dimension failed to provide the relevant information required for effective managerial decision-making in organizational contexts shaped by growing competitiveness, globalization, and market volatility (Cuccurullo et al., 2016; Neely, 1999).

Although the focus has expanded over time — from conventional financial performance measures to a broader set of dimensions — this evolution remained primarily centered on the measurement process. With the establishment of strategy as a formal discipline in the 1980s, PM, driven by the recognition of the need to align measurement with organizational strategic objectives, began to converge with this field (Bititci et al., 2012; Cuccurullo et al., 2016). This integration led to the recognition of PM as a process aimed at establishing a closed-loop control system, in which corporate and functional strategies are defined and implemented, and feedback is obtained through measurement to support appropriate managerial decisions (Bititci et al., 1997). Consequently, while performance measurement remained a key and inseparable phase of PM, it was no longer considered the "heart of the discipline", but rather served primarily to measure performance indicators (Cuccurullo et al., 2016; Lebas, 1995).

In terms of mindset, this shift emphasized that "it became increasingly important to do the right things apart from doing things right", meaning that strong performance on irrelevant metrics is meaningless if not aligned with the company's strategic direction (Bititci et al., 2012; Cokins, 2004; Drucker, 1994). To support the alignment between performance measures and business strategy, new models were developed and others refined. For instance, the Balanced Scorecard (BSC), originally created to address the challenge of balanced measurement, was subsequently adapted to also highlight the importance of linking strategy with the selected performance indicators (Kaplan and Norton, 1996).

2.1.2 Business Intelligence Integration

In addition to the developments in the field of PM discussed in the previous section, it is important to acknowledge the contribution of technological progress. In the 1990s, the rise of BI, conceived to provide business users with direct and more rapid access to information, became an important support of contemporary PM solutions by offering a more suitable technological infrastructure (Eckerson, 2011; Kemper et al., 2013).

This idea of using PM as a process that leverages technology is reflected in the work of the BPM Standards Group (2005) that was established in 2003 to bring greater clarity to the field (Frolick and Ariyachandra, 2006). It stated that the objective of PM, also mentioned by Business Performance Management (BPM), Corporate Performance Management (CPM), and Enterprise

Performance Management (EPM), is to enable a business to "define, measure and manage its performance against strategic goals" through a "set of integrated, closed-loop analytic processes, supported by technology, that address financial as well as operational data". Moreover, the group presented a framework for implementing PM within organizations, comprising four core processes in a closed-loop cycle: strategize, plan, monitor and analyze, and alert and corrective action. A similar four-step approach, represented in Figure 2.1, is also referenced by Eckerson (2011) and Frolick and Ariyachandra (2006), who emphasize its importance in bridging the gap between strategy and action, and in keeping people moving in the same and right direction. A detailed explanation of each step is provided in Appendix A.

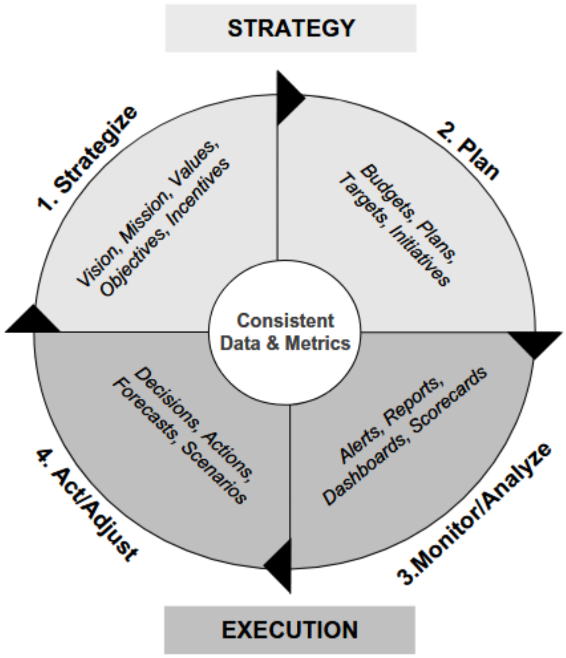

Figure 2.1: Performance Management framework. Source: Eckerson (2011)

2.1.3 Performance Dashboards

Among the tools employed to enable the practical implementation of this cycle, performance dashboards, generally BI-based, have gained particular relevance for supporting the third and fourth steps. According to Eckerson (2011), these tools, which can be used at the operational, tactical, and strategic levels, consist of a "layered information delivery system that parcels out information, insights, and alerts to users on demand so they can measure, monitor, and manage business performance more effectively". For Lempinen (2012), performance dashboards can be defined as "an interactive performance management tool consisting of a measurement system and an information system, and supported by the models and processes for information gathering, processing, distribution, and visualization".

Both definitions convey the idea that performance dashboards are more than simple user interfaces. Therefore, in addition to their visual elements, they integrate all the technological components that support what users see on their screens. Beyond the technological dimension, another relevant part of these PM tools is the set of performance measures, which represent the business dimension of the tool and provide the guidelines for performance dashboard design, including which data should be collected and how it should be filtered, calculated, and presented (Eckerson, 2011; Lempinen, 2012).

To explore the two dimensions in greater detail, the following section focuses on performance measures, presenting methodologies for their definition, while the Section 2.3 analyzes the technological aspects usually involved in the development of performance dashboards.

2.2 Performance Measures

Performance measures, also referred to as metrics or performance indicators, are means to represent in a simplified manner the performance of a phenomenon over time (Barr, 2014; Faveto et al., 2024). With the increasing availability of data, the use of such tools has become even more common, as they facilitate the separation of useful information from irrelevant data and provide a more transparent view of the organization (Rodrigues et al., 2021).

Regarding the types of measures, there are different perspectives to classify them. Some authors adopt a categorization that distinguishes between effectiveness and efficiency indicators. While effectiveness measures refer to the extent to which an organization meets customer needs, efficiency indicators concern the degree to which organizational resources are well utilized (Neely et al., 1995).

Another commonly adopted classification involves the differentiation between lagging (outcome) and leading (driver) indicators (Eckerson, 2011; Kaplan and Norton, 1996; Marr, 2015). The first indicators reflect past results and show whether targets were met. In contrast, the second are predictive, guiding present actions that influence future outcomes.

For Parmenter (2020), this traditional distinction can be misleading, as some indicators can simultaneously be both lagging and leading. Therefore, the author proposes categorizing them as past (focused on historical events), current (reflecting recent or ongoing activities), or future measures (focused on upcoming actions). Moreover, it suggests that metrics be allocated across these categories in proportions of sixty, twenty, and twenty percent, respectively.

Additionally, the author classifies performance measures into four other categories: Key Result Indicators (KRIs), Result Indicators (RIs), Performance Indicators (PIs), and Key Performance Indicators (KPIs). KRIs generally provide the executive board with an overall picture of the organization's progress toward its strategic objectives, while RIs inform management about how teams are collectively contributing to outcomes, being less critical and comprehensive than the former. However, neither KRIs nor RIs allow for the identification of specific corrective actions. In contrast, PIs are linked to the outputs of a specific team and tell how it is performing. KPIs share these features but are more critical, offering timely insights into organizational performance.

Moreover, they are easily understood across all staff levels, prompt timely corrective actions, and are typically non-financial in nature.

Given that these classifications are not universal and sometimes inconsistent, Barr (2014) avoids such categorizations, opting instead to use general terms, such as "performance measures".

Considering the definition of the measures, some aspects can be associated with well-formulated performance indicators. In the view of Eckerson (2011), effective performance metrics should be aligned with twelve key characteristics, summarized in Table 2.1.

Table 2.1: Key characteristics of effective performance measures. Adapted from: Eckerson (2011)

Characteristic	**Description**
Strategic	Aligned with the organization's strategic objectives, helping monitor whether it is on track to achieve them
Simple	Understandable by employees, including its purpose, calculation, and target
Owned	Assigned to a specific owner, establishing clear responsibility for performance outcomes
Actionable	Linked to actions that employees can take to improve performance
Timely	Based on up-to-date data, allowing for prompt interventions and ensuring relevance in decision-making
Referenceable	Supported by transparent data sources and well-documented calculations to promote trust and clarity
Accurate	Grounded in reality, accurately representing the underlying activity, and free from distortions caused, for instance, by data defects
Correlated	Associated with the specific outcomes or behaviors it aims to influence
Game-proof	Resistant to manipulation or exploitation, thus maintaining the integrity and usefulness of the metric
Aligned	Harmonized with other performance indicators to avoid conflicts and ensure coherence within the measurement system
Standardized	Based on consistent definitions across the organization, enabling integration
Relevant	Periodically refreshed, revised, or discarded

Neely et al. (1997) had also recognized the need to identify what constitutes a well-designed metric and introduced a practical approach by materializing the recommendations found in the literature into the Performance Measure Record Sheet. The elements that constitute this framework are detailed in Table 2.2.

Although verifying the presence of these attributes in metric definitions is important, as they represent the desired qualities of effective performance measures, they are not sufficient to guide the selection process. In fact, they do not define which metrics should be chosen. Therefore, these aspects will be addressed in the following section through the analysis of performance measurement methodologies.

Table 2.2: The Performance Measure Record Sheet. Adapted from: Neely et al. (1997)

Element	**Description**
Title	The measure's name should be self-explanatory
Purpose	The rationale for the measure must be specified. A measure without a clear purpose should not be implemented
Relates to	The measure should be linked to business objectives. If it does not support a specific goal, its relevance is questionable
Target	Defines the performance level to be achieved within a set time frame. It should reflect competitive context and stakeholder expectations
Formula	Specifies how the measure is calculated. The formula influences behavior, so it must be carefully designed to reinforce desired actions
Frequency of measurement	Indicates how often the performance measure should be recorded and reported. It depends on data volume and measures importance
Who measures?	Identifies the person responsible for collecting and reporting the data
Source of data	Specifies where the raw data will come from. Consistency in data sources is essential for reliable comparison over time
Who acts on the data?	Identifies the person responsible for taking action based on the data
What do they do?	It is a fundamental part of this sheet that describes the general management process to be followed in response to acceptable or unacceptable performance, recognizing that specific actions may vary depending on context

2.2.1 Performance Measurement Methodologies

Choosing appropriate performance measures is a non-trivial process that requires a good understanding of the organization. One of the most common mistakes in performance measurement is the tendency either to assess every available aspect of the business or to replicate the indicators adopted by other companies (Marr, 2015). Estimates indicate that approximately seventy percent of implemented performance measurement initiatives fail after deployment (Collins et al., 2016). Therefore, selecting appropriate measures requires a structured procedure (Parmenter, 2020). The following sections examine some frameworks associated with this purpose.

2.2.1.1 Balanced Scorecard

As mentioned in Section 2.1.1, the recognition of the need to measure beyond the financial dimension led to the emergence of new methodologies that not only ensure a broader range of dimensions to be assessed but also highlight the importance of alignment with organizational strategy.

Among these, the BSC, developed by Kaplan and Norton (1992), is one of the most popular performance measurement approaches, applied in both theoretical and practical contexts. It enables organizations to align their strategic objectives with performance measures by adopting four distinct perspectives, summarized in Figure B.1 of Appendix B: financial, customer, internal process, and learning and growth (Van De Ven et al., 2023).

The term balanced refers not only to the inclusion of both financial and non-financial measures and to the balance between external and internal performance perspectives, but also to the need for equilibrium between short and long-term objectives, and lagging and leading indicators (Kaplan and Norton, 1996). Some authors have argued that the four perspectives mentioned may not fully capture the complexity of organizations. For instance, Parmenter (2020) proposed an extended version of the BSC by incorporating two additional perspectives: environment and community, and staff satisfaction.

2.2.1.2 Performance Prism

Another well-known framework for performance measurement is the Performance Prism, developed by Neely et al. (2001), consisting of five interrelated facets illustrated in Figure B.2 of Appendix B. In contrast to other common frameworks, it does not assume that performance measures should be strictly derived from organizational strategy. Instead, it proposes that strategies should be formulated on the basis of a comprehensive stakeholder analysis that considers not only customers and shareholders, but also employees, suppliers, and regulators (Tangen, 2004).

Consequently, organizations must first identify their key stakeholders, understand their specific needs and expectations, and clarify what the organization itself expects from them. Only after this step, strategies, processes, and capabilities should be designed and aligned to meet these expectations, with appropriate questions and measures established to assess their implementation (Neely et al., 2001, 2002).

According to Tangen (2004), although BSC and Performance Prism, as well as other defined frameworks, such as Performance Pyramid, are academically well defined, they provide limited guidance on translating the framework into concrete performance measures, particularly with respect to their specification and the frequency of assessment. A similar view is expressed by Barr (2014), who observes that these approaches provide a structure for determining which dimensions of a company are important to measure and emphasize the significance of performance measurement. However, to support practical application, they need to be complemented by further development. Marr and Schiuma (2003) also emphasize that much of the BSC research is case-based, and large-scale empirical testing of the concept appears to be limited. In order to analyze more practically oriented methodologies, the Winning KPIs methodology of Parmenter (2020) will be explored in the next section.

2.2.1.3 Winning KPIs

This approach consists of three main stages, where through a bottom-up perspective the performance measures are defined based on the Critical Success Factors (CSFs) rather than directly from its strategy. According to Parmenter (2020), CSFs are operational aspects that must be consistently well executed to ensure the organization's ongoing health.

To implement the approach, the first stage involves securing commitment from the organization. In addition, a dedicated full-time team, composed of internal staff, should be established to support the definition of performance measures (KPI team).

The second stage focuses on identifying the organization's operational CSFs. To define them, this methodology suggests the team start with a thorough review of the organization's strategic documents, along with interviews to identify the success factors as well as external outcomes, which are the results that emerge when CSFs are consistently executed on a daily basis over an extended period. Subsequently, during a workshop, participants work in teams to analyze the relationships among the previously defined success factors. Those factors exerting the greatest influence on others are identified as potential CSFs. To ensure their appropriate selection, the resulting set of CSFs is then validated to confirm its alignment with the organizational strategy and to ensure that it represents a balanced set of perspectives.

The final stage begins with another workshop where teams define specific performance measures for each CSF and formulate them appropriately. Then, they should classify each measure as past, present, or future oriented. Moreover, measures need to be identified as KRI, RI, KPI, or PI.

After these procedures, each team of the organization should select its performance measures from the set of measures previously created. The KRIs to be presented to the board should also be identified. Finally, the reports in which the measures will be displayed are developed, and the KPI team should provide ongoing support for their use. It is also recommended that both the CSFs and the performance measures be reviewed after one year. A detailed version of this process is presented in Table B.1 of Appendix B.

2.3 Business Intelligence

BI is a field dedicated to transforming raw data into meaningful insights that support and improve organizational decisions, ultimately contributing to the achievement of its goals (Bordeleau et al., 2018). It emerged as a business oriented subfield of Decision Support Systems (DSS), which is a discipline concerned with the development of IT based systems to support decision-making processes (Arnott and Pervan, 2008). Although it is widely accepted that the term "Business Intelligence" was popularized by Gartner in 1989, the first known explanation of the concept was provided by Hans Peter Luhn in 1958 (Azevedo and Santos, 2009; Srivastava et al., 2022).

Over the last decades, BI has received significant attention driven by the decreasing costs of data acquisition and storage, which have led organizations to gather larger datasets as a strategic means of gaining competitive advantage (Azevedo and Santos, 2009; Chaudhuri et al., 2011).

This evolution aligns with the ongoing transformations in industrial settings within the context of Industry 4.0. This concept, introduced by the German government around 2011, refers to the integration of advanced technologies, such as sensors, communication protocols, cloud computing, cyber-physical systems, additive manufacturing, BI, and big data into industrial environments. While many of these technologies are not innovations, their combined application defines the novelty of this digital transformation era, in which BI can play a crucial role in extracting and managing value from the large volume of data generated (Bordeleau et al., 2018). According to Chaudhuri et al. (2011), it has become rare to find a successful company that does not apply BI solutions to extract value from this critical corporate asset: data.

These solutions typically involve different stages of data management, including collection, integration, analysis, and visualization (Bordeleau et al., 2018). The following section details the technological elements that support these processes.

2.3.1 Business Intelligence Architecture

To examine a typical architecture of BI applications, including its components and their interactions, the framework proposed by Ong et al. (2011), which divides the architecture into five layers, will be considered. A similar division is presented by other authors (Chaudhuri et al., 2011; Srivastava et al., 2022).

The first layer consists of the data sources, which provide raw data, either generated inside the company or by external entities, including Enterprise Resource Planning (ERP) systems, flat files, and business partners' databases (Chaudhuri et al., 2011; Srivastava et al., 2022). An appropriate selection of these sources is essential to ensure data reliability and to prevent potential issues in subsequent stages (Ong et al., 2011).

To integrate the data from the identified heterogeneous sources into a unified repository, organizations commonly employ Extract, Transform, and Load (ETL) technologies. Although these are time-consuming processes, often occupying between sixty and eighty percent of a technical team's time, they are crucial for ensuring data quality and consistency (Dayal et al., 2009; Eckerson, 2011). Therefore, after the extraction from the data sources, the data are usually sent to a temporary storage place called the staging area, where, based on predetermined rules, they are transformed into consistent formats and cleansed to detect and correct errors. At the end of the process, the loading into a repository takes place (Ong et al., 2011).

This central storage element is usually a data warehouse designed to be queried by analytical applications. In certain cases, instead of developing an enterprise data warehouse intended to meet the needs of the entire organization, companies choose to create data marts. This approach allows technical teams to reduce both risk and initial capital investment by focusing on the analytical requirements of a particular department or group. Depending on the implementation, it may consist of a set of tables within a larger data warehouse or exist as a separate system, with less storage capacity (Dayal et al., 2009; Eckerson, 2011). In terms of construction, both data warehouses and data marts are developed using a multi-dimensional data model of fact and dimension tables. While a fact table stores quantitative data related to business entities, such as sales, a dimension table contains descriptive attributes, for instance, customer information, that provide contextual meaning to the facts (Ong et al., 2011).

Apart from these two components, the warehouse layer can have an Operational Data Store (ODS), which provides an integrated view of near real-time data, such as transactions, that are important for daily management and short-term decision-making. These systems are usually updated every few minutes or hours, whereas a data warehouse is typically updated on a daily or weekly basis. Still within this layer, data warehouse servers can be complemented by mid-tier servers such as Online Analytical Processing (OLAP), which enable faster analysis by organizing data into multidimensional cubes rather than tables (Chaudhuri et al., 2011; Ong et al., 2011).

In the user layer, various tools and processes can be employed to access the available information. Among these, query tools enable quick retrieval of data, generally for generating reports. OLAP graphical tools also allow users to analyze business data stored in OLAP cubes from multiple perspectives, including the following main operations (Ong et al., 2011):

- **Drill-up**: Increases the level of aggregation by moving to a higher level in the hierarchy or by combining data across fewer dimensions.
- **Drill-down**: Decreases the level of aggregation by moving to a lower, more detailed level in the hierarchy or by combining data across more dimensions.
- **Slice**: Fixes a single dimension to a specific value, generating a smaller sub-cube of the data.
- **Dice**: Selects a subset of the data cube by filtering ranges of values across two or more dimensions.
- **Pivot**: Rotates the axes of a data cube, swapping dimensions to present the data from different perspectives.

Moreover, data mining processes can be employed by users to uncover valuable insights, such as unusual patterns, trends, and relationships hidden within large volumes of data. Other analytical applications, like forecasting and what-if scenario analysis, can also offer valuable functionalities. Finally, data visualization tools, including dashboard displays, offer users an overview of business data through charts, metrics, or tables (Ong et al., 2011).

According to Eckerson (2011), a performance dashboard can integrate, within a single system, most of the elements mentioned in this layer. In fact, beyond simply providing access to performance monitoring through charts and alerts, these tools also enable more advanced data exploration. For example, users can drill down or up to examine exceptions and trends from multiple perspectives. Moreover, they may also access individual transactions and detailed records, which can be used to investigate, for instance, the root causes of specific problems (Widjaja and Mauritsius, 2019).

In addition to the layers presented, Ong et al. (2011) introduces the metadata layer, an informational dimension that consolidates insights about the operations and components of the other layers, including the origin and location of the data, the changes made, and the reporting rules.

Effective management of this layer not only reduces the time required to develop and maintain the entire data ecosystem but also ensures a comprehensive and integrated view of it.

The five layers described and illustrated in Figure C.1 of Appendix C, when present and interconnected in an appropriate manner, contribute to the development of effective BI systems (Ong et al., 2011). However, it is common for companies not to have all these elements available. As organizations' architecture evolves, they typically progress from relying on raw data to employing ad hoc analysis, followed by more advanced descriptive and predictive modeling, and ultimately optimization. The more robust the exploration of data, the greater the insights that can be generated, which in turn amplifies the impact of data-driven decisions on Return on Investment (ROI) (Cokins, 2004).

2.3.2 Data Visualization

As mentioned above, one of the ways users access information is through data visualization tools. In general, visualization refers to the process of constructing a concrete, visually perceivable mental image through the integration of visual elements and variables, including color and spatial positioning. Data visualization, a specific subset of visualization, refers to the visual and interactive exploration as well as the graphical representation of data. Both research and practice highlight its role in the decision-making and information-seeking processes. This contribution occurs through reducing cognitive load and enhancing recall, while also providing a visual overview of complex datasets that facilitate the detection of patterns, relationships, trends, and anomalies, guiding attention to areas warranting further investigation. Moreover, visualization leverages the human visual system to obtain implicit understanding, sometimes referred to as intuition (Zheng, 2017).

A dashboard display is a common form of data visualization, typically composed of other visual elements such as charts, tables, layout and formatting components, as well as interactive controls for user engagement, including command buttons and navigational tools like menus and tabs (Zheng, 2017). To ensure that dashboards convey information through visualization effectively and efficiently, so that perceived data quantities and relationships accurately reflect the actual data and information is communicated in the minimum amount of time, displays should be designed appropriately (Eckerson, 2011; Yigitbasioglu and Velcu, 2012). Some recommendations toward this aim are found in the literature.

Firstly, it is strongly recommended that a dashboard fit entirely on a single screen, as reflected in the definition of Few (2006): "A dashboard is a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance". Even so, the author clarifies that enabling users to navigate to separate screens or different instances of the same screen to access supplementary information is not inherently a poor design choice and can, in fact, be a valuable dashboard feature. However, when all relevant information must be viewed simultaneously to generate the intended insights, fragmenting it across multiple views undermines the advantages of a dashboard. Eckerson (2011) expresses a similar view, noting that a performance dashboard should not necessarily be limited to a single page but ought to provide a top-level summary of all relevant information so that users can monitor performance at a glance. Additionally, it should enable users to navigate with a single click to more detailed data, supporting, for example, drill-down exploration, or to related displays to examine the underlying causes of identified issues. In such cases, the use of visual alerts, such as distinctive colors or flashing indicators, can help users quickly identify when further analysis is required (Yigitbasioglu and Velcu, 2012).

Furthermore, it is important to use an intuitive layout and arrange the elements strategically. As shown in Figure D.1 of Appendix D, elements in the top-left quadrant of the screen typically receive the most attention, while those in the bottom-right receive the least. The center can also serve as an emphasized point, although it is rarely used because it reduces the space available for other items (Eckerson, 2011; Few, 2006).

Another key goal in the visual design process is to maximize data ink, or more precisely, data pixels. This means that, across the entire dashboard, pixels not used to display data, excluding a blank background, should be de-emphasized and minimized to a reasonable level (Few, 2006).

Regarding the quantity of data displayed, it is also important to be careful, as it was identified an inverted-U relationship between the amount of information provided and the accuracy of decision-making. This relationship suggests that there is an optimal level of information in reports that leads to the highest decision accuracy, whereas both an excess and a shortage of information tend to negatively affect it (Yigitbasioglu and Velcu, 2012).

As a dashboard generally presents a variety of data, it incorporates different elements such as charts, text, icons, and images. The selection of the most suitable components for presentation depends on factors such as the data type, the purpose of the message, and the audience's preferences. However, some considerations should be taken into account independently of these factors. For example, bar charts are preferable to pie charts for part-to-whole relationships, since values encoded by bar length are easier to compare than those encoded by slice areas or angles. Another type of chart that should be avoided, given their difficulty of interpretation, are area and radar charts. Apart from these, stacked charts, line charts, box plots, scatter plots, spatial maps, tree maps, and sparklines are also possibilities (Eckerson, 2011; Few, 2006).

Although following these types of recommendations is important, the process of design displays is challenging, and no single form of representation is always superior. Therefore, a dashboard display is never truly finished (Eckerson, 2011).

2.3.3 BI Platforms

With the growth of data visualization as one of the driving forces in the BI industry, different visualization-driven tools have emerged, particularly those aligned with the movement toward self-service BI. This approach emphasizes empowering users by providing platforms that support access to data, without relying heavily on the IT department (Zheng, 2017).

The Gartner Magic Quadrant for Analytics and BI platforms is a market research tool that provides a visual representation of the competitive positioning of leading technology providers in this area. For this reason, it categorizes vendors as leaders, challengers, visionaries, or niche players, based on their completeness of vision and ability to execute (Gartner, 2025). In 2025, as shown in Figure 2.2, Microsoft was positioned as a leader, achieving the highest placement among all vendors in this category, including Tableau, Qlik, and Google (Ganeshan et al., 2025; Manis, 2025).

Power BI is a cloud-based platform that enables the extraction and integration of multiple data sources, as well as data transformation. Through formulas and Data Analysis Expressions (DAX), along with a wide range of visualization features, it enables the creation of dashboards and reports (Gonçalves et al., 2023). Gartner's 2025 report highlighted the role of Copilot for Power BI, which provides intelligent assistance and boosts productivity. Nonetheless, it also identified key limitations, such as rising subscriptions (Ganeshan et al., 2025).

Figure 2.2: Magic Quadrant for Analytics and BI platforms, 2025. Source: Ganeshan et al. (2025)

2.4 Summary

After completing this literature review, it is possible to draw some conclusions regarding the research questions previously defined in Section 1.3.

With respect to Question 1, the explored literature emphasizes the importance of aligning performance measures with the company's strategy and ensuring that they constitute a balanced set, reflecting both different organizational perspectives and the temporal dimension. Moreover, it is important to adopt a structured approach when selecting performance measures. For this purpose, there are methodologies that place greater emphasis on the selection of perspectives to be evaluated, such as the BSC and the Performance Prism, as well as approaches that are more step-based, like the Winning KPIs. Both can be applied in a complementary manner. Beyond these, the literature emphasizes specific characteristics and desirable attributes designed to guide the formulation of the selected measures, as exemplified in the Performance Measure Record Sheet.

Regarding Question 2, the identification of the data to be collected should be derived from the previously established metrics. Then, the existence of an interconnected set of elements — including data sources, ETL process, and a data warehouse — forming a BI architecture facilitates the collection, preparation, and storage of the data. Furthermore, the use of BI platforms, such as Power BI, also provides a practical means of supporting these steps.

In response to Question 3, the literature emphasizes that particular attention should be given to dashboard design, as it directly affects proper use. Accordingly, it is important to define a top-level display with possibilities for further exploration, select a layout that emphasizes the information while presenting it in an appropriate quantity, arrange elements strategically, and choose visual components, such as graphs and tables, based on the presentation context. In terms of tools, Power BI has been highlighted as one of the most widely recognized solutions for implementing these best practices.

Chapter 3

Problem Statement

Before implementing a solution aligned with the company's needs, it is essential to develop an understanding of its context, which is addressed in the first part of this chapter. The subsequent section outlines the existing problems and assesses two possible solutions. Then, the chapter concludes with a summary highlighting the main aspects examined.

3.1 Company Contextualization

To understand the context in which the company operates, this section proceeds from a macro-level analysis, focusing on the company's relationships with other organizations, to a more specific exploration of its core process: production.

3.1.1 Value System

As previously introduced, Company X, managed by Mecwide, is an off-site manufacturing joint venture focused on the prefabrication of chilled water piping systems for data centers. Although the company is exclusively responsible for the manufacturing phase, its operations are embedded within a broader value system, involving various stakeholders and interdependent processes.

This sequence of activities begins with Partner A, one of the joint venture members, who leads the construction management of the data centers, defining the technical and functional requirements of the projects. Subsequently, based on that information, an external company dedicated to integrated engineering services through digital construction develops the three-dimensional models along with the supporting documentation, which serve as the foundation for the subsequent phases. Then, Partner B supplies the accessories required for the production process — such as couplings, elbows, valves, and tees — which takes place on the shop floor of Company X. Once the manufacturing process is completed, the final components are shipped to the site, where they are installed by Mecwide Nordics, a company also owned by Mecwide.

Typically, the data center construction project is organized into distinct areas. Therefore, each project, internally also referred to as a work order, is divided into sub-orders known as sequences, each corresponding to a specific area of the data center. As a result, the entire workflow from the definition of engineering specifications to the final installation is systematically repeated for each individual sequence within the project.

3.1.2 Internal Processes

To better understand the internal dynamics of Company X, its main processes are classified into three major categories: management, core, and support processes, following the classification presented by Leite and Faria (2024).

Regarding management processes, on the one hand, strategic management is conducted at the corporate level and includes, for example, the definition of strategic goals and the annual budget. Operational management, on the other hand, is the responsibility of the plant manager, who oversees, in general, all factory activities. These include production planning, scheduling, and execution, as well as financial monitoring.

Considering the core processes, production is the central activity through which the company creates value, as it directly responds to customer demand. Given its relevance, this process will be explored in greater detail in the next section. Other processes typically considered core, such as product development, are not directly carried out by Company X. As previously mentioned, the entire project modeling and design phase is externally managed.

Finally, support processes are largely executed by Mecwide's central structure. These include processes in the areas of finance, Human Resources (HR), legal affairs, IT, Integrated Management System (IMS), and Safety, Health, and Environment (SHE).

3.1.2.1 Production Process

To facilitate production, transport, and on-site installation, the piping systems of the data center, in addition to being divided into sequences, as previously mentioned, are further broken down into spools during the modeling phase. Spools are defined as preassembled units consisting of pipe segments and accessories, as illustrated in Figure 3.1.

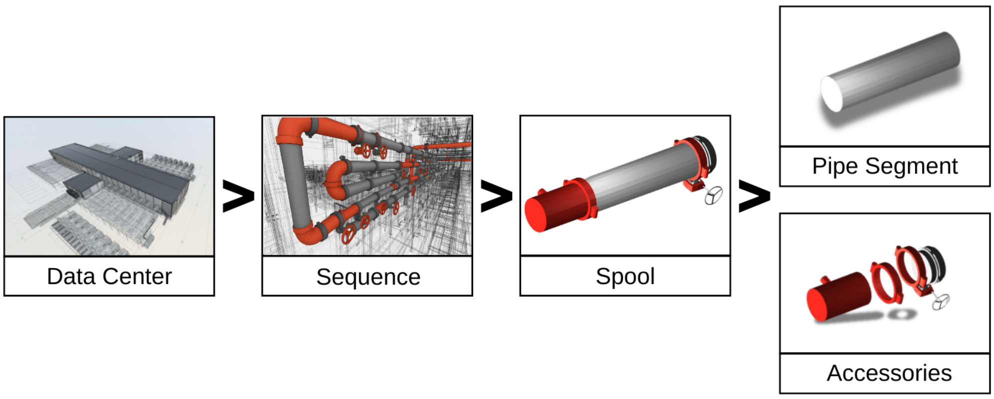

Figure 3.1: Components of the data center piping system

To manufacture these elements, the production process in Company X is carried out across two identical lines, each comprising four stations that support five main operations: cutting, grooving, hole cutting, assembly, and packing. Apart from these operations, which are performed internally with one operator per station, there is one outsourced operation: painting.

Regarding the workflow, summarized in Figure E.1 and illustrated with the images in Figure E.2 of Appendix E, it begins at the cut station. At this stage, the operator receives the pipe cut list generated by the SmartCut online calculator (an example is shown in Figure E.3). This list specifies the segments to be cut from each raw pipe in order to minimize material waste. After that, the cutting operation is performed with an automatic saw, and each resulting segment of the raw pipe is labeled with a unique identification number before proceeding to the next step. At the groove station, a circumferential groove is created at the end of the pipe segment using a roll groove machine, typically to enable connection with another pipe segment or accessories. Then, the assembly station comprises two main operations: hole cutting and assembly. However, these do not occur sequentially. After the hole-cutting operation, performed by a drilling machine, the segments are sent for painting. Once the segments return, the assembly operation is performed manually, combining pipe parts and accessories into spools. Lastly, these units are packed and placed on pallets in preparation for shipment.

As each spool has specific characteristics and is almost unique, it may not pass through all operations. Generally, spools containing pipe segments must go through the cut station and may subsequently require grooving, hole cutting, painting, and assembly operations, depending on the design requirements. In contrast, spools composed solely of accessories are subjected to assembly when required. Regardless of their components, all spools undergo packing. Furthermore, most operations are both preceded and followed by an inspection performed by the operator assigned to that station.

All the steps mentioned are supported and tracked by the Manufacturing Execution System (MES) used by the company, which will be explored in the Section 3.2.1. Apart from the cut list, this system enables the execution of operations in a largely paperless environment.

3.2 Existing Problems

During the initial months of Company X's operations, shop floor activities were managed in an ad hoc manner by the plant manager, with decisions often based on personal judgment. Subsequently, some non-systematic and simple performance analyses were carried out in Microsoft Excel as needed, such as calculating the number of operations performed, the total hours worked, or the quantity of pipe consumed.

However, as the level of activity increased, the limitations of this approach became evident, with manual analyses proving less viable, as these processes had turned progressively more time-consuming due to the growing volume of data and the number of factors that had to be considered. In addition, other types of analyses were necessary, such as verifying whether the production schedule was being followed in order to anticipate potential delivery constraints. Similarly, there was no systematic comparison between the estimated and the actual resources consumed, both financial and non-financial.

This need for a solution was further reinforced by the elements of the executive level, which began requesting detailed insights from the plant manager to be presented during meetings and used to support decisions.

In response to these challenges, the potential use of the company's MES dashboards as a supporting solution was initially analyzed at the beginning of this project, since their functionalities had not yet been fully explored. To evaluate this tool's potential and the data it provides, both the production module of the MES, used by operators on the shop floor, and the office module, intended for the plant manager's use, were explored. The outcomes of this assessment were subsequently presented to the plant manager and are summarized in the following section.

3.2.1 Analysis of the Manufacturing Execution System

The MES of Company X, developed and maintained by Partner B, is built on the Mendix low-code platform and operates within its cloud infrastructure, being connected to three external systems. Firstly, it has endpoints tied to Revit and PrimeLite software, which are used by an external company for the modeling process and the management of the projects, enabling the automatic transfer of construction data, including the Bill of Materials (BOM) and associated drawings for each spool, organized by project and sequence. Additionally, the MES is intended to communicate with the company's ERP system. Although this integration is still under development, it is designed to enable the flow of production-related data from the MES to the ERP through an Application Programming Interface (API).

From a user perspective, the MES is structured around two main modules: production and office. In the former, each workstation has a dedicated interface. The operator begins by selecting the project and sequence, after which a dashboard displays the quantities and time for both completed and remaining tasks, as shown in Figure F.1 of Appendix F. After reviewing this information, the operator selects the task to be processed, which automatically triggers time tracking. At this stage, the operator is generally instructed to perform a pre-operation inspection, with defined parameters to be assessed and the option to record the results of this inspection in the system. If approved, the workflow continues to the operation itself, where the required steps are displayed, as illustrated in Figure F.2. The operator also has the option to view a three-dimensional drawing of the spool in production. To finish the operation, the operator performs a post-operation inspection similar to the previous one. If approved, the time recording ends. If an operation fails, a record is created in the system, which is later analyzed by the team leader and may result in either rework or scrapping of the component. Downtime and material handling events can also be registered through the system.

The office module includes two main areas: operations and quality. Additionally, a scheduling section is available, although it is currently inactive. Within the operations area, the user can access production time records (run time and downtime), as well as consult the raw pipe and spool master sections, which allow tracking the status of raw pipe segments and individual spools, respectively.

A truck loading section is also available, providing records of shipments. In the quality area, users can review the detailed inspection results and records of nonconformities. All the aforementioned information is displayed in tabular form, as shown in the example of Figure F.3.

Moreover, it is possible to select a specific project and sequence and have access to two dashboard displays. The first, represented in Figure F.4, shows the number of tasks completed relative to the total for each operation, along with the hours consumed, budgeted, and remaining, as well as the man-hours per spool (budgeted and actual). The second provides similar information but breaks down each operation by size and adds the calculation of efficiency, as illustrated in Figure F.5.

3.2.1.1 Conclusions

From this analysis, different limitations were identified. Firstly, only a subset of the data is presented in a consolidated format through performance measures or charts, while the remaining information is stored in detailed tables. Secondly, the consolidated interfaces allow results to be viewed only by sequence within a project, with no possibility of analyzing all sequences of a project together or conducting an assessment at the multi-project level. In addition, there was some disagreement about the calculation method of the results, for example, the efficiency measure and the fact that quantities are displayed in units rather than in total inches, which would be more appropriate.

Furthermore, even if existing calculations were revised and new performance measures were developed from the remaining non-aggregated data, the information would still be insufficient to provide the level of detail required by the plant manager. For instance, one request made was to incorporate a measure comparing actual production with the scheduled production defined in a separate tool. Consequently, there would be a need to incorporate data from other sources to enable the development of additional measures.

Given these limitations, another tool was necessary. Therefore, the development of a BI-based performance dashboard from scratch was proposed to provide a tailored solution aligned with the company's needs, enabling closer monitoring and analysis of its activities and, consequently, more informed decision-making.

Before moving on to its creation, it was important to understand Mecwide's experience in the development of this type of project, as well as the usual ways of conducting them, the existing technological support, and whether these factors were favorable to the development of this type of solution. To this end, a readiness analysis was conducted, and the main conclusions are presented in the following section.

3.2.2 Assessment of Readiness for Performance Dashboards Development

As part of the readiness assessment, semi-structured interviews were conducted with Mecwide's head of Corporate Reporting & Information, given their expertise in the development of such projects, and with the manager of the IT Software Department, to clarify the technological architecture.

To ensure guidance and address relevant topics, a set of open and closed-ended questions was prepared in advance, as presented in Table G.2 of Appendix G. The results of the closed-ended questions are summarized in Figure G.1, using a Likert-type scale in which one corresponded to poor, two to fair, three to good, four to very good, and five to excellent. These questions were adapted from evaluation criteria previously defined by other authors for similar purposes, which are presented in Table G.1.

3.2.2.1 General aspects

This analysis allowed to understand that the company fosters a management culture based on measurement, recognizing that performance related information should be employed to provide an understanding of the organization's current status and to support decisions on where it should go and how to get there. Moreover, the need to share performance results with partners is even more common.

In line with these principles, the company initially had focused its performance analyses on the financial dimension. However, given the limitations of this approach, it implemented the BSC in 2013, which has remained in use to the present day. Throughout its development and subsequent updates, efforts have been made to ensure alignment between the selected performance measures and the company's strategy, which has also been assessed as well structured, clear, and coherent. Moreover, a factor that has contributed to the success of this tool is the strong commitment of the executive committee, which has been involved both in its development and in its use. In fact, their engagement extends beyond the quarterly meetings dedicated to monitoring the BSC indicators, which also include department heads and managers (middle management), to the regular use of this and other performance dashboards to track performance.

Regarding the support of middle management in the use of performance dashboards, although it is not as significant as that of the executive committee, it has been increasing. One way to promote this engagement was to assign them responsibility for specific BSC indicators. Thus, they not only contribute to defining these measures but are also accountable for taking action. Furthermore, acknowledging the importance of grounding their decisions in data, they have also begun requesting the development of additional dashboards tailored to the needs of their respective departments or units. The current portfolio of dashboards includes, in addition to the BSC, procurement, financial, commercial, and working hours dashboards, with others under development for the HR and IMS-SHE departments. There are also managers who prefer to conduct data analyses in a less structured manner, using solutions they have developed themselves.

Considering the process of creating performance dashboards, it generally involves the tool requester and the BI team, which is responsible for providing support in data collection, transformation, dashboard display development, and user manual creation. As such, there is no trained team responsible for defining the indicators. Instead, these are defined by the requester, who specifies their description, calculation method, data source, and applicable filters. A drawing of the desired interface is also typically provided. Although there is no dedicated team for defining the indicators, some guidance is given to ensure that the selected indicators are relevant, at least somewhat aligned with the overall strategy, and supported by viable data sources. Some help is also given on the proposed displays to ensure they follow certain principles considered important, such as selecting chart types that are appropriate for the intended purpose.

In the future, given the growing demands of these projects, it is anticipated that a dedicated team will be required to oversee the entire process, from collaborating with the dashboard requester to defining the indicators in a more structured manner, designing the dashboard prototypes, and coordinating with the BI technical development team to ensure a more controlled and consistent approach.

After the dashboards are created, there is currently no established schedule for their review, including the type of metrics, formulas, and displays, with updates being made only when necessary. Targets, although not defined for all indicators, are typically updated on an annual basis.

3.2.2.2 BI Architecture

In relation to the BI architecture, the interviewees indicated that continuous improvement efforts have been undertaken to ensure its ongoing enhancement, and it can currently be assessed as generally "good". When compared with the BI architecture model presented in Figure C.1 of Appendix C, Mecwide currently has implemented elements in all layers.

Regarding the first layer, the primary data source is the company's ERP system, based on Sage software. Additional sources are internally developed applications, such as Fleet Control and the Holidays application, along with flat files stored on SharePoint. After extraction, data transformation and cleaning are performed through predefined rules implemented in Python and PHP scripts, which allow, for example, renaming columns and creating new tables with data from different sources. Then, the data are loaded into the data warehouse, generally once a day, where it is organized into fact and dimension tables. At present, there are no ODS, data marts, or OLAP cubes.

In the user layer, data can be consulted by querying, for example, through Power Query in Microsoft Excel. However, most information is accessed via dashboard displays, which are primarily developed in Qlik but also in Power BI. Note that not all data used for the development of these tools comes from the data warehouse. In some cases, additional information is required and is extracted directly from the source, being then transformed within the BI platform. After the dashboards are developed and published, their data are automatically updated according to the required frequency. In addition, users can access data through static reports generated from the dashboards, using the NPrinting reporting platform for Qlik and Power Automate for Power BI. To date, more advanced solutions such as data mining have not been applied, with the results instead being presented primarily in a descriptive manner.

With respect to the metadata layer, this dimension is still in the initial phase of development. Recently, for example, all tables in the data warehouse were mapped, and for each column, the data type, maximum character length, and description were documented. This type of initiative is expected to help address certain issues related to the quality and quantity of data, which were assessed as "good". However, this classification is somewhat ambiguous, as it depends on the type of data. For instance, financial data are considered excellent, whereas other categories, such as HR related data, require improvement.

3.3 Summary

Given the company's positioning within its value system, it is evident that the interconnection among all stakeholders requires a high level of coordination across processes and digital systems. Consequently, incorrect decisions can still have a major impact. Furthermore, the different characteristics of the products manufactured, often varying from spool to spool, add complexity and demand a higher level of detail to be considered, compared to standardized products.

These aspects, together with the increased level of operations, the absence of established monitoring and analysis, and the recognition by the superiors of the limitations of current procedures, underscore the importance of implementing a support solution through the development of a BI-based performance dashboard.

Another positive factor supporting the development of this project is that the readiness assessment indicated that Mecwide has prior knowledge of this type of initiative and maintains an established BI architecture, which is favorable to transforming data into actionable information. However, the processes for defining performance measures and designing dashboards appear to be less clearly defined.

This project, therefore, seeks to explore practices that go beyond the company's commonly used procedures, with the aim of developing the required performance dashboard in a more structured manner, both in terms of defining the indicators and in developing the dashboard itself. The following chapter outlines the steps involved to achieve these objectives.

Chapter 4

Solution Development

The present chapter outlines the steps involved in developing the proposed performance dashboard. Following a structure similar to the practical execution process, it is organized into three main phases. The first addresses the selection and definition of performance measures, the second focuses on data processing, from collection to preparation for analysis, and the third describes the creation of the dashboard displays. Finally, the chapter concludes with a summary that highlights how the development process addressed the research questions within this specific context.

4.1 Phase 1: Selection and Definition of Performance Measures

To identify the performance measures to be displayed on the dashboard, a different approach was used instead of relying on the company's usual process, in which the plant manager would define the indicators. Moreover, it was decided to proceed in a way that goes beyond simply collecting requirements and defining indicators based on them.

For this purpose, the phase began with the identification of the CSFs (previously introduced as Critical Success Factors), which are defined by Parmenter (2020) in the Winning KPIs methodology as "operational issues or aspects that need to be done well day-in and day-out by the staff in the organization". In this study, however, these aspects were not defined as requiring daily execution; rather, they were considered factors that need to be carried out regularly either by operators or the plant manager. To ensure the relevance of these choices, this process was conducted in alignment with the company's strategy.

Following this step, the performance measures were selected for each CSFs and then defined. To describe each indicator with appropriate detail at this stage, the elements of the Performance Measure Record Sheet proposed by Neely et al. (1997) were used, with additional aspects added to complement them. The next sections outline each of these steps in greater detail.

4.1.1 Identification of the Critical Success Factors

This first step was carried out in a meeting attended by five members of the organization: two representatives of Mecwide's executive committee with deeper knowledge, involvement, and accountability for Company X's activities; the plant manager, as the primary user of the performance dashboard; and two other elements from the areas of Corporate Reporting & Information and Planning & Operations Control, who provided oversight and guidance throughout the project.

The meeting began with an explanation of the methodology to be applied for selecting and defining the performance measures. Subsequently, one of the executive committee members presented Company X's strategy, from which the following aspects were highlighted:

- **Mission:** To prefabricate components of water piping systems for data centers.
- **Vision:** To be a reference in providing these solutions within the growing data center construction industry.
- **Values:** To be guided by the principles of excellence, safety, and respect for employees, partners, and the environment.

Moreover, in alignment with these aspects, the company's three main strategic goals were summarized as follows:

- **Be faster:** Contribute to reducing time to market in data center construction.
- **Be better:** Provide components that foster customer satisfaction and are produced under conditions consistent with the company's values.
- **Be cheaper:** Support the delivery of more economical solutions for the construction of data centers.

Even though these three characteristics are generally achieved through the application of off-site construction, as compared to a purely on-site approach, as mentioned in the introductory chapter, they may not be realized if careful management of manufacturing activities is lacking. Furthermore, these goals are intended to ensure that Company X stands out among other companies that manufacture similar components in controlled environments.

Building on this foundation, the second part of the meeting focused on identifying the CSFs for each strategic goal, to determine what needs to be done regularly to achieve these goals.

Regarding the first goal, the main CSF was defined as the company's ability to deliver all sequences of projects in full and on time. In fact, the deadlines set by the client are already tight and are often affected by external delays in processes preceding production, which makes timely delivery particularly challenging. For this reason, this factor must be closely monitored.

Considering the objective of being better, three CSFs were identified. First, it is essential to guarantee quality in internal operations by carefully controlling their outputs. Second, creating a context in which the principles of SHE responsibility are embedded in daily routines is also fundamental. Third, it is necessary to ensure customer satisfaction, not only through the products themselves but also through accompanying interactions and support.

For the objective of being cheaper and delivering more affordable solutions to clients, the company focused on optimizing its operations. Since budget execution is already aligned with this concern, the first CSF associated with this objective is to address budget deviations in a timely manner. Furthermore, the impact of costs that affect the solutions delivered can also be reduced through the distribution of fixed costs, particularly those related to manpower, across a larger sales volume. In this context, the use of available capacity emerges as the second CSF aligned with this strategic objective.

Following the identification of these six CSFs, the project progressed to the step of selecting performance measures, as detailed in the subsequent section. Since these tools are designed to evaluate the extent to which the CSFs are being implemented, it was necessary to ensure the establishment of a clear and consistent alignment between the two.

4.1.2 Selection of Performance Measures

This step began with the preparation of a list of suggested performance measures for each CSF, intended to facilitate their subsequent selection in a collaborative manner.

To this end, an initial collection of approximately 180 indicators used in manufacturing contexts was conducted. Subsequently, during their analysis, duplicate and closely related measures were eliminated, and the remainder were examined in relation to the defined CSFs. Performance measures demonstrating an association were allocated accordingly, whereas those with no apparent link to any CSF were excluded. The outcome of this analysis led to the development of the supporting list presented in Table H.1 of Appendix H, and summarized in Table 4.1.

Table 4.1: Collected performance measures associated with each CSF

CSF	Performance Measure
Deliver in full and on time	On-Time, In-Full (OTIF)
	Schedule attainment
	Hours spent versus total planned
Guarantee quality in internal operations	Quality ratio
	Scrap ratio
	Actual to planned scrap ratio
	Rework ratio
	First time pass yield
Incorporate SHE principles into daily routines	Greenhouse gas emissions
	Energy consumption
	Water and fuel consumption
	Quantity of waste
	Number of SHE incidents
	Total Recordable Incident Rate (TRIR)
	Lost Time Injury Frequency Rate (LTIFR)
Ensure customer satisfaction	Customer complaint rate
	Customer satisfaction index
Address budget deviations	Deviation from the project budget
	Revenue versus costs
Use the available capacity	Worker efficiency

Then, in sessions attended by the same participants from the first meeting, with the exception of the executive committee representative, the proposed performance measures for each CSF were analyzed. It should be noted that these meetings did not aim to define all aspects of the metrics, but rather to focus on their selection, with the intention of conducting a more detailed exploration of each chosen metric at a later stage. Thus, during this analysis, three main decisions were made:

- **Acceptance or rejection of proposed measures:** Some measures were accepted as initially proposed or with slight adjustments, while others were excluded as non-priorities.
- **Introduction of new measures:** Additional metrics were suggested in this meeting by the user to extend the analysis in the context of Company X.
- **Adjustment to align with existing indicators:** Certain measures were either adapted or newly introduced to align with equivalent metrics already implemented in other measurement contexts within Mecwide. This decision is consistent with the "standardized" characteristic of effective performance measures identified by Eckerson (2011) and presented in Table 2.1 of Section 2.2, which highlights the importance of applying consistent measurement choices across the organization.

With the aim of exploring each decision in greater detail, the following section presents the rationale behind the selection of the performance measures.

4.1.2.1 Analysis of the proposed performance measures

First, considering the "Deliver in full and on time" CSF, the OTIF performance measure was accepted as a simple means of assessing the percentage of sequences delivered on the agreed date with the correct quantities.

Furthermore, it was recognized that, beyond monitoring this indicator, it is also important to examine the reasons for delivery failures that contribute to its low performance. Internally, a potentially relevant factor in this analysis is the degree of compliance with the production schedule. Indeed, when the schedule is not respected, it can compromise proper delivery. For this reason, the suggested schedule attainment indicator was also approved to compare actual production against the previously scheduled production output. This choice was reinforced by the fact that the plant manager had previously pointed it out as an important aspect to be evaluated.

In turn, to investigate the causes of schedule attainment problems, internal factors such as staff shortages, equipment unavailability, and operational inefficiencies can also be considered. To evaluate the latter aspect, the remaining proposed indicator for this CSF, which compares planned and actual operation times, was also selected. For the other potential causes of scheduling failures, no further indicators were introduced. Instead, they were regarded as aspects to be investigated further if no justification could be identified through the analysis of the proposed metrics.

Apart from these performance measures, the user also required the inclusion of a metric to assess the severity of shipment delays, calculated as the average number of days beyond the agreed delivery date.

To evaluate the implementation of the "Guarantee quality in internal operations" CSF, the indicator actual to planned scrap ratio was discarded, as no planned scrap quantity has yet been established. Similarly, first-time pass yield was not chosen as it was considered less relevant than the three selected metrics: quality, scrap, and rework ratio.

In the analysis of the proposed indicators for the "Incorporate SHE principles into daily routines" CSF, the importance of using measures already implemented by the SHE department of Mecwide was highlighted. Accordingly, it was proposed to include the Lost Time Frequency Rate (LTFR), Total Recordable Injury Frequency (TRIF), and Severity Rate (SR) for safety and health monitoring. The first two are similar to the TRIR and the LTIFR presented in Table 4.1, although they are based on different formulas. It was also decided to incorporate the number of days without safety incidents and to report them according to the categories of the Safety Pyramid model. An explanation of this framework and its categories is provided in Table H.9 of Appendix H.

To assess the sustainability dimension, the SHE department also uses some indicators, namely electricity, water, and fuel consumption. In the case of Company X, only the first was adopted. Moreover, it was requested to include two additional metrics related to the waste generated rate and the pipe waste ratio. In relation to the proposed greenhouse gas emissions indicator, it was decided that its monitoring is not appropriate at the moment.

Regarding the "Ensure customer satisfaction" CSF, both proposed indicators are already used by Mecwide. The customer satisfaction index, captured through a questionnaire sent to clients, is complemented by two additional metrics calculated from specific survey questions: the customer satisfaction index – SHE and the differentiation index. Therefore, these two measures will also be displayed on the dashboard. With respect to complaints, the company does not calculate a rate but instead records them in absolute terms. To ensure consistency, the same approach will be adopted in this project.

For the "Address budget deviations" CSF, it was decided to use the financial performance measures already applied by Mecwide, which are aligned with the elements of the Profit and Loss (P&L) statement. Accordingly, gross margin and Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA) were selected as the main indicators. For each of these, the variation against the corresponding budgeted values should then be calculated.

Lastly, for the CSF focused on "Use the available capacity", it was proposed to introduce a performance measure that compares the number of hours that workers actually spend executing work orders with the total available hours. Although this metric seems similar to the one proposed in Table 4.1 for this CSF, its goal is not to assess worker performance, but rather to evaluate how the available capacity in terms of manpower is being managed.

As there are two ways of tracking the hours workers actually spend on tasks – one manually reported by the plant manager in the ERP module designated as the Time Report System (TRS), and the other recorded through the MES by the operators – and since significant discrepancies were identified, a temporary measure was also required to compare the two types of records.

4.1.3 Definition of Performance Measures

After the selection process, each indicator was explored and defined in detail. To support this step, the Performance Measure Record Sheet proposed by Neely et al. (1997) and presented in Table

2.2 of Section 2.2 served as the basis. In addition to its elements, the unit of measurement and the applicable filters considered relevant for the analysis were also specified. Moreover, beyond considering the periodicity with which the measures should be recorded and reported, related in this case to data updating, the frequency of their analysis was also taken into account.

Thus, for each indicator, an appropriate name was initially defined to facilitate its analysis, together with the specification of its purpose, formula to be applied, the corresponding unit of measurement, and the relevant filters. Subsequently, the data sources required to feed these metrics were identified, which led to some modifications in the previous elements due to the structure and availability of the data, as illustrated by the OTIF measure. Regarding the identification of the person responsible for analyzing and acting on the measures, this role was assigned to the plant manager for all indicators. To help guide this process, some suggested actions to address the results were also identified.

Finally, with this information defined, the performance measures and their elements were presented in a meeting, where the targets, as well as the frequency of analysis, were established. Moreover, at this initial stage, the dashboard was set to refresh on a daily basis. However, the actual availability of updated information depends on the underlying data sources, which must be populated at a periodicity consistent with the defined frequency of the analysis. In cases where data collection and registration in sources is not automated, a responsible person was identified to ensure the timely entry of the information.

In Table 4.2, the final performance measures defined through this process are presented, together with the identification of the tables in the Appendix H where the detailed elements for each measure are provided.

Table 4.2: Selected performance measures associated with each CSF

CSF	**Performance Measure**	**Table**
Deliver in full and on time	OTIF	H.2
	Average days late	H.3
	Schedule attainment ratio	H.4
	Time efficiency ratio	H.5
Guarantee quality in internal operations	Quality ratio	H.6
	Scrap ratio	H.7
	Rework ratio	H.8
Incorporate SHE principles into daily routines	Number of safety incidents	H.9
	LTFR	H.10
	TRIF	H.11
	SR	H.12
	Days without accidents	H.13
	Electricity consumption rate	H.14
	Waste generated rate	H.15
	Pipe waste ratio	H.16
Ensure customer satisfaction	Customer satisfaction index	H.17
	Customer satisfaction index - SHE	H.18
	Differentiation index	H.19
	Customer complaints	H.20

(continued on next page)

CSF	Performance Measure	Table
Address budget deviations	Gross margin	H.21
	EBITDA	H.22
Use the available capacity	Workers utilization ratio	H.23
	MES versus TRS	H.24

Considering these performance measures, it is possible to verify their extent, as they cover different dimensions of the company, as well as their alignment with the company's strategy, having the potential not only to support the plant manager's decision-making, but also to do so in an effective way. However, they are almost entirely focused on past events, which can represent a point for improvement in the future by fostering more proactive management decisions.

4.2 Phase 2: Collection and Preparation of Data

After defining the performance measures to be incorporated into the performance dashboard, the project advanced to the second stage, in which the necessary data had to be collected and prepared.

To support these steps, as well as the subsequent phase focused on visualization, the BI platform selected was Microsoft Power BI. This option, which is aligned with market trends as highlighted in the Gartner Magic Quadrant in Figure 2.2 of Section 2.3.3, was chosen by the company due to its prior familiarity with the tool and the recognition that it is easier to explore than the alternative platform employed internally, Qlik. In the next sections, the main aspects employed in this phase of the project are explained, reflecting the contribution of using this tool.

4.2.1 Data Sources

During the definition of performance measures, the corresponding data sources had already been identified. These sources can be divided into two types: tables stored in Mecwide's data warehouse and Microsoft Excel spreadsheets available on SharePoint. While the former comprises data on customer surveys, claims, accidents, working hours, and financial records (excluding budget data), the latter consolidates information from the MES and the scheduling tool, as well as registers of energy consumption and waste generation.

At the beginning of this project, it was stated that incorporating MES data into the company ERP and subsequently into the data warehouse would enable automated retrieval, similar to the information already managed there. Nevertheless, the integration suffered successive delays, and to ensure the timely development of the performance dashboard, a temporary solution was adopted: manually exporting data from the MES and storing it in SharePoint. Once the integration is completed, the source will be migrated to warehouse tables, enabling fully automated extraction.

Regarding the data stored in spreadsheets, standardized templates were created to ensure consistent recording and to restrict entries to only the necessary information, as illustrated in Figure I.1 of Appendix I. Instead of granting the personnel responsible for data collection direct access to the SharePoint location where these files are stored, copies of the templates were distributed for that purpose. Thus, the staff must complete the file and submit it to a designated internal BI team email. Upon receipt of an email with the specified subject line, a Power Automate flow, such as the one represented in Figure I.2, is triggered, automatically updating the corresponding SharePoint file with the new data.

4.2.2 Implementation of the ETL Process

The extraction of data from the identified sources was carried out using Power Query in Power BI. Once obtained, the data were transformed to ensure an appropriate structure for the subsequent steps. It should be noted that the data from the data warehouse had already undergone an initial transformation before being loaded into this repository and are therefore generally in a more consistent format, requiring fewer adjustments than the data stored in SharePoint.

Thus, the transformations were executed in the Power Query editor and were implemented through the underlying M scripting language, which is the language behind the tool, either automatically generated by interface actions or manually written.

Among the transformations executed, these included removing duplicate rows as well as unnecessary columns and records, e.g., only data from 2024 onward was retained. Moreover, data types were adjusted to match the characteristics of each column, converting values into formats such as decimal number, integer number, date, date/time, text, or boolean.

Regarding data formats, some adjustments were required, such as removing unnecessary spaces and standardizing date values. For instance, date fields from MES records were converted to the "DD/MM/YYYY" format, and columns containing timestamps were adjusted to account for a five-hour offset in the original entries. It was also necessary to ensure that fields with the same name across different tables referred to the same concept. For example, while some tables contained a field labeled "diameter" that represented the nominal diameter, in others the same field referred to the outside diameter. To ensure consistency, all columns containing this attribute were transformed to the nominal value. Furthermore, the field names across the tables were harmonized to ensure consistency and to avoid cases where the same attribute appeared under different names.

Another transformation applied was the unpivoting of certain columns, transforming wide tables into a long format, which facilitated the analysis. For instance, in the table with the inspection records, the evaluated parameters, originally distributed across multiple columns, were consolidated into a single column, with the corresponding results recorded in a separate field.

In other situations, new columns were created using information from other fields within the same table, while in certain cases, single columns were split into multiple fields. For example, in some tables, the field "AX3", an identifier used for projects and other elements and required to filter records for a reporting unit (defined by the field "AX9", e.g., Company X has a unique "AX9" value), was missing. Given its importance, this field was created by combining information from other fields presented in the table, according to an existing rule.

Other columns were also added through merging tables, mostly using left outer joins, which keep all the records from the main table while adding any matching information from the others, but also inner and full outer joins, which allow either the retrieval of only the records with matches in both tables or the combination of all instances from the tables involved regardless of whether a match exists.

During this stage, new tables were created as well through the combination of rows of the existing ones. A specific case was the consolidation of the quantities executed across different operations, which were originally divided between two separate tables, into a single unified structure.

An overview of the main functions used in the transformations can be found in Table J.1 of Appendix J, while detailed examples of the steps applied to the customer satisfaction survey data and the inspection records are provided in Figures J.1 and J.2, respectively.

To finalize the ETL process, the tables were then loaded into the Power BI front-end interface, enabling the creation of the data model, which will be explained in the following section. Whenever data are refreshed, this entire ETL process is executed automatically.

4.2.3 Construction of the Data Model

At this stage, the relationships among the available tables were established in the Power BI model view. This step was important to integrate the data for subsequent measure calculations and the creation of visual elements, leading to the development of the data model illustrated in Figure 4.1.

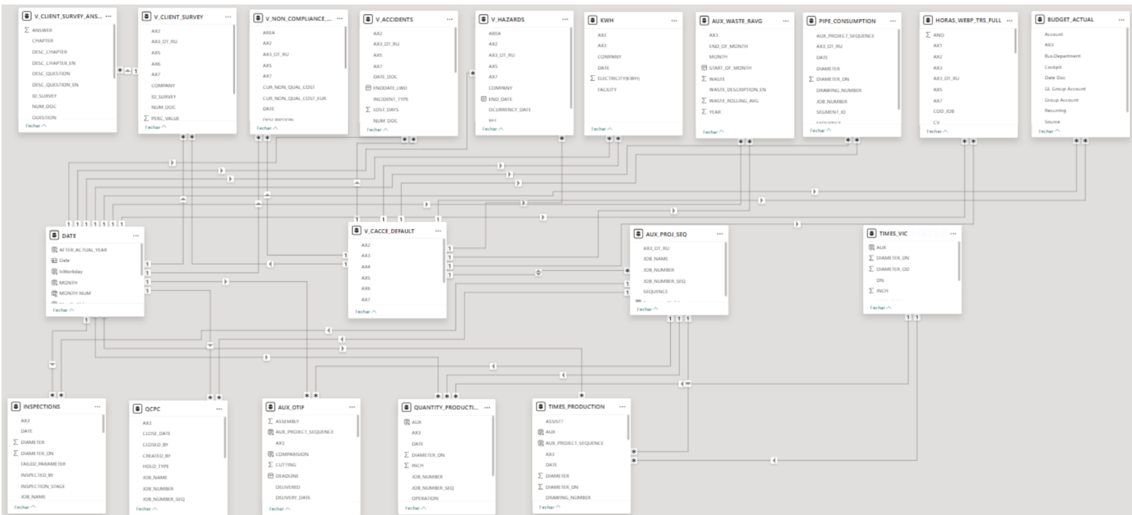

Figure 4.1: Data model of the performance dashboard

Apart from the tables loaded from Power Query, this model also comprises additional ones created with the DAX formula language to support data analysis. For example, one of the most relevant cases was the creation of the DATE table using the CALENDARAUTO function. It generated a single-column table containing a continuous sequence of dates derived from the data in the model, which was complemented with additional calculated columns such as month and year. Another instance is the BUDGET_ACTUAL table, which consolidates information from the two financial sources V_ACCOUNTING and BUDGET, thereby facilitating the calculation of metrics.

Regarding the content of the other interconnected tables, V_CLIENT_SURVEY_ANSWERS and V_CLIENT_SURVEY store information about customer satisfaction surveys. The former contains the answers to each survey question along with their respective weights, while the latter records general data such as project identification and survey submission date. The V_NON_COMPLIANCE table contains information about registered client claims.

With respect to the SHE dimension, the V_ACCIDENTS table has records of reported accidents, whereas V_HAZARDS documents situations with the potential to cause harm. In addition, the KWH, AUX_WASTE_RAVG, and PIPE_CONSUMPTION tables comprise data on electricity consumption, waste generated, and pipe usage, respectively.

Concerning the quality of internal operations, the INSPECTIONS table records assessment results, while the QCPC table captures Quality Control Process Charting (QCPC) records generated not only from inspection failures but also from other factors outside the production process that may affect quality (e.g., errors in spool drawings detected before production starts).

The AUX_OTIF table was created to facilitate the calculation of the OTIF indicator, containing information such as the total spools of the sequence, the quantity of spools shipped, and the planned and actual shipment dates. More directly related to the production process, QUANTITY_PRODUCTION_PA combines both produced and planned quantities. In turn, TIMES_PRODUCTION stores the durations of executed operations, while TIMES_VIC contains, for each operation and component diameter, the hour/inch execution rates used in the scheduling tool. Furthermore, the table HORAS_WEBP_TRS_FULL includes the records of working hours registered in this case in the ERP system.

Furthermore, the AUX_PROJ_SEQ table contains the project identification in the ERP ("AX3" column) and in the MES system ("JOB_NUMBER" column), since these differ, as well as information on the sequences of the different projects. Finally, V_CACCE_DEFAULT stores the analytical axes, which support the identification and filtering of data across different dimensions, such as cost center ("AX2"), project ("AX3"), site ("AX5"), business unit ("AX7"), and reporting unit ("AX9").

Concerning the relationships among these tables, all those shown at the top and bottom of the Figure 4.1 (except TIMES_VIC) are connected to the DATE table with a many-to-one cardinality and a single direction of the cross-filter. This configuration ensures that when a filter is applied to the DATE table, the related tables reflect the restriction. However, when filters are applied to the other tables, the effect is not propagated back to the DATE table.

Moreover, these tables exhibit another primary relationship. The tables at the top of the figure are connected to the V_CACCE_DEFAULT table through the field "AX3", also with a many-to-one, single-direction relationship. This means that each record in the former corresponds to a single value in the latter. Moreover, when filters are applied to V_CACCE_DEFAULT, the top tables are also restricted, but not vice versa. Likewise, the tables at the bottom of the figure are linked to the AUX_PROJ_SEQ table, in this case through a composite field consisting of project and sequence.

The V_CACCE_DEFAULT and AUX_PROJECT_SEQ tables are, in turn, connected through a one-to-many relationship based on the column "AX3". In this case, however, the cross-filter direction is bidirectional, meaning that both tables mutually influence each other when filters are applied.

In addition to these relationships, secondary one-to-many connections exist between the tables V_CLIENT_SURVEY and V_CLIENT_SURVEY_ANSWERS, using the field "NUM_DOC", which identifies the survey and links the questionnaires to their respective responses. Moreover, the TIMES_VIC table is connected to the QUANTITY_PRODUCTION_PA, TIMES_PRODUCTION tables through a composite attribute consisting of diameter and operation.

As shown in Figure K.1 of the Appendix K, the data model also includes additional tables that are not directly connected through relationships. This is because such direct connections were not required for the analysis. Nevertheless, these elements served as intermediate sources, for example, in the creation of the tables that form part of the relational model.

4.3 Phase 3: Creation of the dashboard displays

The final phase of the project execution focused on the development of the dashboard displays. In this context, it involved the design of prototypes, the calculation of performance measures based on the previously defined elements, the data prepared, and the user requirements, and, finally, the representation of the results through visual and interactive components. During these steps, best practices in data visualization were taken into account to enhance the effectiveness of the information conveyed.

4.3.1 Design of displays

Before the actual creation of the displays in Power BI, basic prototypes were designed in accordance with user requirements and by taking into account recommended practices in visualization. This allowed them to be validated and adjusted in advance, thereby reducing the need for future changes in later stages of execution.

One of the decisions in this process was related to the creation of a top-level display, aimed at consolidating the main performance measures to facilitate monitoring, as recommended by Few (2006) and Eckerson (2011). Moreover, to provide access to further information and to support more detailed analysis when required, additional pages accessible from this first one were also proposed.

Following these decisions, a layout was defined with the aim of being intuitive and consistent across all dashboard displays. As shown in Figure 4.2, the final proposal consisted of a left section with the company logo at the top and the filters below, a header section with space for the display title and navigation buttons, and a main content area occupying the remaining space.

The visual presentation of performance measures in the content area of the top-level display was influenced by some decisions taken at this stage. First, concerning the time frame, it was

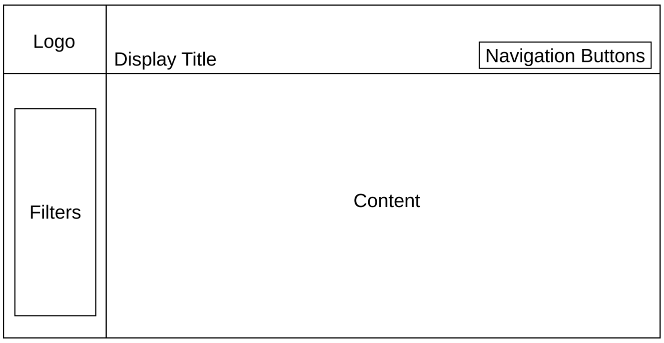

Figure 4.2: Layout of the dashboard displays

determined to present the indicators using a Year-to-Date (YTD) format. This means that, for each indicator, the cumulative value from the beginning of the year up to the month under analysis is displayed. Furthermore, to enhance the analysis, it was decided to show a comparison of this value with both the defined target and the value recorded for the same period in the previous year, referred to as Last-Year-to-Date (LYTD), by calculating the percentage variation between them, using the formula in Equation 4.1. Accordingly, the Reference Value in this formulation corresponds either to the defined target or to the LYTD value.

$$\text{Variation (\%)} = \frac{\text{Current Value} - \text{Reference Value}}{\text{Reference Value}} \times 100 \tag{4.1}$$

To complement this information and provide a better understanding of trends, a chart element was also proposed to illustrate the evolution of the values of each indicator over time and the respective target.

Later in the process, the need for an additional time frame was identified, allowing the indicators to be displayed in a Month-to-Date (MTD) format, meaning that it reports solely the values for the selected month. To avoid information overload, it was decided to provide the user with the option of selecting the desired time frame through a slicer while interacting with the dashboard. Consequently, when MTD is selected, not only does the indicator value change for the month selected, but the comparisons also shift. In this case, the monthly value is compared both with the defined target and with the corresponding value for the same month in the previous year under analysis. In addition, the chart no longer displays cumulative values but instead presents the monthly results.

To present all these elements in an organized and easily interpretable way on the screen, it was suggested to place them within a dedicated frame for each performance measure. Within this structure, the displayed results varied according to the selected time frame (YTD or MTD), as illustrated in Figure 4.3. To facilitate the interpretation of variations, distinctive colors were decided to be applied. Therefore, if the indicator performs worse than the comparative value, it is shown in red, and in green in the opposite situation.

In terms of the arrangement of the frames for each performance measure within the content area, it was proposed to group the indicators associated with the same CSF and, correspondingly,

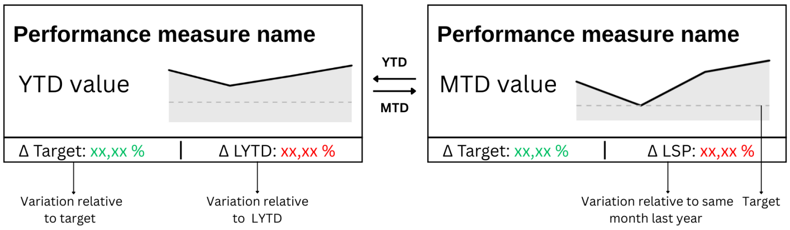

Figure 4.3: Schematic representation of performance measure frames with YTD (left) and MTD (right) time frame selections

with the respective strategic goal, to reinforce the user's awareness of how each indicator contributes to the achievement of those goals. Furthermore, considering the possibilities resulting from this initial organization and the number of elements to be positioned, the frames were arranged to enhance the visibility of the indicators requiring more frequent analysis. Whenever possible, they were placed on the left side and in the upper areas of the screen. Later, some elements were adjusted to better align their placement with user preferences.

The additional screens accessible from the main display were designed according to similar principles but targeted at complementary analytical needs, generally presenting information on indicators related to the same CSF. Thus, these pages were proposed to retain the main indicators presented on the top-level display, but with greater detail — by including more information in the graphical axis displays and the previous year's trend — while also incorporating the additional visual elements requested. For example, in the detailed view related to quality, ratios by operation were included, along with the absolute number of inspections resulting in approval, scrap, or rework, and the causes of failures.

Regarding the choice of visual and interactive elements, such as tables, charts, and filters, this is addressed in Section 4.3.3, following the explanation of measure calculations presented in the next section.

4.3.2 Calculation of Measures

In this step, the performance measures were calculated in Power BI using the DAX language, with the purpose of being subsequently applied in the dashboard visual elements. This process considered the formulas previously defined during the specification of the indicators, the data already prepared and structured in the data model, as well as the design requirements outlined in the previous section. Although each indicator is based on a unique formula, the specific visualization requirements led to the creation of at least seven distinct DAX measures per indicator. The objectives of these calculations are synthesized in the Table 4.3 with corresponding examples provided in the indicated figures of Appendix L.

Note that for each type of measure listed, the overall structure is almost preserved across all indicators. The main variation lies in the embedded calculation formula, which adapts to the logic of the corresponding performance measure, as illustrated in the example provided in Figure L.1 of Appendix L, for the measure one.

Table 4.3: List of the main types of calculated measures used in the dashboard

#	Measure	Description	Example
1	YTD / MTD value	Calculates the indicator's value over the selected period (YTD or MTD)	Figure L.2
2	YTD / MTD display	Formats the output of measure #1 for use in visual elements, returning either its value or "N/A" when the result is blank	Figure L.3
3	Target value	Retrieves the defined target of the performance measure for the selected year from the table with the target values	Figure L.4
4	Target variation	Derives the percentage variation between measure #1 and measure #3	Figure L.5
5	Previous year variation	Determines the percentage variation of measure #1 compared to the same period in the previous year	Figure L.6
6	YTD / MTD chart value	Computes the indicator in a format suitable for monthly charts	Figure L.7
7	Previous year chart value	Calculates the indicator value for the same period in the previous year in a format appropriate for monthly charts	Figure L.8

In the calculations carried out, different DAX functions were employed. In particular, the DATESYTD and DATESMTD functions were used to compute cumulative and monthly values, e.g., in measures one and six of Table 4.3, while SAMEPERIODLASTYEAR and DATEADD enabled access to values from equivalent periods in the previous year, which were particularly relevant for measures five and seven. Filtering functions such as CALCULATE made it possible to evaluate expressions in specific filter contexts, while LOOKUPVALUE was used to retrieve corresponding values from other tables, as in the case of the measure tree. Furthermore, logical functions, including IF and SWITCH, were also applied, with the latter allowing the behavior of each measure to be dynamically adapted according to the YTD/MTD slicer selection. Lastly, aggregate functions like AVERAGE, SUM, and COUNTROWS, together with mathematical functions such as DIVIDE, were included in almost every calculation.

4.3.3 Development of the displays

This step constituted the final milestone of the solution's development, where the outputs of the previous stages were integrated to construct the dashboard displays through which the end user can monitor and analyze results to support the decision-making process. For this purpose, different Power BI elements were employed to present the calculated measures, such as matrices, tables, and chart visuals.

Regarding the latter, specific types were employed. In the case of the top-level display, a line chart was used but styled to resemble a sparkline, presenting only a condensed view of the metric's trend over the months of the year, without a visible scale or legend, which are displayed only on mouse hover. For similar purposes in the detailed displays, these line charts were enriched, showing both scales on the axis as well as the corresponding legend. To present temporal variations, clustered column charts were also employed, e.g., to display results by month and by operation station, while 100% stacked bar graphs were used to illustrate part-to-whole relationships, namely to show how the month's shipments were divided into the categories "early", "on-time", and "late". For these graphs, with the months displayed on the x-axis, a dynamic behavior was implemented in relation to the date filters. Thus, when a specific month and year were selected, this axis displayed all months up to that point, together with their corresponding values (MTD or YTD), rather than showing only the value for the selected month.

Considering the other types of charts, a funnel chart was implemented to represent the Safety Pyramid in a format closer to its conventional presentation, displaying incidents by category. In addition, waterfall charts (also referred to as variance charts) were used to illustrate the variance between two variables, while tree maps were employed to visualize categorical data, for instance, the failed parameters in each type of inspection. Given the set of charts chosen, the adoption of less recommended chart types, such as pie charts, radar charts, and area charts, was avoided.

The drill-down feature was also explored, allowing users to click on a graph to access more specific information within the corresponding data hierarchy.

For the filters applied, drop-down style filters were chosen to allow the user to control the information displayed in the visuals, namely "Year" and "Month" linked to the corresponding fields of the DATE table, and "Project MES", "Project MW", and "Sequence" from the AUX_PROJ_SEQ table. Although the project filters correspond to the same entity, since project names differ between MES and the ERP, as previously mentioned, both were included. However, there is a correspondence between them. Once one project is selected in one filter, the other cannot be set to a different project simultaneously. A relationship also exists between these filters and the sequences, whereby selecting one of the former makes only the corresponding sequences available in the latter filter. Another aspect of the filters, as well as the MTD/YTD slicer, is that they are synchronized across displays to simplify the user experience, thereby keeping the selections active when navigating between pages. Date filters are included on all pages, whereas the remaining filters depend on the specific case.

In addition to the filters directly manipulated by users, others were applied at the visual level to restrict data to specific stations or to display the top-N elements. Furthermore, a page-level filter was implemented to ensure that only values related to Company X were considered. In this case, the "AX9" field from the V_CACCE_DEFAULT table was used with its unique company-specific value. In such situations, the user does not have the possibility to modify the filters during the use of the dashboard.

Alongside the MTD/YTD slicer, which adjusts the analysis period as previously described, it was necessary to include an additional slicer in some of the frames of the top-level display (Figure 4.3) to enable the user to vary the performance measure displayed within the same rectangle. To format the color of the percentage variation values in these frames, conditional formatting was applied using rule-based criteria, displaying values in green when better than the target and in red when worse.

Still in this phase, tooltip pages were created and associated with the visuals. For this purpose, the content of each tooltip was designed on a separate page and then linked to a given element in another, allowing users to access the additional information by hovering the cursor without leaving the current page. Bookmark elements were also employed to enable interactions within the same page. For instance, selecting a button allows certain elements to be displayed while others remain hidden, thereby preventing information overload while still supporting detailed analysis.

4.4 Summary

This chapter outlined the main steps involved in the creation of the performance dashboard, divided into three main phases. Although they were presented sequentially, some decisions made at later stages occasionally prompted refinements in earlier phases to ensure overall consistency and coherence, with the exploration presented here already incorporating those adjustments.

In doing so, this chapter also provides the basis for answering the research questions previously defined in Chapter 1, within this specific project. Regarding the first, the performance measures were selected in alignment with the aspects recognized as critical to achieve the strategic objectives, resulting in a set of indicators not only consistent with the company's strategy but also covering different dimensions such as operations, quality, SHE, customer, and financial aspects, with a perspective primarily focused on past-oriented performance. After that, each measure was defined in detail, considering attributes such as name, purpose, formula, unit of measurement, target, frequency of analysis, actions to address results, data source, and filters appropriate for analysis.

Considering the second question, the necessary data were obtained from sources either connected to the data warehouse or derived directly from Excel spreadsheets. Power Query was employed to extract and transform the data in order to facilitate subsequent steps. Subsequently, the resulting tables were loaded into Power BI, where a relational data model was developed to establish the required connections, considering either the cardinality and direction of the cross-filter in the established relationships.

Finally, in relation to the last research question, the creation of the dashboard displays within the same platform included the definition of basic prototypes for both the top-level and detailed displays, with an intuitive and consistent layout. The representation of the performance measures was influenced by the chosen time frame (YTD and MTD), the requirement for percentage comparison with the target, and the same period of the previous year. Together with the collected data and the formulas of the indicators, these elements guided the calculation of the measures using the DAX language. Subsequently, they were incorporated into different visual components such as tables, matrices, and graphs, with non-recommended chart types being avoided. The drill-down feature was also explored, as well as other interactive elements, including filters, slicers, tooltips, and bookmarks.

Chapter 5

Results

This chapter begins with the presentation of the performance dashboard developed in a structured and detailed manner. Accordingly, each of its displays is examined individually, describing not only its general content and how it relates through the incorporated visual and interactive elements, but also its alignment with the critical success aspects and the organizational strategy to foster support for effective decision-making. Subsequently, the results of this solution's assessment are presented, discussing both the strengths that validate its effectiveness and the limitations encountered, as well as practical suggestions for future improvements.

5.1 Presentation of the Performance Dashboard

The developed performance dashboard is divided into a top-level display and eight additional pages, which are presented in this section. For confidentiality reasons, some data have been modified and certain aspects have been omitted. With regard to the performance measures presented in the displays, a detailed explanation is not provided here, as they are already documented in the record sheets referenced in the Table 4.2 of Section 4.1.3.

5.1.1 Top-level Display

The top-level display, shown in Figure 5.1 and detailed in Figure M.1 of the Appendix M, focuses on providing an easy way to monitor the main performance measures by dividing them into three columns, each representing a strategic goal. Within each column, the placement of the performance measures is further influenced by the CSFs they are intended to monitor or to which they are related. Thus, this arrangement aims to provide users with a clearer perception of the linkage between performance measures, CSFs, and strategic goals, thereby enhancing the potential of the dashboard to support more effective decision-making.

Moreover, the performance measures with a weekly analysis frequency were positioned in the left and upper-middle areas of the display to enhance their visibility.

In terms of layout, the dashboard follows a structure similar to that defined in the design phase, which is consistently maintained across the remaining pages. The available filters and the

MTD/YTD slicer are positioned on the left. At the top, there are two types of interaction buttons. Those with a plus icon are placed next to each strategic goal, allowing users to open a drop-down menu listing the related pages, where the performance measures presented below can be explored in greater detail, as illustrated in Figure M.2.

In addition, the information button located in the upper-right corner opens an information panel, as shown in Figure M.3, which provides further details about each performance measure, including its description, formula, and unit of measurement. This panel also includes a button configured to open the dashboard manual in PDF format.

In relation to the content of the display, the main performance measures are presented within frames similar to those described in Section 4.3, each presenting the indicator value expressed in this case as YTD, given the time frame selected in the slicer, the percentage variation relative to the target, and to the LYTD value. In cases where no values are available, the element shows "N/A". Moreover, it includes a graphical representation of both the indicator and its target, with additional information displayed when the mouse cursor is hovered over. In some cases, the indicators related to the same CSF are placed within the same frame, making it possible to switch the view using the slicers inside. For example, in the case of the quality ratio, changing the selection allows users to display either the scrap ratio or the rework ratio.

Figure 5.1: Top-level display of the performance dashboard

Concerning the detail pages, these are explored in the following sections according to their related strategic goal.

5.1.2 Displays Aligned with the Goal "Be Faster"

In alignment with the strategic goal "Be Faster", three displays were developed to provide a more detailed view of the associated performance measures.

Firstly, the Shipments display, represented in Figure 5.2, provides additional information on the OTIF and average days late performance measures, detailed in the frames located on the top-left side. In addition, for the OTIF indicator, the shipments of sequences considered in its calculation are distributed across the categories "early", "on-time", and "late" in the Shipment status chart. By clicking on the plus icon button within this frame, users can also view this distribution in absolute numbers rather than percentages, as shown in Figure M.4 of the Appendix M. For the average days late indicator, the user can evaluate how much shipments deviated from the scheduled shipping date, whether ahead of or behind schedule, through the Deviation days chart. Furthermore, at the bottom, a detailed table presents the specifications of each shipment, including the project and sequence identifiers, the planned and actual shipment dates, the deviation, and the corresponding status. To facilitate interpretation, this information is accompanied by a color-coded element. Note that in this display, the MTD time frame is selected, with the chart elements reflecting these values.

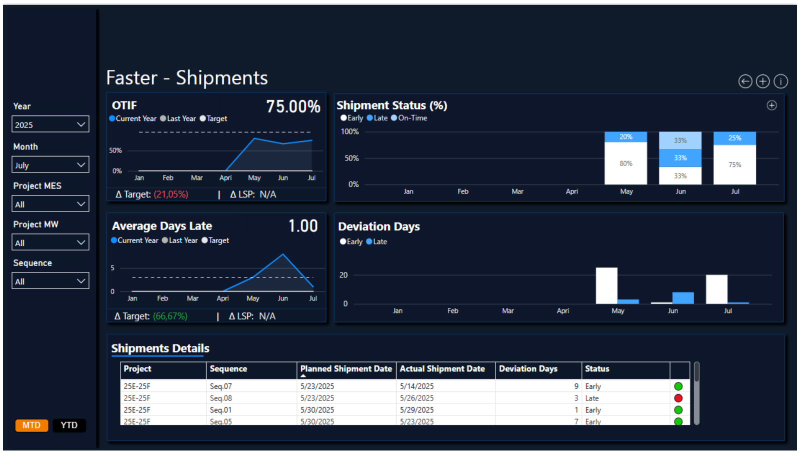

Figure 5.2: Performance dashboard display containing data on shipments

Secondly, the Schedule tracking page, illustrated in Figure 5.3, focuses on the exploration of the schedule attainment ratio. To this end, it allows the user to view this performance measure by operation over the months in the top-right corner. Moreover, it presents a comparison below between the planned and actual quantities produced (in inches) over time for each operation, which serves as the basis for the calculation of this indicator. For each operation, a more detailed daily tracking is also available, as exemplified in the table related to the hole-cutting operation.

The last page related to this strategic goal is the Time tracking display, presented in Figure 5.4, which also shows the time efficiency ratio by operation over time in the upper-right corner, with the option to display the hours spent on each operation by clicking the plus icon button. At the bottom of the page, the time spent for each operation is further detailed according to the executed component's main characteristic, the nominal diameter. Additionally, considering the time consumed and the quantities executed in inches, it is possible to calculate the hour/inch rate and compare it with the standard value used in the scheduling process.

5.1.3 Displays Aligned with the Goal "Be Better"

For the "Be Better" goal, there are also three associated displays. The first, depicted in Figure 5.5, is dedicated to the "Guarantee quality of internal operations" CSF. In addition to the main

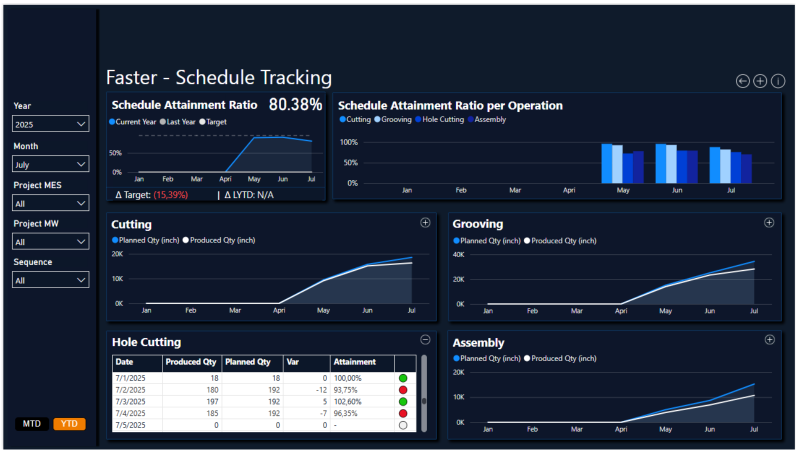

Figure 5.3: Performance dashboard display for analyzing the schedule attainment

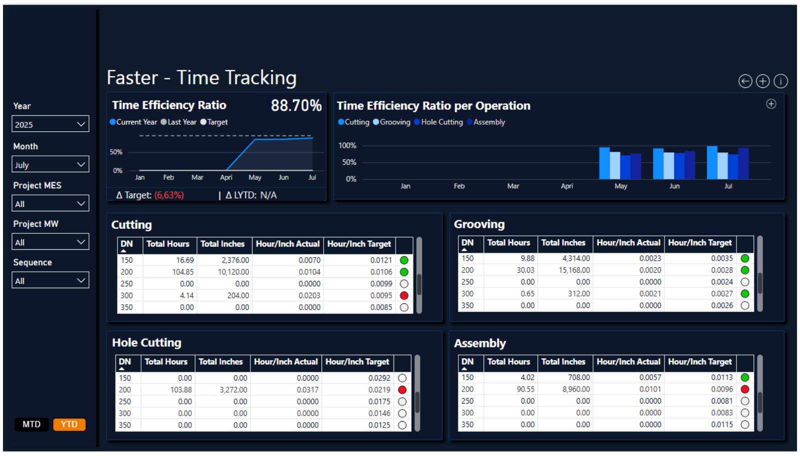

Figure 5.4: Performance dashboard display related to time tracking

performance measures, quality, scrap, and rework ratio, it also presents their values by related operation and stage of execution of the inspection (pre or post-operation).

Moreover, it provides access to the quantities of inspections that resulted in approval, rework, or scrap, as shown in the case of rework when clicking on the plus button. In the third column of the screen, the tree map allows the user to understand, for each type of inspection, which assessed parameters failed, and by drilling down into the map, it also provides the related causes, as shown in Figure M.5 of the Appendix M. Below this map, the causes of the QCPC records are also presented. These records are generated not only when an inspection fails, but also due to other factors that can affect the quality of future operations, such as previously detected drawing errors. By hovering over the info button, a tooltip shows the meaning of each cause, as illustrated in Figure M.6.

The other display related to this goal focuses on the analysis of client satisfaction, as presented in Figure 5.6, including customer satisfaction, customer satisfaction-SHE, and differentiation indexes, all of which are calculated based on the customer satisfaction survey. Additionally, it presents the survey results in greater detail by breaking down customer assessments according to

Figure 5.5: Performance dashboard display dedicated to the quality of internal operations

the questionnaire areas, as shown in the Customer satisfaction by area chart. When placing the mouse pointer over the info icon, the user can also view the specific questions related to each dimension through a tooltip, thereby facilitating the analysis. Below, the top three and bottom three projects in terms of the customer satisfaction index can be displayed. In this case, since a project is selected in the Project MES filter, only that project is shown in both graphs. This page also includes the customer complaints indicator, which in this case is displayed as "N/A" since no claims have been recorded for the filtering conditions.

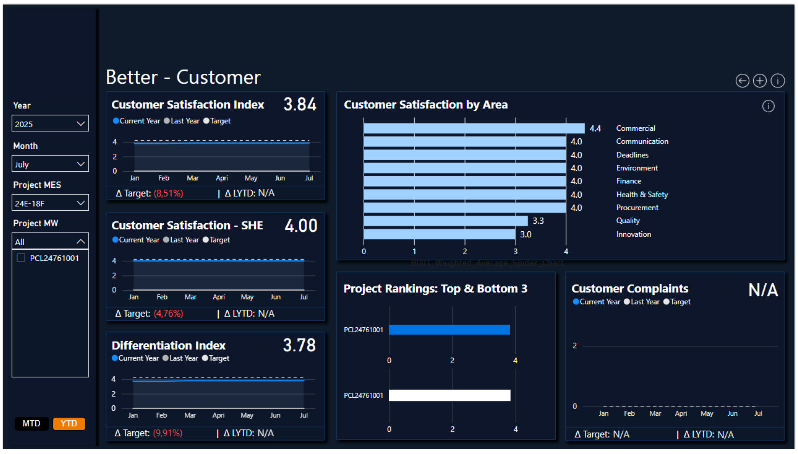

Figure 5.6: Performance dashboard display focused on the customer satisfaction dimension

In Figure 5.7, the last display for this goal is presented, focusing on assessing the CSF related to the incorporation of SHE principles into the daily routines. The first column of this display presents the indicators related to the health and safety dimension (LTFR, TRIF, and SR), which, for the selected filter data, show no values. In fact, as illustrated in the Safety pyramid chart in the top-middle frame, only records of first aid incidents and hazards are included, and these are not considered in the calculation of the first indicators. Below this visual, the number of days without safety accidents is also displayed, showing both the current value and the record achieved to date.

The bar chart within this frame aims to display the last five periods without accidents. However, in this case, only two of these periods were registered, corresponding to the actual and recorded values. By selecting each bar, it is possible to view the start and end date of each accident-free period.

The last column is dedicated to the sustainability dimension, presenting electricity consumption, the waste generated rate (with the amount of each type of waste specified in the tree map), and the pipe waste ratio, showing both the quantity of pipe wasted and the amount integrated into the product in the bar chart.

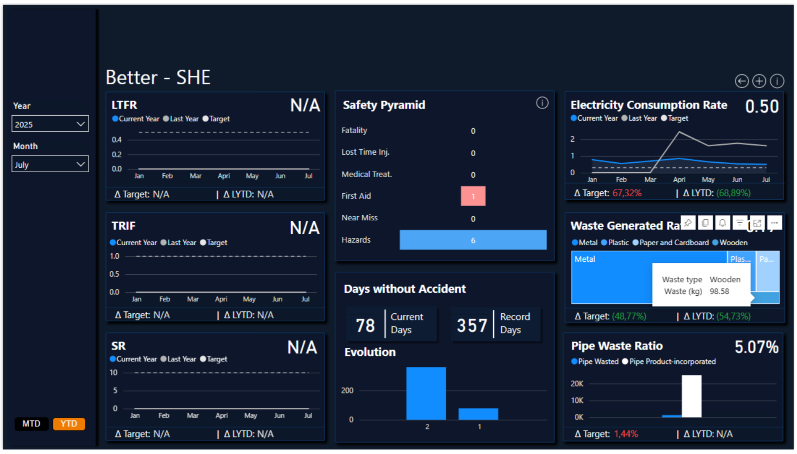

Figure 5.7: Performance dashboard display concerning the SHE dimension

5.1.4 Displays Aligned with the Goal "Be Cheaper"

The last set of displays is aligned with the strategic goal "Be Cheaper", for which two main pages were developed, each corresponding to a specific CSF.

The first focused on addressing budget variations, presents the indicators EBITDA and gross margin, as well as the revenue value at the top, as indicated in the Figure 5.8. Moreover, at the bottom, four different detailed tabs are available. In the currently selected tab, the P&L table is presented, which provides a more detailed understanding of the results, specifically by incorporating the costs that affect the value of the gross margin (job shop costs and project direct costs) and others included in the calculation of EBITDA (structure, operations support, and other non-recurring costs). The table also provides a comparison with the budget values across the MTD, YTD, and LYTD time frames, enriching the potential of the analysis.

When selecting the "Overview – Cockpit" tab, as presented in Figure M.7 of Appendix M, the results from the first table can be analyzed in greater detail, as the values are further disaggregated by sub-groups called by cockpits. For instance, within structure costs, cockpits such as IT Management and Finance are present, each consolidating its corresponding expenses.

Furthermore, as shown in Figure M.8, by selecting the "Bridge" option, it is possible to explore the variation of EBITDA in the MTD and YTD time frames against the budget through a variance chart. This chart considers the variation in the gross margin by representing the value of the price and quantity effect (explained in Table H.21 of Appendix H), as well as the variation of the remaining elements of the first table. Moreover, the "Bridge Structure & Operations" tab in Figure M.9 provides a similar visual representation, but focused on the variation in the costs of operations support and structure, further disaggregated by cockpits.

Figure 5.8: Performance dashboard display centered on the financial dimension

Finally, the last available page is dedicated to the "Use the available capacity" CSF. As illustrated in Figure 5.9, it presents the workers utilization ratio performance measure together with the underlying values used in its calculation, specifically the hours allocated to projects and the remaining hours, presented monthly. Similarly, it presents the MES versus TRS indicator along with the respective hours registered in each system, enabling a comparison between the two methods of recording working time.

Figure 5.9: Performance dashboard display dedicated to assessing the use of available capacity

5.2 Assessment of the Solution

After the dashboard displays were finalized, they were presented in a meeting with the plant manager and the other two members who had accompanied the project, from the areas of Corporate Reporting & Information and Planning & Operations Control. As this took place during the final week of the project, which did not allow for a follow-up period of tool usage, a manual was created to ensure proper utilization. Thus, it not only explains the functionalities of each display to support the end user but also provides technical information intended to assist in ongoing development, such as details on the data sources, the ETL process applied, and the calculation of the measures.

Following the initial stage of the dashboard implementation and the corresponding natural adjustments, it was recommended that the dashboard undergo a first detailed review after six months, unless major needs arise earlier, and thereafter be reviewed annually. This periodic assessment aims to ensure that the dashboard remains relevant to the organization, in terms of the performance measures included, the types of visual elements, and the underlying analyses it allows users to perform.

Moreover, in this final stage of the project, feedback on the developed solution was obtained. For this purpose, a set of closed-ended questions was prepared, as shown in Table N.1 of Appendix N, with the corresponding answers summarized in Figure N.1. In addition to the numerical results, assessed through a Likert-type scale in which one corresponded to very poor, two to poor, three to fair, four to good, and five to very good, further insights were gathered, along with suggestions for future improvements.

Analyzing the results obtained, the questions related to the first phase of the project (questions one and two), namely the selection and subsequent definition of the performance measures, both received the highest rating. According to the interviewees, the process employed demonstrated a concern for choosing indicators aligned with the company's strategy, focusing not only on the operational dimension but also on a broader perspective, and was defined with a detailed level of specification that will be important for interpreting the dashboard results. Regarding the adequacy of the number of measures chosen, addressed in question three, an average score of 4.3 was obtained. Although a more accurate assessment will only be possible after practical use, the current distribution, where part of the indicators are monitored weekly and the remainder monthly, seems feasible.

Considering the quality of the data included in the dashboard, assessed in question four, this aspect was identified as an important area for improvement, as some issues were found in the data provided by the MES and the scheduling tool. Since these problems were originated at the source, improvements, namely through the correct use of the MES and the continuous completion of the schedule, are expected to enhance the quality of the data in the dashboard accordingly. The remaining data presented only minor issues, resulting in an overall assessment of 3.3. One of the suggestions given regarding this topic was the development of a dedicated data quality display, which could, for instance, facilitate the identification of records with incomplete parameter values.

For question five, which addressed the quality of the results presented on the dashboard, the outputs seemed to reflect the underlying data, with an assessment of 4.3, although further validation will only be possible after extended use.

With respect to the organization of the dashboard between the top-level display and the remaining pages, assessed in question six, it received the maximum rating. This structure was recognized as allowing the user to obtain an overall view in which potential red flags can be identified, and subsequently to analyze the indicators in greater detail as specific needs arise.

The assessment of the arrangement of the elements in the top-level display in question seven resulted in an evaluation of 4.3, with some divergence of opinion regarding the use of the slicers to view different indicators within the same frame. For the plant manager, this was not considered an issue. However, an element emphasized that, through the practical use of the tool, it would be important to determine which indicators are the most relevant to present in this display and to reduce their number, thereby ensuring that all remain visible at a glance. For the remaining pages, the placement of the visual elements also received an overall rating of 4.3 in question eight, together with some suggestions for improvement. For example, in the financial section, it was suggested that the detailed tables be placed on individual pages, thereby facilitating the analysis.

As for the choice of visual elements, including charts and tables, this aspect received a result of 5 in question nine. Question ten, which focused on the selection of other interactive elements such as filters, slicers, bookmarks, and tooltips, obtained a score of 4.7, accompanied by some suggestions for improvement. For example, it was suggested to allow filtering the data by week, to facilitate the analysis of performance measures monitored at that frequency. Moreover, since two production lines are currently operating, in contrast to only one at the beginning of the project, it was also recommended to include a line filter. Finally, in the financial display, the addition of a tooltip was suggested to facilitate the interpretation of the abbreviations used in the cockpits.

The last and more comprehensive question also received an assessment of 4.7, acknowledging that the BI-based solution developed has the potential not only to support data-driven decision-making but also to do so in alignment with the company's strategy, thereby contributing to support its PM process, linking strategy and action in the same direction.

5.3 Summary

This chapter presents the final result of the project. Although this is conveyed through the description of the performance dashboard displays, they reflect the execution of all the phases outlined in Chapter 4.

Structurally, the dashboard is composed of a top-level display tailored for monitoring and eight additional pages designed to enable more detailed analysis, incorporating more granular charts, tables, and matrices. Regarding the characteristics of the display, it is important to highlight that the design and placement of the performance measures were conceived to reinforce the perceived linkage between performance measures, CSFs (implicitly), and strategic goals, thereby enhancing the dashboard's potential to support more effective decision-making. Moreover, the placement of the indicators was designed to emphasize those requiring more regular analysis. In terms of layout, it is similar to that defined in the prototypes, while also incorporating buttons for page navigation, as well as buttons to access information about the performance measures and the developed manual.

In this chapter, some brief recommendations were also provided for the implementation phase and the future periodicity of reviews. Moreover, feedback on the developed solution was collected. Overall, the assessed questions received ratings between good and very good, with the solution being recognized as having the potential to support the decision-making and, more broadly, the PM process, particularly considering its alignment with the company's strategy. Finally, along with this feedback, some suggestions for future improvements were also gathered, including the addition of extra filters and information tooltips, as well as the development of a display focused on data quality assessment.

Chapter 6

Conclusions and Future Work

The increasing complexity of the business context has reinforced the critical role of effective and informed decision-making for achieving success. The integration of PM and BI principles offers a means of addressing these challenges. While PM focuses on aligning strategy and execution through a closed-loop process, BI provides the necessary technical foundation. One solution that has the potential to integrate both fields is the performance dashboard. By doing so, such tools not only support the monitoring and analysis of performance but also deliver relevant insights for decision-making aligned with the company's strategy.

The main objective of this dissertation was to develop a BI-based performance dashboard to support the plant manager of an off-site manufacturing company specializing in the prefabrication of components for data centers' chilled water piping systems. Before this project, decision-making relied primarily on intuition and non-systematic analyses, an approach that became increasingly inadequate as operations expanded. The need for a more structured solution was further reinforced by the expectations of senior management, who promote and value the grounding of decisions in data-driven evidence.

In response to this objective, the development of this solution was structured into three phases, aligned with the defined research questions and informed by the literature review. In the first phase, the performance measures to be incorporated into the performance dashboard were selected. Rather than basing this choice directly on pre-defined requirements from the plant manager or on a set of indicators selected by them, a different approach was followed to ensure that the chosen measures were truly relevant. To this end, the CSFs linked to the company's three main goals were identified, as a means of determining what needs to be done regularly to ensure their accomplishment. Based on these factors, performance measures were then derived to assess the extent of their implementation.

The selected measures included both newly introduced indicators and others already applied in different measurement contexts within the Mecwide, thereby ensuring consistency. After this selection, the indicators were thoroughly defined using the recommended attributes of the Performance Measure Record Sheet, including name, purpose, formula, target, data sources, actions to address or further explore the results, as well as complementary elements such as relevant filters for the analysis and the unit of measurement. The outcome of this stage was a set of indicators aligned with the company's strategy, encompassing different perspectives — operations, quality, SHE, customer, and financial — with an emphasis on past-oriented performance.

The second phase, building on the sources identified in the previous stage, focused on obtaining data either from sources connected to the data warehouse or directly from Excel spreadsheets. For this purpose, Power Query was employed to extract the data, transform it into an appropriate format, and load it into Power BI. Subsequently, the resulting tables, along with others created within this environment using the DAX language, were linked to develop a data model. In this process, both the cardinality of the relationships and the direction of the cross-filters were considered to ensure correct interactions.

The final phase comprised the creation of the dashboard displays within the same platform, which involved developing basic prototypes for both the top-level and detailed views, designed to follow an intuitive and consistent layout. The representation of the performance measures, in the content area, was shaped by the selected time frames (YTD and MTD), the requirement for percentage comparisons with the target, and the value of the same period of the previous year, as well as the inclusion of graphs showing the temporal variation of the actual values alongside the targets and last year's results. Together with the collected data and the indicator formulas, these elements influenced the calculation of the measures using the DAX language.

In practice, these phases culminated in the creation of a performance dashboard consisting of a top-level display designed for monitoring the main performance measures and eight additional pages intended to enable more detailed analysis. In terms of display characteristics, it is worth emphasizing that the design and positioning of the performance measures were conceived to highlight the linkage between performance measures, CSFs (implicitly), and strategic goals, thereby enhancing the dashboard's potential to support more effective decisions. Furthermore, the arrangement of the indicators was intended to give prominence to those requiring more frequent analysis. Concerning the type of visual elements adopted, emphasis was placed on the use of tables, matrices, and charts, with non-recommended chart types being avoided. The drill-down functionality was also employed, together with other interactive elements such as filters, slicers, tooltips, and bookmarks. Moreover, navigation buttons were added to facilitate movement across pages and provide access to complementary information.

Once the solution was completed, feedback was gathered regarding its development. Overall, apart from concerns related to the quality of the incorporated data — stemming from issues in the MES and schedule tool — the evaluation questions obtained average scores above 4.3. The solution was therefore recognized as having significant potential to support the decision-making and, more broadly, the PM process, particularly due to its alignment with the company's strategy, reflected primarily in the chosen metrics and reinforced by the design and organization of the display's elements.

In terms of future work, it is important to advance to the implementation phase of the tool, during which the plant manager will actually explore the delivered solution, supported by the manual created and the BI team to correct potential issues. Furthermore, from this initial stage of implementation, it will be crucial to address the main problem identified, namely, the incorrect use of the MES and the incomplete filling of the scheduling, since only then will the tool be able to reflect reality accurately.

After this phase, the identified potential improvements should be implemented, including some already mentioned at the end of the project, namely the addition of further filtering capabilities, such as by production line and by week, the inclusion of information tooltips, and the creation of a display dedicated to data quality assessment. Furthermore, it would be valuable to explore the synchronization of alarms with the tool, enabling the automatic monitoring of changes in data values and the receipt of notifications via email or Teams, thereby ensuring greater control.

Another relevant aspect is the completion of the integration between the MES and the ERP, which will enable the automatic extraction of data from the former. With this change, the current data sources — spreadsheets in SharePoint containing information from the MES — will have to be replaced by corresponding tables in the data warehouse. Although this transition requires a certain degree of technical effort, it is expected to significantly increase the overall value of the dashboard by enhancing its level of automation.

To overcome the limitation of the past orientation of the measures, it would be appropriate to implement more predictive indicators in the future. For instance, based on the operational status, it should be possible to determine whether a given sequence can be delivered according to the estimated shipping date. Using this information, a projected OTIF could be generated, providing alerts for potential delivery constraints more proactively.

In addition, it will be important to adhere to the tool's review periods, with an initial assessment recommended six months after the implementation phase, followed by subsequent reviews on an annual basis. During these reviews, both the performance measures and the displays in which they are presented should be reassessed.

To conclude, this project addressed the proposed objective by creating a BI-based solution that enables the monitoring and analysis of relevant aspects and promotes more informed decision-making by the plant manager of the Company X. Furthermore, since it was developed in alignment with the established strategy, the solution strengthens the ability to make effective decisions, thereby helping to transform strategy into action and keep the company moving in the same and right direction.

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Appendix A

Performance Management Framework

To put PM into practice, four main steps are proposed and detailed below (BPM Standards Group, 2005; Eckerson, 2011; Frolick and Ariyachandra, 2006):

- **Strategize:** In the first step, executives define or update the organization's vision, answering the question "Where do we want to go?", its mission, which reflects "Why are we here?", and the values that guide and influence both. These values should be considered to be timeless and deeply held beliefs that preserve the organization's identity (Cokins, 2004). Based on these three elements, the organization then defines its objectives, both short and long-term, and establishes performance metrics to assess progress. Each team, department, and business unit should also formulate strategies and plans that are consistent with these top-level strategies and plans. For instance, a customer-centric strategy could result in the identification of high customer satisfaction or excellent product quality as critical drivers and adopt measures such as a customer satisfaction index or the number of defects per thousand units to monitor performance over time. Although many organizations find this step challenging, especially when it comes to defining metrics aligned with strategy, it is regarded a critical phase of the cycle.
- **Plan:** During the plan step, managers within the organization create plans aimed at helping achieve the previously defined objectives. These plans may involve developing or redefining initiatives, projects, and processes. One of the primary tools used to support these activities is the budget, which enables the allocation of human, technological, and financial resources. In addition, other tools such as forecasting applications can be considered. For this process to be successful, it is not enough to ensure consistency with the previous step, but also that the organization adopts a standardized planning approaches across all units, supported by common processes and shared definitions.
- **Monitor and Analyze:** Regarding the third step, this is where performance results linked to the previously defined performance metrics are presented to the different levels of the organization. As a result, stakeholders are able to monitor and analyze information, track progress toward strategic objectives, and ultimately make more informed and proactive decisions. To support this process, BI infrastructure is typically appropriate, including capabilities for collecting, integrating, and storing data from diverse sources, as well as analytical tools.
- **Act and Adjust:** Finally, in the last part of the cycle, it is crucial that users respond with timely corrective actions to prevent potential issues from escalating or, alternatively, to take advantage of emerging opportunities before they disappear. These interventions may involve

revising plans, processes, updating forecasts, or even reconsidering new targets. To support this, certain systems already integrate alert functionalities and intelligent technologies that can recommend, or, in some cases, performing automated actions, without requiring human input.

In summary, the first two steps define the strategy through goal setting and planning, while the final steps ensure its execution by monitoring performance and enabling adjustments. When properly followed, the four steps align the entire organization toward a common direction.

Appendix B

Performance Measurement Methodologies

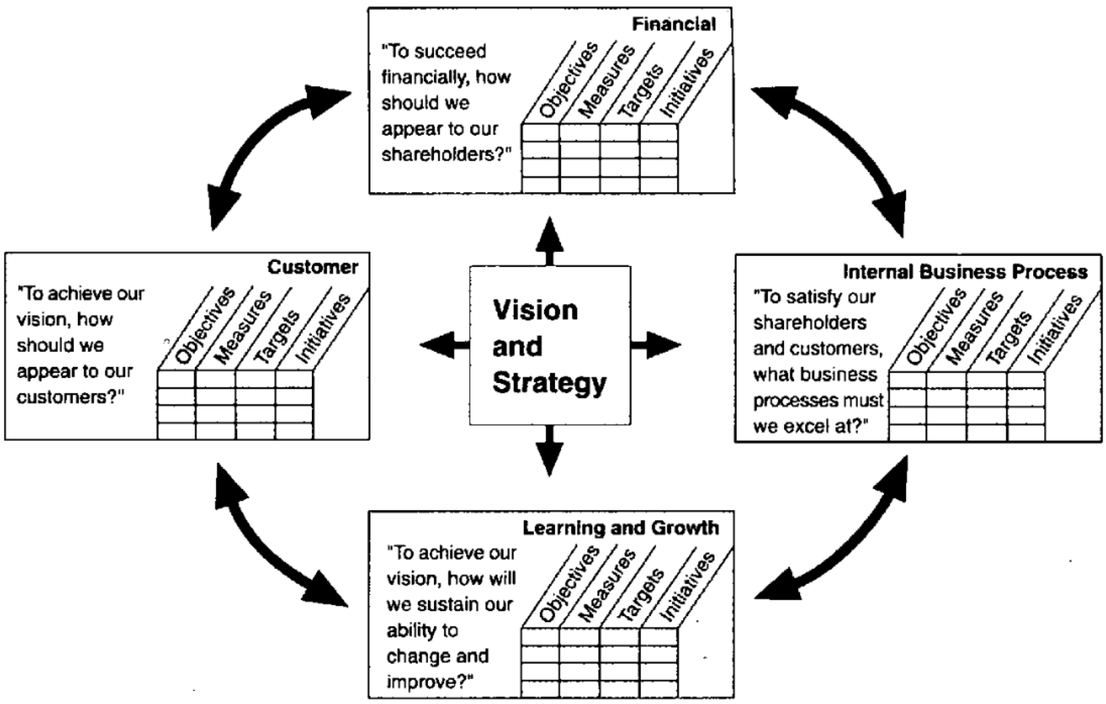

Figure B.1: BSC perspectives. Source: Kaplan and Norton (1996)

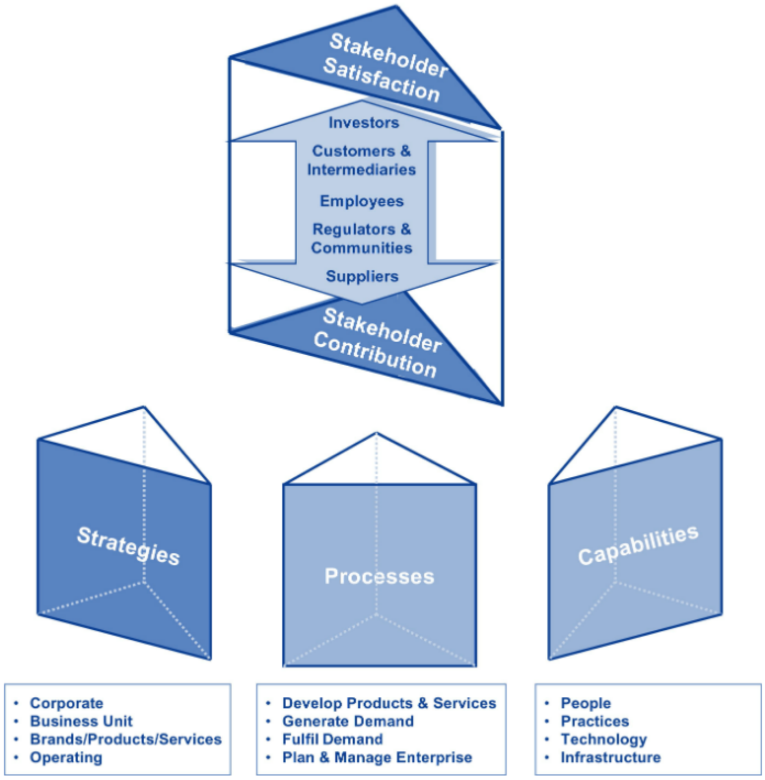

Figure B.2: The five facets of Performance Prism. Source: Neely et al. (2001)

Table B.1: Implementation plan for the Winning KPIs. Adapted from: Parmenter (2020)

Stage	Step	Description
Getting the enterprise committed to the change and up-skilling the in-house KPI team	Sell the KPI project to the CEO, the senior management team, and other internal experts	The initiative should begin with an elevator delivered pitch, followed by an engaging presentation, and conclude with a focus group session aimed at securing organizational approval
	Locate an external facilitator to mentor the KPI team	The external facilitator (with experience in performance measurement and KPI development/implementation) supports timeline definition, KPI team sizing/selection, and ongoing guidance as the team advances through learning, exploration, and implementation
	Select a small in-house KPI team and provide them with training	Choose a balanced mix of internal experts and emerging leaders, fully dedicated to the project. Senior management plays a supportive role in the project, and it is advised that one senior manager be designated as the KPI team leader. After training, the team develops the project implementation plan
	Promote the KPI project among all employees to foster engagement	Ensure employees invited to the two-day performance measurement workshop understand its significance and recognize it as a valuable activity
Ascertaining organization's operational critical success factors	Identify the existing success factors and desired external outcomes	KPI team starts with a thorough review of the organization's strategic documents along with interviews to identify the success factors and external outcomes. For this step, wording is essential. It is advised that the success factors meet the SMART criteria: being Specific (avoiding vague or empty words), Measurable (using language that lends itself to measurement), Achievable (clearly conveying the idea in a realistic way), Relevant (aligned with organizational priorities), and Time-sensitive (focused on the present)

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Stage	Step	Description
	Organize workshops to identify and validate the CSFs	Run a two-day workshop where teams map relationships among success factors. Each team selects the five most influential factors based on the number of connections they impact. Afterward, the number of times each factor is selected across all teams is considered. Those most frequently chosen are considered potential CSFs Place also short- and long-term desired outcomes at the center of the map to reveal factors that drive multiple outcomes. Typically, it led to a shortlist of 10–15 factors; a second round with experienced participants resolves scoring inconsistencies and shortens the list to 6–8 CSFs. Test the CSFs against the six BSC perspectives and strategic goals to ensure balance and alignment. Communicate the final CSFs to stakeholders not involved in the process
Determining measures and getting the measures to drive performance	Conduct a performance measurement workshop to equip relevant staff with the skills needed to develop meaningful performance measures	Select experienced staff for a two-day workshop on designing relevant measures. Derive measures from CSFs: start with the easiest CSF to measure, define expected outcomes, describe related good/poor performance, and propose measures. Classify each measure as past, present, and future-oriented. Document measures in a database (name, description, CSF, frequency)
	Refine the measures after the performance measures workshops	The KPI team removes duplicates and low-quality indicators, discards those with unfavorable cost–benefit for data collection, and rewords unclear items. Evaluate each measure's strength and data feasibility, then classify as KRI, RI, KPI, or PI
	Organize a performance measures gallery to identify and eliminate ineffective or poorly designed indicators	Staff review the defined measures and provide feedback to eliminate weak or redundant indicators
	Each team should select their performance measures from the finalized database	Team sets will comprise mainly relevant RIs and PIs plus some organizational KPIs. Using more than 10 measures regularly is not recommended

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Stage	Step	Description
	Find the KRIs to be reported to the board	Derive KRIs from CSFs and outcome statements that reflect external impacts. Select no more than 10 KRIs and each aligned to a BSC perspective, to maintain clarity and focus
	Confirm that the KPIs meet all the key features that define a real KPI	Select no more than 10 KPIs. Each KPI is: nonfinancial; measured frequently (24/7, daily, or weekly); used by top management; action-indicating; linked to specific teams; high-impact across key areas and BSC perspectives; and encourages the right behavior without negative side effects
	Design the reporting framework for displaying the performance measures	The reporting structure must meet needs at different organizational levels and deliver information fast enough to support timely decisions, applying data-visualization best practices and avoiding spreadsheet-based reports in favor of specialized reporting software
	Assist the organization in effectively applying the selected performance measures	Over subsequent months, ensure accurate and timely reporting and support corrective actions. Implement training to educate existing and new staff on KPI use
	Review the CSFs and performance measures after one year	Conduct a review to assess whether adjustments are needed to the CSFs and associated measures

Appendix C

BI Architecture

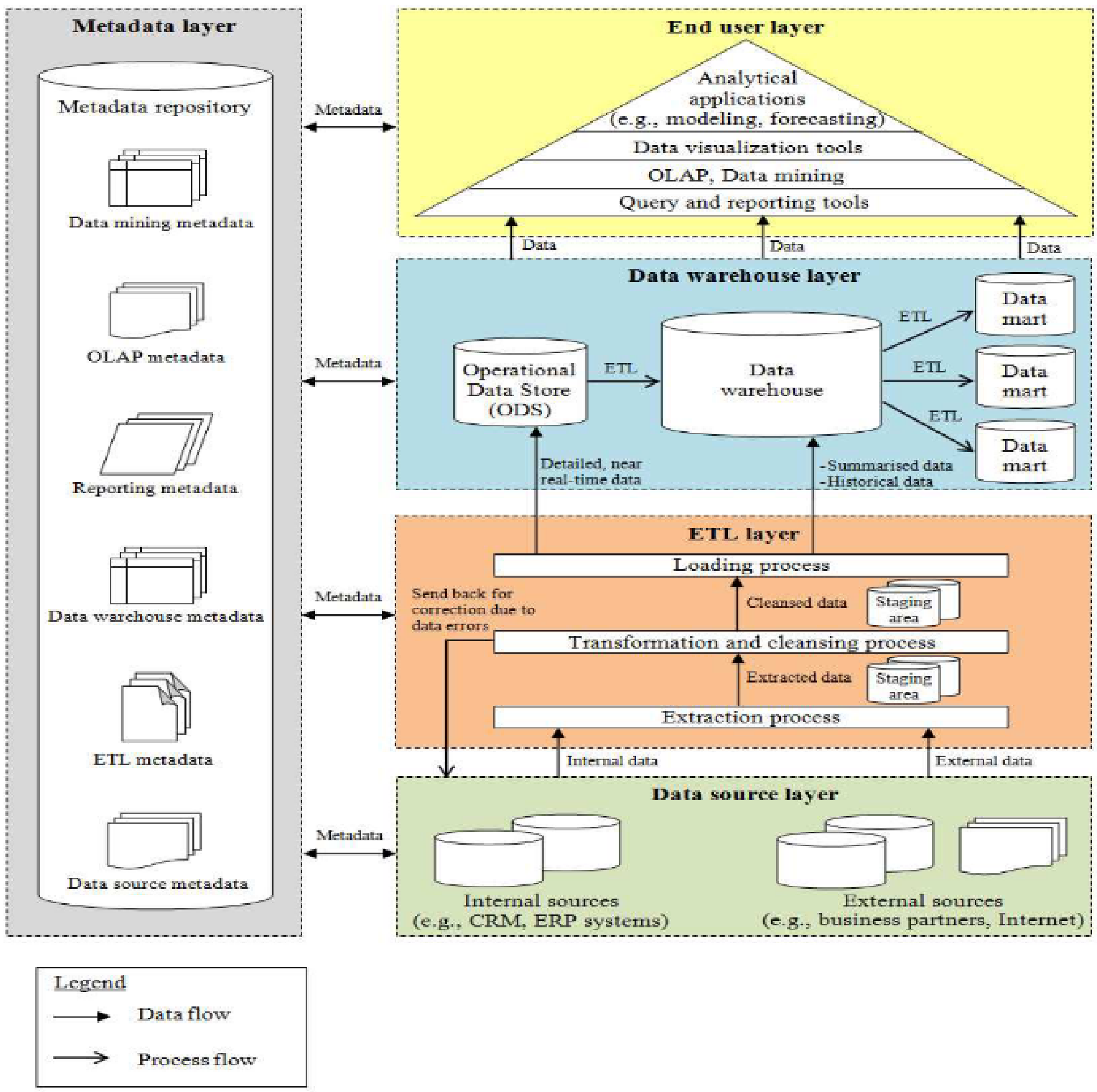

Figure C.1: Schematic representation of the five-layered BI architecture framework. Source: Ong et al. (2011)

Appendix D

Data Visualization

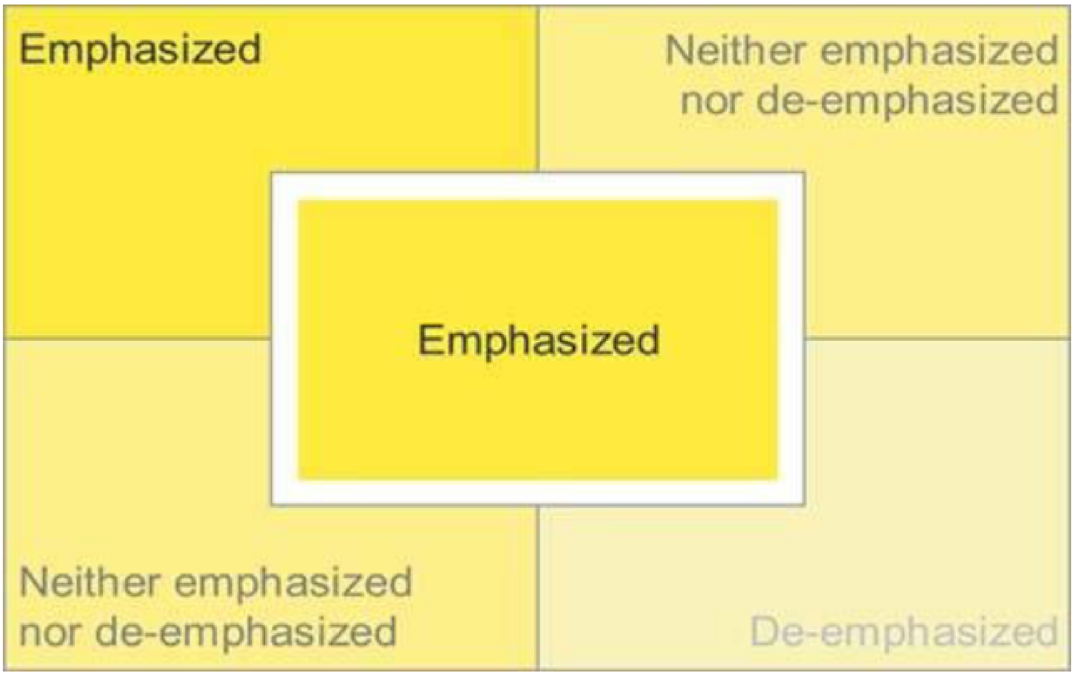

Figure D.1: Degrees of emphasis across screen areas. Source: Few (2006)

Appendix E

Production Process

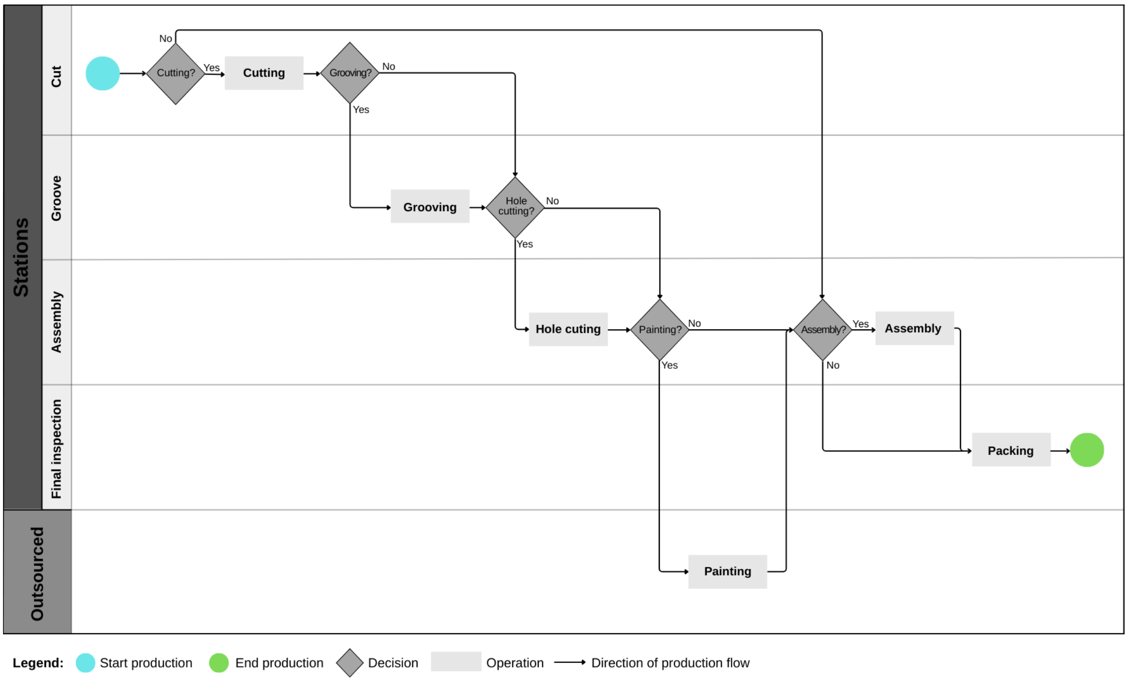

Figure E.1: Swimlane diagram of the Company X production workflow

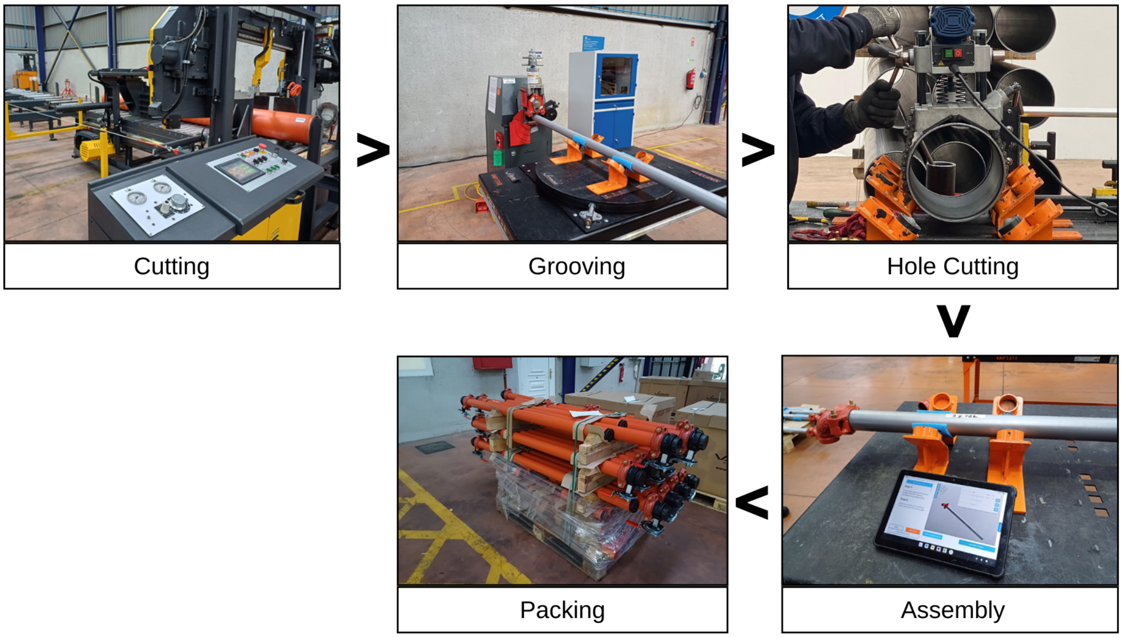

Figure E.2: Internal operations of the Company X production process

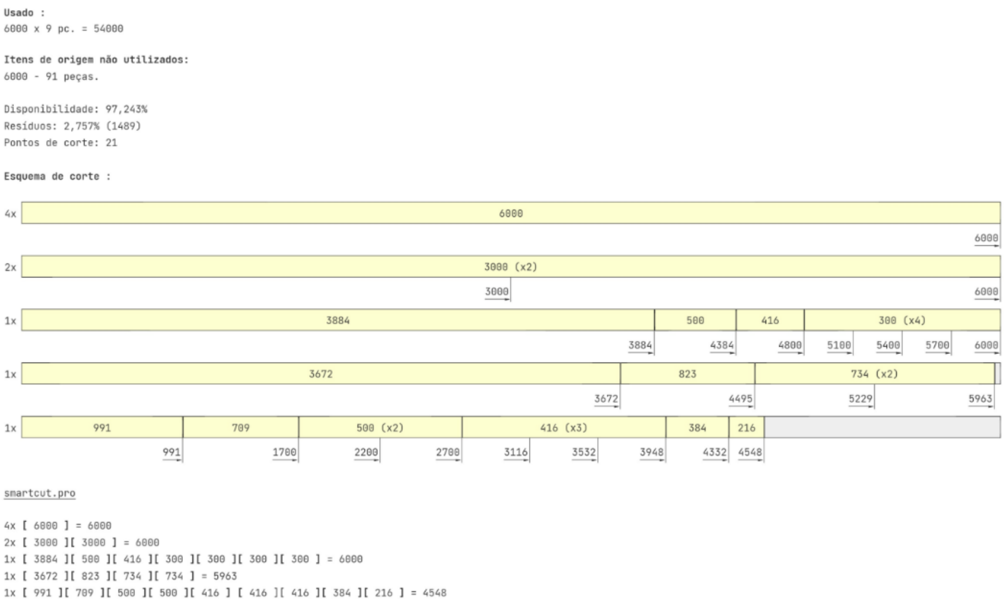

Figure E.3: Cut list generated by the SmartCut calculator

Appendix F

Manufacturing Execution System

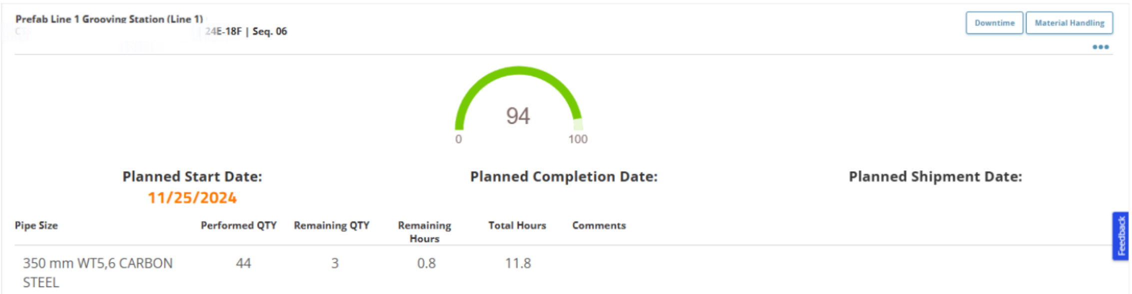

Figure F.1: Example of MES production module interface - dashboard

Figure F.2: Example of MES production module interface - operations instructions

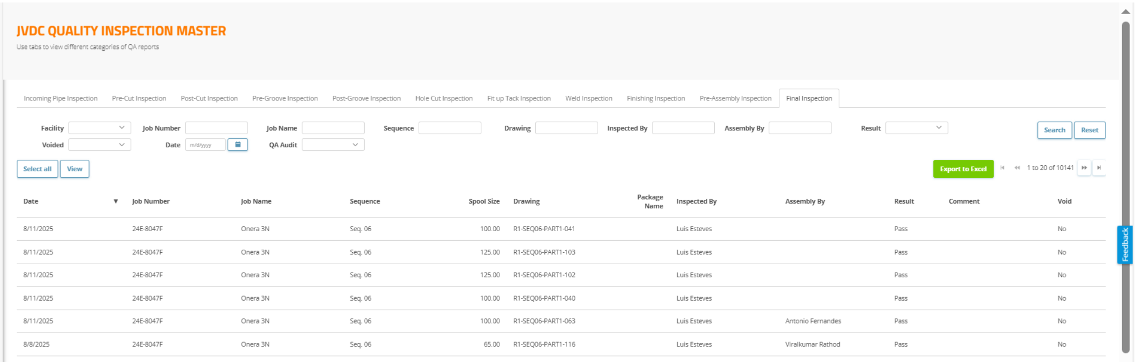

Figure F.3: Example of MES office module interfaces – detailed data view

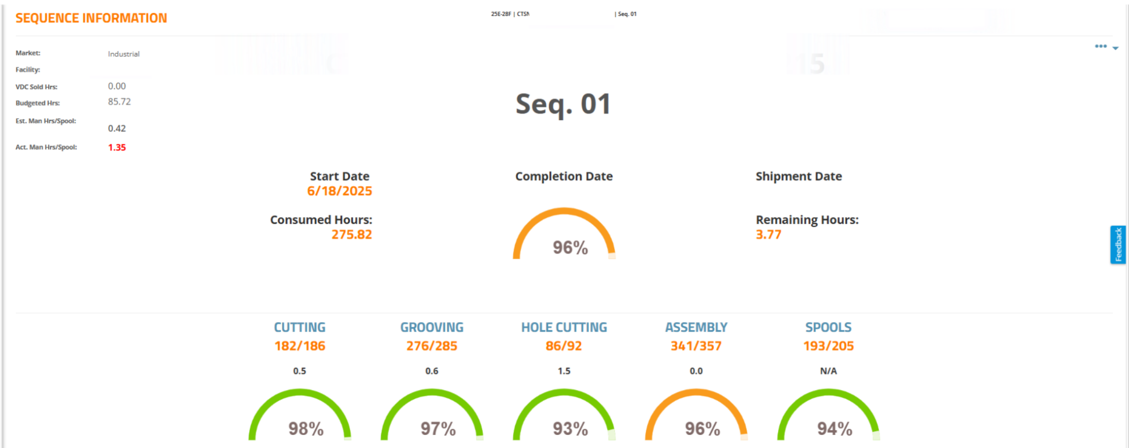

Figure F.4: Example of MES office module interfaces – dashboard display (1)

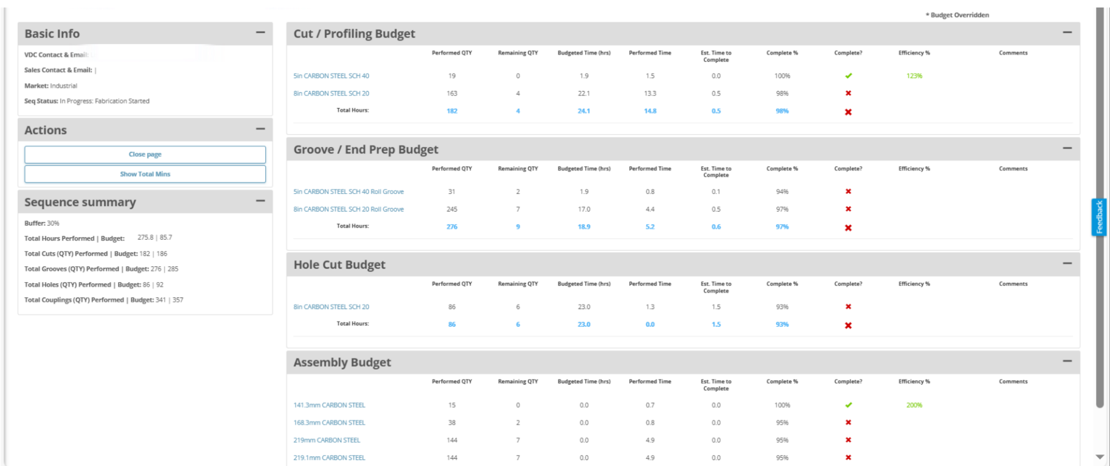

Figure F.5: Example of MES office module interfaces – dashboard display (2)

Appendix G

Assessment of Organizational Readiness

Table G.1: General questions to assess organizational readiness for developing performance measures and dashboards

Topic	#	Question	Adapted from
Culture of measurement	1	Does the organization have a measurement-driven culture and base its decisions on evidence rather than intuition?	Eckerson (2011)
Strategy	2	Does the organization have a strategy with well-defined mission, vision, values, goals, objectives, and performance measures?	Eckerson (2011)
Sponsorship	3	Does senior management recognize the importance of these projects, provide active support, and dedicate time to their promotion and oversight?	Eckerson (2011)
	4	Are middle managers willing to support these initiatives and share performance results transparently, without perceiving them as a threat to their positions?	Eckerson (2011)
Need	5	Is the development of the performance dashboard driven by an urgent need arising from the inability to track and measure performance?	Eckerson (2011)
Teams	6	Does the company have business and technical staff with the necessary skills and experience to implement these type of solutions, including expertise in designing performance measures and in building and integrating the technological components of the solution?	Eckerson (2011), Parmenter (2020)
	7	Do the business and technical teams demonstrate alignment, effective collaboration, and mutual trust?	Eckerson (2011)
Resources	8	Is there a robust technical infrastructure that allows users to access data?	Eckerson (2011)
	9	How does the company evaluate its data in terms of quantity and quality?	Barr (2014), Eckerson (2011)

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Topic	#	Question	Adapted from
Performance measures and dashboard	10	Does the company usually use defined methodologies to select and implement indicators, such as the BSC or Winning KPIs?	Parmenter (2020)
	11	Who is usually involved in the process of developing these tools?	Barr (2014)
	12	Is the relationship between the strategy and the measures clear and well-defined?	Eckerson (2011)
	13	What time frames are typical for the different stages of choosing and reporting measures, and using them to pursue targets?	Barr (2014)
	14	Does the reporting of performance measures follow certain principles of data visualization?	Parmenter (2020)

Table G.2: Interview questions to evaluate Mecwide's readiness to develop performance dashboards

#	Question	Type	Related Question(s) from Table G.1
1	How would you rate the culture of managing through performance measures in the company?	Closed-ended	1
2	How would you rate Mecwide's strategy in terms of clarity, coherence, and the definition of goals, objectives?	Closed-ended	2
3	How would you rate Company X's strategy in terms of clarity, coherence, and the definition of goals and objectives?	Closed-ended	2
4	How would you rate the commitment and support of top-level executives in the development and use of dashboards?	Closed-ended	3
5	How would you rate the commitment and support of managers in the development and use of dashboards?	Closed-ended	4
6	How clear is the relationship between the strategy and the measures displayed in the dashboards?	Closed-ended	12
7	How would you rate the relationship between those who define the metrics and those who develop the dashboards?	Closed-ended	7
8	How do you rate your technical infrastructure (including data warehouses, analytical tools, servers, storage, networks and the people to feed and maintain the environment)?	Closed-ended	6, 8

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#	Question	Type	Related Question(s) from Table G.1
9	How would you rate the quality and availability of data to populate performance dashboard metrics?	Closed-ended	9
10	What types of dashboards are used in the company, and for what purposes?	Open-ended	–
11	Is there an established process in the company for developing dashboards, including the definition of performance indicators and dashboard development and implementation?	Open-ended	10, 14
12	Do you use any performance measurement frameworks like the BSC?	Open-ended	10
13	Who defines the performance measures to be presented in the dashboard? Do you have a team trained in designing measures?	Open-ended	6, 11
14	In addition to the data warehouse, does the company also use data marts or other sources?	Open-ended	8
15	Which type of BI software does the company use, and why? Are dashboards still being developed in Excel?	Open-ended	8
16	When do people have access to the BSC? Only during quarterly meetings?	Open-ended	13
17	How often are the dashboard data typically refreshed?	Open-ended	13
18	Is there a defined periodicity for reviewing the metrics used in the dashboards, including the type of metrics, formulas, and targets?	Open-ended	13

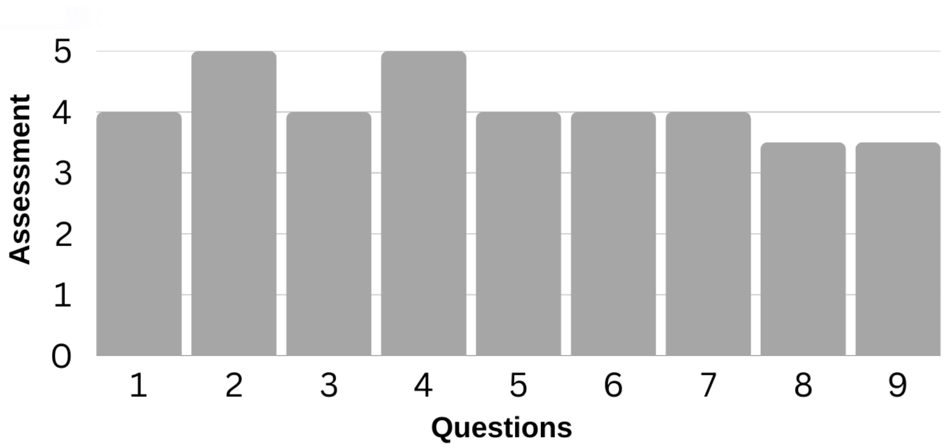

Figure G.1: Results of closed-ended questions of the readiness analysis

Appendix H

Performance Measures

Table H.1: List of indicators used in the performance measures selection meeting

Goal & CSF	#	Performance Measure	Description	Formula	Adapted from
Be better: Guarantee quality in internal operations	1	Quality ratio	It expresses the relationship between good quantity (GQ) and produced quantity (PQ)	$\frac{GQ}{PQ}$	ISO (2014), Khan and Bilal (2019), Marek et al. (2020)
	2	Scrap ratio	It determines the relationship between scrap quantity (SQ) and produced quantity (PQ)	$\frac{SQ}{PQ}$	ISO (2014), Khan and Bilal (2019), Swarnakar et al. (2021)
	3	Actual to planned scrap ratio	It is defined as scrap quantity (SQ) over planned scrap quantity (PSQ), indicating the amount of scrap produced versus the planned amount	$\frac{SQ}{PSQ}$	ISO (2014)
	4	Rework ratio	It assesses the relationship between rework quantity (RQ) and produced quantity (PQ)	$\frac{RQ}{PQ}$	ISO (2014), Khan and Bilal (2019), Rodrigues et al. (2021)
	5	First time pass yield	It gives the proportion of items that satisfy quality requirements in the initial process run without rework (good parts), computed as good parts (GP) over inspected parts (IP).	$\frac{GP}{IP}$	ISO (2014), Khan and Bilal (2019)
Be better: Incorporate SHE principles into daily routines	6	Greenhouse gas emissions	It measures the amount of greenhouse gases released during manufacturing, where E is the specific carbon emission of the activity and A is the amount of the activity	$E \times A$	SCW.AI (2024)

(continued on next page)

Goal & CSF	#	Performance Measure	Description	Formula	Adapted from
	7	Energy consumption	It calculates the amount of energy used in operations	Power $\times$ Time	SCW.AI (2024), Swarnakar et al. (2021)
	8	Water and fuel consumption	–	–	Swarnakar et al. (2021)
	9	Quantity of waste	–	–	Rodrigues et al. (2021)
	10	Number of safety, health, and environmental incidents	–	–	Marek et al. (2020)
	11	Total Recordable Incident Rate (TRIR)	It calculates recordable workplace incidents per hundred full-time employees over a given period, typically one year, using the number of recordable injuries (NRI) and total hours worked (THW)	$\frac{\text{NRI} \times 200{,}000}{\text{THW}}$	SCW.AI (2024)
	12	Lost Time Injury Frequency Rate (LTIFR)	It shows how many lost time injuries occur per million hours worked, using the number of lost time injuries (NLTI) and total hours worked (THW)	$\frac{\text{NLTI} \times 1{,}000{,}000}{\text{THW}}$	SCW.AI (2024)
Be better: Ensure customer satisfaction	13	Customer complaint rate	It gives the percentage of number complaints (NC) of customers relative to total products sold (TPS)	$\frac{\text{NC}}{\text{TPS}}$	SCW.AI (2024)

(continued on next page)

Goal & CSF	#	Performance Measure	Description	Formula	Adapted from
	14	Customer satisfaction index	It measures customer satisfaction, typically via a survey	–	Marek et al. (2020), SCW.AI (2024)
Be faster: Deliver in full and on time	15	On-time, in-full (OTIF)	It gives the percentage of orders that reached customers on schedule and complete. (NOTIF: Number of orders delivered on time and in full; NO: Number of orders)	$\frac{\text{NOTIF}}{\text{NO}}$	SCW.AI (2024)
	16	Schedule attainment	It measures the proportion between actual production output and the planned production output	$\frac{\text{Started work orders}}{\text{Planned work orders}}$	SCW.AI (2024)
	17	Hours spent versus total planned	–	–	Rodrigues et al. (2021)
Be cheaper: Address budget deviations	18	Deviation from the project budget	–	–	Rodrigues et al. (2021)
	19	Revenue versus costs	–	–	Rodrigues et al. (2021)
Be cheaper: Use the available capacity	20	Worker efficiency	It measures the proportion of actual personnel work time (APWT) on production orders relative to the employee's actual attendance time (APAT)	$\frac{\text{APWT}}{\text{APAT}}$	ISO (2014)

Table H.2: Record sheet of performance measure: OTIF

Element	**Description**
Purpose	It measures the percentage of sequences shipped on time and in full. Instead of using the delivery date at the site and client information to confirm whether the shipment was complete, the formula relies on the shipment date and the associated spools shipped, given the difficulties in accessing the former two sources of information. Therefore, sequences are considered on time and in full if shipped by the agreed date and containing all spools
Relates to	Be faster: deliver in full and on time
Formula	$\frac{\text{Number of sequences shipped on time and in full}}{\text{Number of sequences shipped}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	If the measure value falls below the target, examine the schedule attainment indicator to identify potential causes and prevent recurrence. Furthermore, evaluate the extent of late deliveries by analyzing the average days late metric
Source of data	SharePoint (MES): total number of spools in the sequence, total number of spools of the sequence shipped, and actual data on the last shipment for the sequence SharePoint (Schedule plan): planned shipment data
Filter	Date (year, month), project

Table H.3: Record sheet of performance measure: Average days late

Element	**Description**
Purpose	It indicates the severity of shipment delays by calculating the average number of days beyond the agreed shipment date
Relates to	Be faster: deliver in full and on time
Formula	$\frac{\sum(\text{Actual shipment date of late shipments} - \text{Planned shipment date})}{\text{Number of late shipped sequences}}$
Unit of measurement	Day
Frequency of analysis	Weekly
Actions	Same as for OTIF
Source of data	Same as for OTIF
Filter	Date (year, month), project

Table H.4: Record sheet of performance measure: Schedule attainment ratio

Element	**Description**
Purpose	It evaluates how much of the schedule production has been successfully completed, and may be used to explore the causes of failures in the OTIF indicator
Relates to	Be faster: deliver in full and on time
Formula	$\frac{\text{Quantity of approved executed production}}{\text{Quantity of scheduled production}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	Identify whether a specific operation causes the problem. Moreover, examine the time efficiency ratio indicator to identify inefficiencies in the production process. If none are found, explore other possible causes such as staff shortages, equipment unavailability, quality problems, or external factors, including the late delivery of information from previous external processes, supplier delays, or delays in the painting process (outsourced)
Source of data	SharePoint (MES): quantity produced and approved in quality inspections in inches SharePoint (Schedule plan): quantity scheduled in inches
Filter	Date (year, month), project, sequence

Table H.5: Record sheet of performance measure: Time efficiency ratio

Element	**Description**
Purpose	It compares the planned process time with the actual time spent on the activities performed and may be used to identify deviations that affect scheduling attainment
Relates to	Be faster: deliver in full and on time
Formula	$\frac{\text{Planned time}}{\text{Actual time consumed}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	Identify whether a specific operation is causing the issue. If the values are significantly above the target, assess the quality of the records, which can first be examined using the indicator Recorded Hours – MES versus TRS. A low value in this indicator may suggest errors in recording the actual time consumed
Source of data	SharePoint (MES): actual time consumed SharePoint (Schedule plan): planned time
Filter	Date (year, month), project, sequence

Table H.6: Record sheet of performance measure: Quality ratio

Element	**Description**
Purpose	It indicates the percentage of inspections that meet quality requirements out of the total inspections conducted
Relates to	Be better: guarantee quality in internal operations
Formula	$\frac{\text{Number of inspections approved}}{\text{Number of inspections}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	Identify whether the issue is caused by a specific operation, and analyze the underlying causes of failures (internal, e.g., operator error and equipment error, or external, e.g., raw material defects). When necessary, implement measures, including worker training
Source of data	SharePoint (MES): inspection records
Filter	Date (year, month), project, sequence

Table H.7: Record sheet of performance measure: Scrap ratio

Element	**Description**
Purpose	It measures the proportion of inspections that resulted in scrap relative to the total number of inspections performed, where scrap refers to a pipe segment, accessory, or spool that is discarded as waste
Relates to	Be better: guarantee quality in internal operations
Formula	$\frac{\text{Number of inspections that fail and generate scrap}}{\text{Number of inspections}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	Same as for the quality ratio
Source of data	Same as for the quality ratio
Filter	Date (year, month), project, sequence

Table H.8: Record sheet of performance measure: Rework ratio

Element	**Description**
Purpose	It measures the proportion of inspections that resulted in rework relative to the total number of inspections performed, where rework, in this case, refers to the need to return to a previous station to correct the identified failure
Relates to	Be better: guarantee quality in internal operations
Formula	$\frac{\text{Number of inspections that fail and generate rework}}{\text{Number of inspections}} \times 100$
Unit of measurement	%
Frequency of analysis	Weekly
Actions	Same as for the quality ratio
Source of data	Same as for the quality ratio
Filter	Date (year, month), project, sequence

Table H.9: Record sheet of performance measure: Number of safety incidents

Element	**Description**
Purpose	It measures the number of safety incidents across the categories defined in the safety pyramid model. This model, also known as the safety triangle, was introduced by Herbert W. Heinrich, who found that for every accident resulting in a major injury, there were approximately twenty-nine accidents causing minor injuries and around 300 incidents without injury (Freibott, 2013). Over time, safety professionals have refined and expanded this framework by incorporating additional categories of incidents into the original triangle (McSween and Moran, 2017). In general, these models emphasize the critical importance of managing risks at the base of the pyramid, as doing so significantly reduces the likelihood of severe accidents at the top. In Mecwide's case, the safety pyramid model used follows a structure similar to the categories of the Conoco Phillips Marine model, which presents a more detailed distribution: for every fatality, there are about thirty lost workday cases, 300 recordable injuries, and approximately 300,000 unsafe acts or at-risk behaviors. Internally, these categories of incidents are referred to by different names: hazards (unsafe acts or at-risk behaviors), near misses, first-aids, medical treatments (both corresponding to recordable injuries), Lost Time Injuries (LTI), and fatalities
Relates to	Be better: incorporate SHE principles into daily routines
Formula	Fatalities = Number of major injuries that often result in abandonment of work LTIs = Number of accidents with more than four lost workdays Medical treatments = Number of accidents with more than zero and up to four lost workdays First Aid = Number of accidents with injury but without loss of working days Near Misses = Number of incidents without injury Hazards = Number of reported situations that represent a potential safety risk
Unit of measurement	Incident
Frequency of analysis	Monthly
Actions	Identify the causes and ensure compliance with safety practices
Source of data	Data warehouse (V_Hazards table): records of hazards Data warehouse (V_ACCIDENTS table): records of the other type of incidents
Filter	Date (year, month)

Table H.10: Record sheet of performance measure: LTFR

Element	Description
Purpose	It represents the number of LTIs that occurred during a specific period per 200,000 man-hours worked
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Number of LTIs}}{\text{Worked time}} \times 200{,}000$
Unit of measurement	Accident
Frequency of analysis	Monthly
Actions	Identify the causes and ensure compliance with safety practices
Source of data	Data warehouse (V_ACCIDENTS table): records of accidents Data warehouse (HORAS_WEBP_TRS_FULL table): worked time
Filter	Date (year, month)

Table H.11: Record sheet of performance measure: TRIF

Element	Description
Purpose	It assesses the number of accidents per 200,000 man-hours worked, including both LTI and medical treatment cases
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Number of LTIs and medical treatments}}{\text{Worked time}} \times 200{,}000$
Unit of measurement	Accident
Frequency of analysis	Monthly
Actions	Same as for the LTFR
Source of data	Same as for the LTFR
Filter	Date (year, month)

Table H.12: Record sheet of performance measure: SR

Element	Description
Purpose	Represents the average number of lost workdays per accident, considering both LTI and medical treatment cases
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Lost days}}{\text{Number of LTIs and medical treatments}}$
Unit of measurement	Day
Frequency of analysis	Monthly
Actions	Same as for the LTFR
Source of data	Data warehouse (V_ACCIDENTS table): records of accidents
Filter	Date (year, month)

Table H.13: Record sheet of performance measure: Days without accidents

Element	**Description**
Purpose	It represents the number of consecutive days without a recordable accident, considering LTI, medical treatments, and first aid
Relates to	Be better: incorporate SHE principles into daily routines
Formula	Current date – Date of last accident
Unit of measurement	Day
Frequency of analysis	Monthly
Actions	Same as for the LTFR
Source of data	Data warehouse (V_ACCIDENTS table): records of accidents
Filter	Date (year, month)

Table H.14: Record sheet of performance measure: Electricity consumption rate

Element	**Description**
Purpose	It measures the amount of electrical energy used per hour of work
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Electricity consumption}}{\text{Worked time}}$
Unit of measurement	kWh / h
Frequency of analysis	Monthly
Source of data	SharePoint: amount of energy consumed Data warehouse (HORAS_WEBP_TRS_FULL table): worked time
Filter	Date (year, month)

Table H.15: Record sheet of performance measure: Waste generated rate

Element	**Description**
Purpose	It measures the amount of waste generated per worked hour
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Quantity of waste generated}}{\text{Worked time}}$
Unit of measurement	kg / h
Frequency of analysis	Monthly
Actions	Understand whether a specific type of residue contributes to the increased value and, if possible, take actions to reduce it
Source of data	SharePoint: quantity of waste generated Data warehouse (HORAS_WEBP_TRS_FULL table): worked time
Filter	Date (year, month)

Table H.16: Record sheet of performance measure: Pipe waste ratio

Element	Description
Purpose	It measures the proportion of pipe discarded as waste relative to the total pipe used in production, including both the pipe incorporated into spools and the pipe lost as waste
Relates to	Be better: incorporate SHE principles into daily routines
Formula	$\frac{\text{Quantity of wasted pipe}}{\text{Quantity of pipe used in production}} \times 100$
Unit of measurement	%
Frequency of analysis	Monthly
Actions	Understand the potential causes, such as changes in the scrap generated or in characteristics of the projects
Source of data	SharePoint (MES): quantity of pipe used SharePoint: quantity of pipe discarded as waste
Filter	Date (year, month)

Table H.17: Record sheet of performance measure: Customer satisfaction index

Element	Description
Purpose	It assesses the degree of customer satisfaction based on the results of the customer satisfaction survey, which is usually sent four times throughout ongoing projects. Each survey question is evaluated on a five-point scale (ranging from one to five) and assigned a specific weight to reflect its relative importance in the overall assessment
Relates to	Be better: ensure customer satisfaction
Formula	$\frac{\sum(\text{Answer of question} \times \text{weight of question})}{\sum \text{Weight of question}}$
Frequency of analysis	Monthly
Actions	Understand the causes of a low index, identify which survey answers had the greatest impact, and take the necessary actions to prevent future problems
Source of data	Data warehouse (V_CLIENT_SURVEY table): survey metadata Data warehouse (V_CLIENT_SURVEY_ANSWERS table): individual answers
Filter	Date (year, month), project

Table H.18: Record sheet of performance measure: Customer satisfaction index - SHE

Element	**Description**
Purpose	It assesses the degree of customer satisfaction based on the results of the customer satisfaction survey, considering only the questions related to the SHE dimension
Relates to	Be better: ensure customer satisfaction
Formula	Same as for the customer satisfaction index, but only considering questions related to SHE perspective
Frequency of analysis	Monthly
Actions	Same as for the customer satisfaction index
Source of data	Same as for the customer satisfaction index
Filter	Date (year, month), project

Table H.19: Record sheet of performance measure: Differentiation index

Element	**Description**
Purpose	It evaluates how the company differentiates itself from the competition and is calculated based on specific questions from the customer survey
Relates to	Be better: ensure customer satisfaction
Formula	Same as for the customer satisfaction index, but is calculated using only the questions defined as relevant for assessing differentiation
Frequency of analysis	Monthly
Actions	Same as for the customer satisfaction index
Source of data	Same as for the customer satisfaction index
Filter	Date (year, month), project

Table H.20: Record sheet of performance measure: Customer complaints

Element	**Description**
Purpose	It considers the absolute number of recorded client complaints
Relates to	Be better: ensure customer satisfaction
Formula	Number of recorded client complaints
Unit of measurement	Complaint
Frequency of analysis	Monthly
Actions	Understand the reasons for the claim with the client
Source of data	Data warehouse (V_NON_COMPLIANCE table): records of complaints
Filter	Date (year, month), project

Table H.21: Record sheet of performance measure: Gross margin

Element	Description
Purpose	It calculates the company's revenue that remains after deducting project direct costs and shop floor costs (e.g., purchase of consumables and personal protective equipment). It can also be expressed in percentage terms, showing the proportion of revenue that remains after deducting these costs. Both are part of the P&L statements of the company
Relates to	Be cheaper: address budget deviations
Formula	Gross margin = Revenue - Project direct costs - Shop floor costs Gross margin (%) = $\frac{\text{Gross margin}}{\text{Revenue}} \times 100$
Unit of measurement	€ or % (respectively)
Frequency of analysis	Monthly
Actions	When comparing the actual value of gross margin with the corresponding budget value, which serves as the target, any discrepancies identified can be analyzed using the Quantity Effect (QE) and Price Effect (PE) calculations. The former captures the impact of revenue deviations on the gross margin, reflecting the effect of increases or decreases in sales volume, while the latter reflects the influence of variations in the gross margin (%) on actual revenue, thereby indicating whether performance was better or worse than planned. The formulas employed in these calculations are presented below: $\text{QE} = \left(\text{Revenue}_{\text{actual}} - \text{Revenue}_{\text{budget}}\right) \times \text{Gross margin (\%)}_{\text{budget}}$ $\text{PE} = \left(\text{Gross margin (\%)}_{\text{actual}} - \text{Gross margin (\%)}_{\text{budget}}\right) \times \text{Revenue}_{\text{actual}}$ $\text{Variation gross margin} = \text{Gross margin}_{\text{actual}} - \text{Gross margin}_{\text{budget}}$ Variation gross margin = $QE + PE$
Source of data	Data warehouse (V_ACCOUNTING table): actual values SharePoint: budget values
Filter	Date (year, month)

Table H.22: Record sheet of performance measure: EBITDA

Element	**Description**
Purpose	It measures the company's earnings, calculated by deducting from the gross margin the costs not directly related to production. These include operations support costs (e.g., salaries of staff providing operational and technical support, and electricity expenses), structural costs, which are necessary for the functioning of the organization (e.g., expenses related to activities carried out by internal departments such as Finance, HR, IMS, and IT), and other costs, which encompass non-recurrent expenses.
Relates to	Be cheaper: address budget deviations
Formula	EBITDA= = Gross margin - (Operations support + Structure + Other costs) $\text{EBITDA (\%)} = \frac{\text{EBITDA}}{\text{Revenue}} \times 100$
Unit of measurement	€ or % (respectively)
Frequency of analysis	Monthly
Actions	When comparing the actual value with the respective budget value, which serves as the target, any discrepancies may be attributed either to variations in the gross margin, which should be explored as explained in Table H.21, or to changes in other costs. To analyze the latter in more detail, both structure and operations support costs should be examined at the next level of subdivision. In practice, this means that each of these categories (operations support and structure) is further divided into smaller groups, referred to as cockpits. A cockpit represents a functional area that consolidates the costs associated with its activities. For example, within structure costs, there are cockpits such as IT Management and Finance, each of which aggregates its specific expenses. By breaking down the analysis to this level, it becomes possible to assess variations cockpit by cockpit and identify which ones are contributing to the changes in the EBITDA value
Source of data	Data warehouse (V_ACCOUNTING table): actual values SharePoint: budget values
Filter	Date (year, month)

Table H.23: Record sheet of performance measure: Workers utilization ratio

Element	Description
Purpose	It considers the relationship between the actual time workers are allocated to production processes and their total available time, providing a perspective on the utilization of available manpower capacity. It is not a metric focused on evaluating worker performance, but rather on how the available capacity is being managed
Relates to	Be cheaper: use the available capacity
Formula	$\frac{\text{Actual time allocated to production processes}}{\text{Total available time}} \times 100$
Unit of measurement	%
Frequency of analysis	Monthly
Source of data	Data warehouse (HORAS_WEBP_TRS_FULL table): hours allocated to production and total hours available
Filter	Date (year, month)

Table H.24: Record sheet of performance measure: Recorded hours - MES versus TRS

Element	Description
Purpose	It is a temporary measure identified because there are two ways to measure the time workers spend on production processes: one manual, in TRS (a module within the company's ERP), and the other in MES, registered directly by the operator. As discrepancies between these two types of records were found and workers were informed about this incorrect recording, this measure was chosen to assess whether improvements would occur
Relates to	Be cheaper: use the available capacity
Formula	$\frac{\text{Actual time allocated to production processes recorded in MES}}{\text{Actual time allocated to production processes recorded in TRS}} \times 100$
Unit of measurement	%
Frequency of analysis	Monthly
Actions	Promote and train the proper use of the MES
Source of data	SharePoint (MES): hours recorded in MES Data warehouse (HORAS_WEBP_TRS_FULL table): hours recorded in TRS
Filter	Date (year, month)

Appendix I

Data Collection

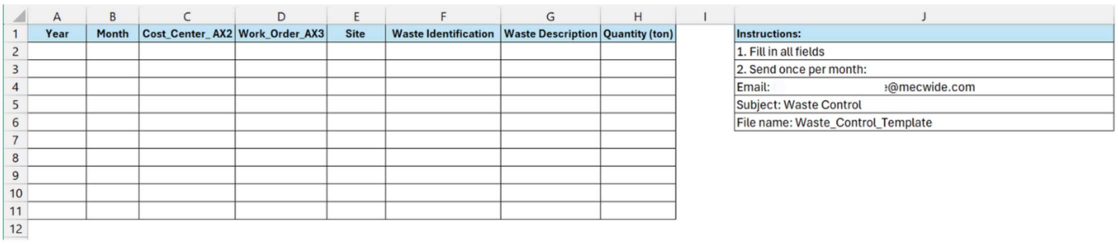

Figure I.1: Template used to record data on waste generated

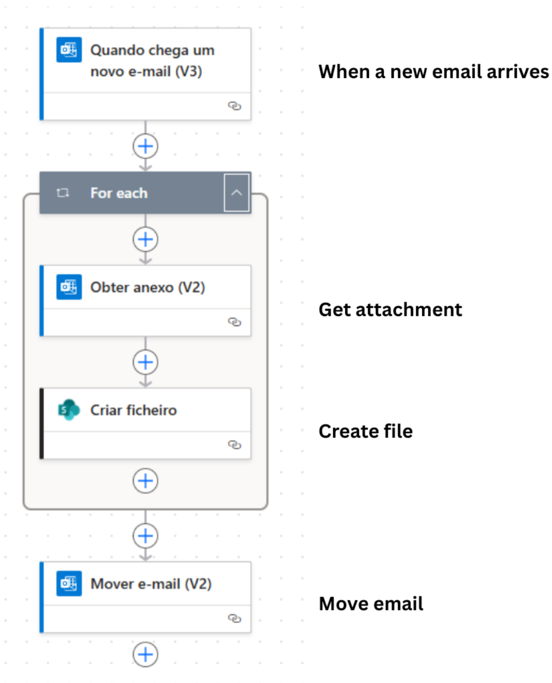

Figure I.2: Power Automate flow to update data on the SharePoint spreadsheet

Appendix J

Data Transformation

Table J.1: Overview of main M functions used in Power Query transformations

Function	Description
Table.RemoveColumns	Removes specified columns from a table
Table.AddColumn	Adds a new column based on a custom formula
Table.RenameColumns	Renames columns in a table
Table.ReorderColumns	Changes the order of columns in a table
Table.TransformColumnTypes	Changes the data to a specific type (e.g., decimal number, integer number, and text)
Table.DuplicateColumn	Creates a copy of an existing column in the same table
Table.SplitColumn	Splits a column into multiple columns based, e.g., on a delimiter or fixed length
Table.Distinct	Removes the duplicate rows from the table
Table.SelectRows	Filters rows in a table based on specified conditions
Table.ReplaceValue	Replaces values in a column with new alternatives
Table.Pivot	Converts the values of rows in a column into new columns
Table.UnpivotOtherColumns	Unpivots columns by transforming their values into rows
Table.NestedJoin	Joins two tables based on a key column, producing a nested table as a result. The join types include inner, outer, left, and right
Table.ExpandTableColumn	Expands a nested table column into multiple columns
Table.Combine	Combines multiple tables into a single table
Table.Group	Groups rows by one or more column keys and applies aggregate functions (e.g., sum and average)
Table.Sort	Sorts rows in a table by one or more columns
Table.AddIndexColumn	Adds a column containing sequential index numbers
Table.ExpandListColumn	Expands a list column into rows of a table

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Function	Description
Table.FromList	Converts a list into a table
Table.IsEmpty	Returns true if a table has no rows
List.Distinct	Returns a list with duplicate values removed
List.Min	Returns the minimum value from a list
List.Max	Returns the maximum value from a list
List.InsertRange	Inserts a list of values into another list at a specified position
Text.Contains	Returns true if a text string contains a specified sub-string
Text.AfterDelimiter	Returns the portion of text that appears after a specified delimiter
Text.From	Converts a value into text
Text.Upper	Converts all characters in a text string to uppercase
Text.End	Returns the last n characters of a text string
Text.StartsWith	Returns true if a text string begins with a specified substring
Duration.Days	Returns the number of days in a duration

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#	Step	Description	Power Query Code
1	Extract data	Extract "V_CLIENT_SURVEY" table from the data warehouse	Sql.Database(...) Origin{[Schema="dbo",Item="V_CLIENT_SURVEY"]}[Data]
2	Remove duplicates	Remove potencial duplicate rows	Table.Distinct(dbo_V_CLIENT_SURVEY)
3	Filter the relevant surveys	Filter surveys to include only those submitted in 2024 or after	Table.SelectRows(Distinct_rows, each Date.Year([SUB_DATE])>= 2024)
4	Change data types	Convert column to the correct data types	Table.TransformColumnTypes(#"Filter_sub_data_>=2024",{{"SUB_DATE", type date}})
5	Rename columns	Rename specific columns in accordance with their respective analytical axes	Table.RenameColumns(Change_type,{{"PROJECT", "AX2"}, {"CLIENT", "AX6"}})

6	Add AX3 column	This column represents one of the analytical axes corresponding to the identification of the work order and is included to enable future relationships within the data model
		
		The creation of column "AX3" (designated here as "AX3_OT_RU") follows two scenarios: if the value in "AX2" column starts with "PCL", then "AX3" is generated by concatenating "AX2" with "001". In all other cases, "AX3" is formed by concatenating "AX2" with the last two digits of "AX5" and the last two digits of "AX7". If either "AX5" or "AX7" has the value "NAP", the corresponding suffix is replaced with "00".
			Table.AddColumn(
			  Change_column_name,
			  "AX3_OT_RU",
			  each
			    let
			      cost = Text.From([AX2]),
			      siteSuffix = if Text.Upper(Text.From([AX5])) = "NAP" then "00" else Text.End(Text.From([AX5]), 2),
			      buSuffix = if Text.Upper(Text.From([AX7])) = "NAP" then "00" else Text.End(Text.From([AX7]), 2)
			    in
			      if Text.StartsWith(cost, "PCL") then
			        cost & "001"
			      else
			        cost & siteSuffix & buSuffix, type text)

7	Reorder columns	Reorder the columns into a logical and structured sequence that facilitates table analysis	Table.ReorderColumns(Add_AX3_OT_RU,{"NUM_DOC", "AX2", "AX3_OT_RU", "AX5", "AX6", "AX7", "SEND_DATE", "SUB_DATE", "COMPANY", "ID_SURVEY", "TOTAL", "PERC_VALUE"})

Figure J.1: Data transformations applied to the customer satisfaction survey table

#	Step	Description	Power Query Code
1	Extract data	Extract "INSPECTIONS" table from the SharePoint	Excel.Workbook(Web.Contents(...), null,true) Origin{[Item="INSPECTIONS", Kind="Table"]}[Data]
2	Remove duplicates	Remove potencial duplicate rows	Table.Distinct(Inspections_Sheet)
3	Filter out null inspections	Excludes incomplete inspections (those without an "Overall Result"), ensuring only finalized records are retained	Table.SelectRows(Distinct_rows, each ([Overall Result] <> null))
4	Change data types	Converts columns to the correct data types	Table.TransformColumnTypes(Filter_non_overall_result, {{"Rework", type logical}, {"Scrap", type logical},{"Diameter", type number}, {"Date", type date}})
5	Remove spaces	Strips all spaces from the "Sequence" column to avoid downstream issues	Table.ReplaceValue(Change_type_variable_1," ","",Replacer.ReplaceText,{"Sequence"})
6	Add inspection stage column	Creates a column marking each inspection as "Pre" or "Post" based on the "Type inspection" column	Table.AddColumn(Remove_space, "INSPECTION_STAGE", each if Text.Contains([Type inspection], "Pre") then "Pre" else if Text.Contains([Type inspection], "Post") then "Post" else "Post")
7	Add operation column	Removes "Pre/Post" prefix from "Type inspection" to isolate operation. Keeps value unchanged if no prefix, e.g., in "Incoming Pipe"	Table.AddColumn(Input_inspection_stage, "OPERATION", each if Text.Contains([#"Type inspection"], "-") then Text.AfterDelimiter([#"Type inspection"], "-") else [#"Type inspection"])
8	Add nominal diameter column	This step adds a column that maps each value in the "Diameter" column to its corresponding nominal diameter using the lookup table "TIMES_VICTAULIC", through a layered fallback strategy that ensures the best possible match even when the data is imprecise. First, if the "Diameter" is null or equal to zero, the original value is returned without further processing. If a value exists, the logic first attempts to find an exact match between "Diameter" and the "Diameter_DN" field in the lookup table. If no exact match is found, it applies a rounding strategy on "Diameter_DN" by calculating the floor and ceiling of the "Diameter" and comparing those rounded values to the rounded versions of "Diameter_DN", using RoundDown and RoundUp. If this still results in no match, the logic proceeds to attempt an exact match between "Diameter" and "Diameter_OD" field. If that also fails, it applies the same rounding fallback logic again, this time using the "Diameter_OD" values. The first successful match in any of these layers returns the corresponding "Diameter_DN" value. If no match is found at all, the function returns the original diameter. The goal of this process is to standardize the use of nominal diameters across the model in order to avoid future inconsistencies that could arise from mixing outer and nominal diameters in calculations and visualizations	Table.AddColumn(Input_operation_wo_stage_2, "DIAMETER_DN", each let diameter = [Diameter], victaulic = TIMES_VICTAULIC, result = if diameter = null or diameter = 0 then diameter else let // 1. Exact match with DIAMETER_DN matchID = Table.SelectRows(victaulic, each [DIAMETER_DN] = diameter), result1 = if Table.RowCount(matchID) > 0 then matchID{0}[DIAMETER_DN] else let // 2. Rounded match with DIAMETER_DN floorVal = Number.RoundDown(diameter), ceilVal = Number.RoundUp(diameter), matchID1 = Table.SelectRows(victaulic, each Number.RoundDown([DIAMETER_DN]) = floorVal), matchID2 = Table.SelectRows(victaulic, each Number.RoundUp([DIAMETER_DN]) = floorVal), matchID3 = Table.SelectRows(victaulic, each Number.RoundDown([DIAMETER_DN]) = ceilVal), matchID4 = Table.SelectRows(victaulic, each Number.RoundUp([DIAMETER_DN]) = ceilVal), resultIDapprox = if Table.RowCount(matchID1) > 0 then matchID1{0}[DIAMETER_DN] else if Table.RowCount(matchID2) > 0 then matchID2{0}[DIAMETER_DN] else if Table.RowCount(matchID3) > 0 then matchID3{0}[DIAMETER_DN] else if Table.RowCount(matchID4) > 0 then matchID4{0}[DIAMETER_DN] else null, result2 = if resultIDapprox <> null then resultIDapprox else let // 3. Exact match with DIAMETER_OD matchOD = Table.SelectRows(victaulic, each [DIAMETER_OD] = diameter), resultOD = if Table.RowCount(matchOD) > 0 then matchOD{0}[DIAMETER_DN] else let // 4. Rounded match with DIAMETER_OD match1 = Table.SelectRows(victaulic, each Number.RoundDown([DIAMETER_OD]) = floorVal), match2 = Table.SelectRows(victaulic, each Number.RoundUp([DIAMETER_OD]) = floorVal), match3 = Table.SelectRows(victaulic, each Number.RoundDown([DIAMETER_OD]) = ceilVal), match4 = Table.SelectRows(victaulic, each Number.RoundUp([DIAMETER_OD]) = ceilVal), resultODapprox = if Table.RowCount(match1) > 0 then match1{0}[DIAMETER_DN] else if Table.RowCount(match2) > 0 then match2{0}[DIAMETER_DN] else if Table.RowCount(match3) > 0 then match3{0}[DIAMETER_DN] else if Table.RowCount(match4) > 0 then match4{0}[DIAMETER_DN] else diameter in resultODapprox in resultOD in result2 in result1 in result, type number)
9	Add inch column	Performs a left outer join between the current table and the "TIMES_VICTAULIC" lookup table using a composite key consisting of "DIAMETER_DN" and "OPERATION", keeping all rows from the current table and adding matching data where available	Table.NestedJoin(Input_nominal_diameter_1, {"DIAMETER_DN", "OPERATION"}, TIMES_VICTAULIC, {"DIAMETER_DN", "OPERATION"}, "TIMES_VICTAULIC", JoinKind.LeftOuter) Table.ExpandTableColumn(Input_inch_1, "TIMES_VICTAULIC", {"Inch"}, {"TOTAL_INCH"}) Table.TransformColumnTypes(Input_inch_2,{{"TOTAL_INCH", type number}})
10	Add resolution code column	For the inspections with a "Fail" overall result, a Quality Control Process Charting (QCPC) register is generated. To retrieve the corresponding QCPC information, namely the "Resolution Code", a left outer join is performed between this table and the "QCPC" table using the "QCPC ID" as the key	Table.NestedJoin(Input_inch_3, {"QCPC ID"}, QCPC, {"QCPC ID"}, "QCPC", JoinKind.LeftOuter) Table.ExpandTableColumn(Input_QCPC_resolution_code_1, "QCPC", {"Resolution Code Abbr"}, {"RESOLUTION_CODE_ABBR"})
11	Unpivot inspection parameters	Converts parameter columns that are evaluated during the inspection into row-level data using "FAILED_PARAMETER" and "RESULT" column, allowing each inspection check to be treated individually for easier analysis Removes the suffix " Result" from the values in the "FAILED_PARAMETER" column	Table.UnpivotOtherColumns(Input_QCPC_resolution_code_2, {"Date", "Job Number", "Job Name", "Sequence", (...),"AX3"}, "FAILED_PARAMETER", "RESULT") Table.ReplaceValue(Change_column_to_line_1," Result","",Replacer.ReplaceText,{"FAILED_PARAMETER"})
12	Add job number-sequence column	This column is added as a merge of "Job Number" and "Sequence" to support relationships in the data model	Table.AddColumn(Remove_redundancy, "JOB_NUMBER_SEQ", each [Job Number]&[Sequence])
13	Rename and reorder columns	This includes standardizing column names to uppercase, replacing spaces with underscores where needed, and reordering the columns into a logical and structured sequence that facilitates table analysis	Table.RenameColumns(...) Table.ReorderColumns(...)

Figure J.2: Data transformations applied to the inspections records table

Appendix K

Data Model

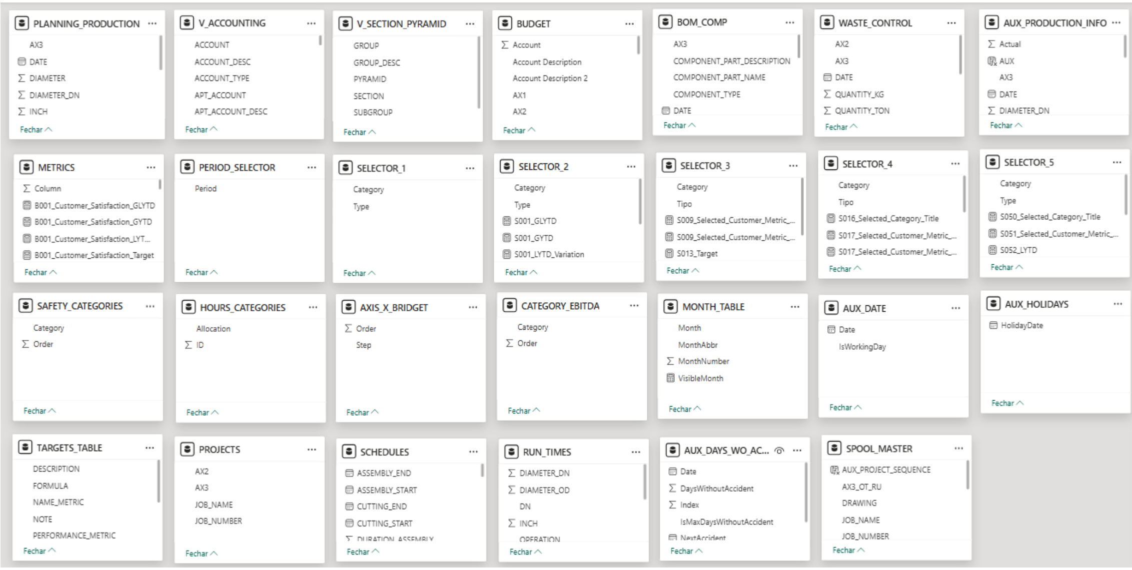

Figure K.1: Tables in the data model without direct relationships

Appendix L

Calculated Measures

```
B040_QR_YTD =
VAR SelectedPeriod = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR Result =
    SWITCH(
        SelectedPeriod,

        "YTD",
            DIVIDE(
                CALCULATE(
                    COUNTROWS(INSPECTIONS),
                    INSPECTIONS[FAILED_PARAMETER] = "Overall",
                    INSPECTIONS[RESULT] = "Pass",
                    DATESYTD('DATE'[Date])
                ),
                CALCULATE(
                    COUNTROWS(INSPECTIONS),
                    INSPECTIONS[FAILED_PARAMETER] = "Overall",
                    DATESYTD('DATE'[Date])
                ),
                0
            ),
            DIVIDE(
                CALCULATE(
                    COUNTROWS(INSPECTIONS),
                    INSPECTIONS[FAILED_PARAMETER] = "Overall",
                    INSPECTIONS[RESULT] = "Pass",
                    DATESMTD('DATE'[Date])
                ),
                CALCULATE(
                    COUNTROWS(INSPECTIONS),
                    INSPECTIONS[FAILED_PARAMETER] = "Overall",
                    DATESMTD('DATE'[Date])
                ),
                0
            ),
        BLANK()
    )
RETURN
    Result
```

```
B004_Client_Claims_YTD =
VAR SelectedPeriod = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR Result =
    SWITCH(
        SelectedPeriod,
        "YTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD('DATE'[Date])
            ),
        "MTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESMTD('DATE'[Date])
            ),
        BLANK()
    )
RETURN
    Result
```

Figure L.1: Correspondence between DAX codes of the same type of measure (measure one), with highlights indicating similarities

```
B004_Client_Claims_YTD =
VAR SelectedPeriod = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR Result =
    SWITCH(
        SelectedPeriod,
        "YTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD('DATE'[Date])
            ),
        "MTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESMTD('DATE'[Date])
            ),
        BLANK()
    )
RETURN
    Result
```

Figure L.2: DAX code for the type one measure (YTD/MTD value) applied to the performance measure customer complaints

```
B004_Client_Claims_YTD_Display =
VAR V_YTD = [B004_Client_Claims_YTD]
RETURN
IF(
    ISBLANK(V_YTD),
    "N/A",
    V_YTD
)
```

Figure L.3: DAX code for the type two measure (YTD/MTD display) applied to the performance measure customer complaints

```
B004_Client_Claims_Target =
VAR SelectedMetric = "B004"
VAR SelectedYear = SELECTEDVALUE('DATE'[YEAR])
VAR TargetValue = LOOKUPVALUE(
    TARGETS_TABLE[TARGET],
    TARGETS_TABLE[PERFORMANCE_METRIC],SelectedMetric,
    TARGETS_TABLE[YEAR],SelectedYear
)
RETURN TargetValue
```

Figure L.4: DAX code for the type three measure (target value) applied to the performance measure customer complaints

```
B004_Client_Claims_Target_Variation =
VAR V_YTD = [B004_Client_Claims_YTD]
VAR Target = [B004_Client_Claims_Target]
Var Var_Target = DIVIDE(V_YTD - Target, Target, 0)

RETURN
IF(
    NOT ISBLANK(V_YTD) && NOT ISBLANK(Target) && Target<>0 && NOT ISBLANK(Var_Target),
        FORMAT(Var_Target, "0.00%;(0.00%)"),
        "N/A"
    )
```

Figure L.5: DAX code for the type four measure (target variation) applied to the performance measure customer complaints

```
B004_Client_Claims_LYTD_Variation =
VAR Period = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR CurrentValue = [B004_Client_Claims_YTD]
VAR ComparisonValue =
    SWITCH(
        Period,
        "YTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD(SAMEPERIODLASTYEAR('DATE'[Date]))
            ),
        "MTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESMTD(DATEADD('DATE'[Date], -1, YEAR))
            ),
        BLANK()
    )
VAR Delta = DIVIDE(CurrentValue - ComparisonValue, ComparisonValue, 0)
RETURN
    IF(
        NOT ISBLANK(CurrentValue) &&
        NOT ISBLANK(ComparisonValue) &&
        ComparisonValue <> 0 &&
        NOT ISBLANK(Delta),
        FORMAT(Delta, "0.00%;(0.00%)"),
        "N/A"
    )
```

Figure L.6: DAX code for the type five measure (previous year variation) applied to the performance measure customer complaints

```
B004_Client_Claims_GYTD =
VAR SelectedPeriod = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR SelectedMonthGraph = SELECTEDVALUE(MONTH_TABLE[MonthNumber])
VAR CurrentYear = MAX('DATE'[Year])
VAR MinDisplayDate = DATE(CurrentYear, SelectedMonthGraph, 1)
VAR MaxDisplayDate = EOMONTH(MinDisplayDate, 0)
VAR Result =
    SWITCH(
        SelectedPeriod,
        "YTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD('DATE'[Date]),
                'DATE'[Date] <= MaxDisplayDate
            ),
        "MTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD('DATE'[Date]),
                'DATE'[Date] >= MinDisplayDate && 'DATE'[Date] <= MaxDisplayDate
            ),
        BLANK()
    )
RETURN
    IF(ISBLANK(Result), 0, Result)
```

Figure L.7: DAX code for the type six measure (YTD/MTD chart value) applied to the performance measure customer complaints

```
B004_Client_Claims_GLYTD =
VAR SelectedPeriod = SELECTEDVALUE(PERIOD_SELECTOR[Period], "YTD")
VAR SelectedMonthGraph = SELECTEDVALUE(MONTH_TABLE[MonthNumber])
VAR CurrentYear = MAX('DATE'[Year]) - 1
VAR MinDisplayDate = DATE(CurrentYear, SelectedMonthGraph, 1)
VAR MaxDisplayDate = EOMONTH(MinDisplayDate, 0)
VAR Result =
    SWITCH(
        SelectedPeriod,
        "YTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD(SAMEPERIODLASTYEAR('DATE'[Date])),
                'DATE'[Date] <= MaxDisplayDate
            ),
        "MTD",
            CALCULATE(
                COUNTROWS(V_NON_COMPLIANCE_CORRECTIVE_ACTION),
                V_NON_COMPLIANCE_CORRECTIVE_ACTION[ORIGIN] = "Client Claim",
                DATESYTD(SAMEPERIODLASTYEAR('DATE'[Date])),
                'DATE'[Date] >= MinDisplayDate && 'DATE'[Date] <= MaxDisplayDate
            ),
        BLANK()
    )

RETURN
    IF(ISBLANK(Result), 0, Result)
```

Figure L.8: DAX code for the type seven measure (previous year chart value) applied to the performance measure customer complaints

Appendix M

Performance Dashboard Displays

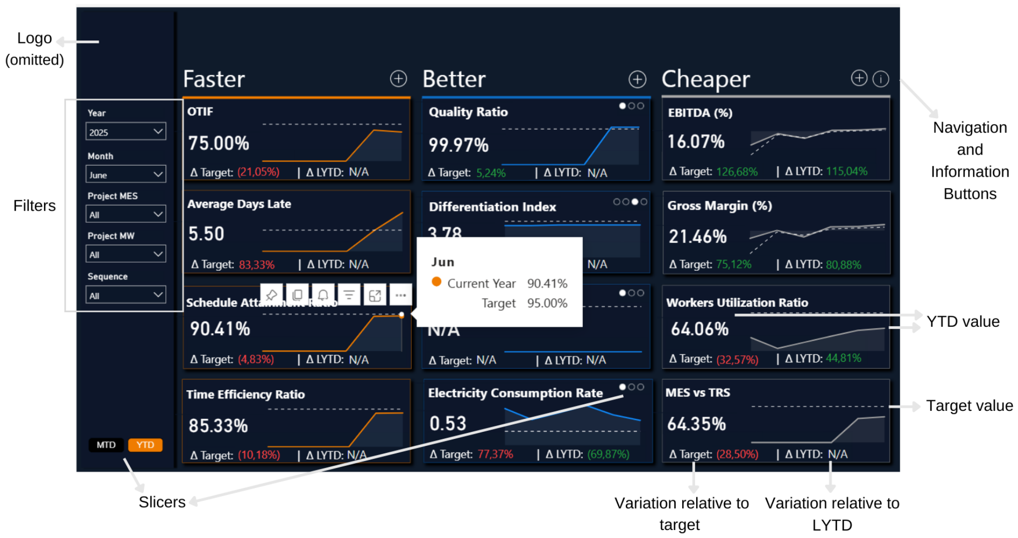

Figure M.1: Identification of the elements of the top-level display

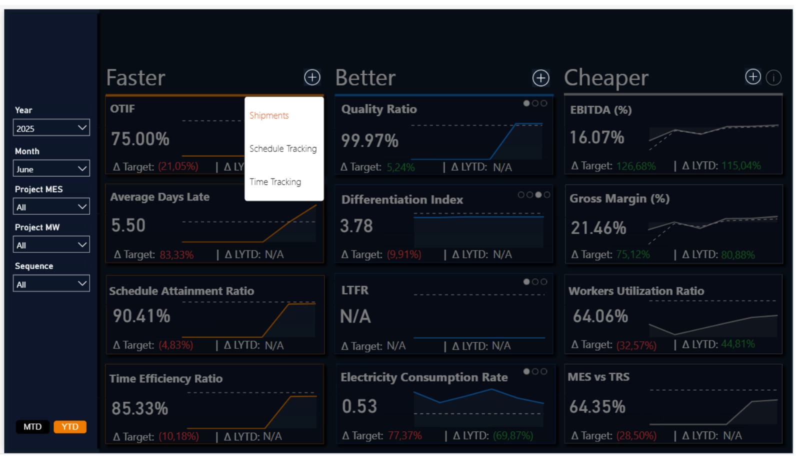

Figure M.2: Example of the drop-down menu in the top-level display

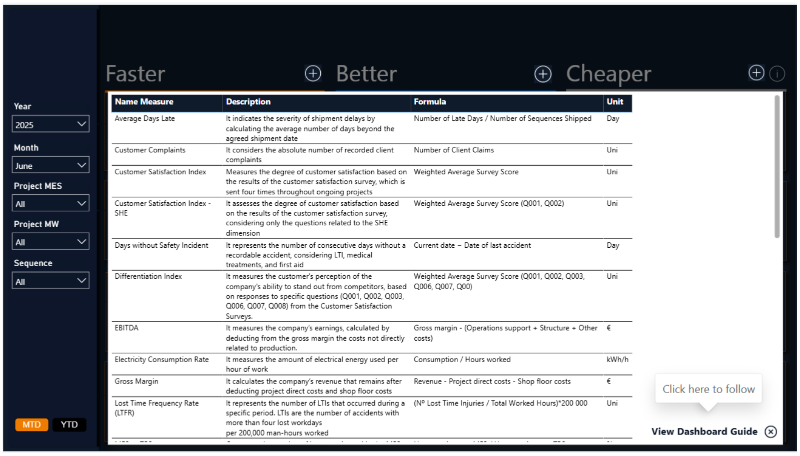

Figure M.3: Information panel of the performance dashboard in the top-level display

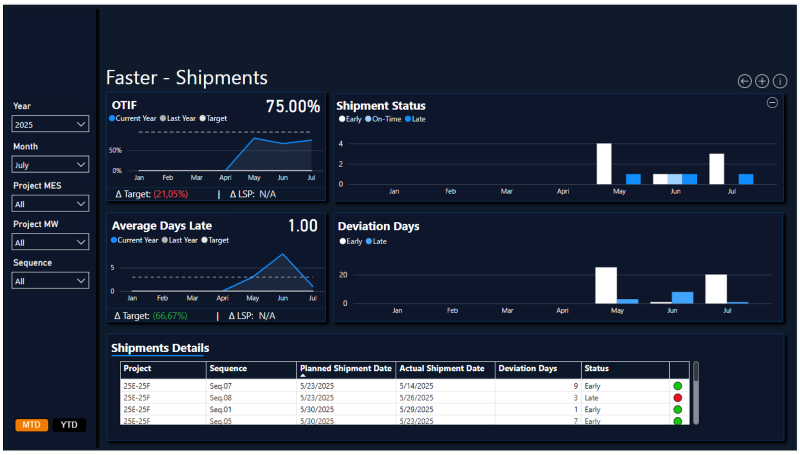

Figure M.4: Performance dashboard display containing shipment data with Shipment status presented in absolute numbers

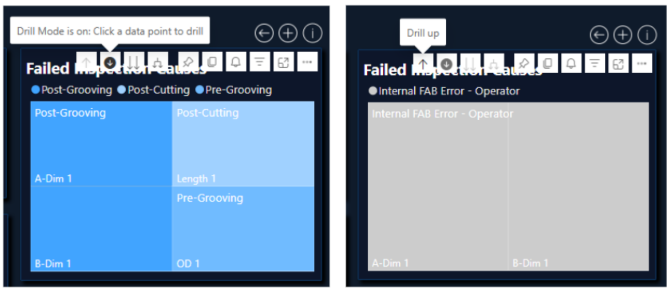

Figure M.5: Example of the drill-down option in the tree map within the Quality display

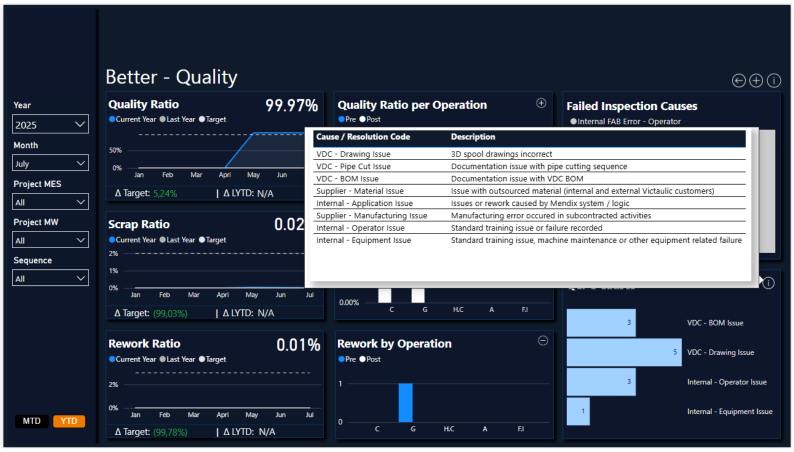

Figure M.6: Illustration of the tooltip feature in the Quality display

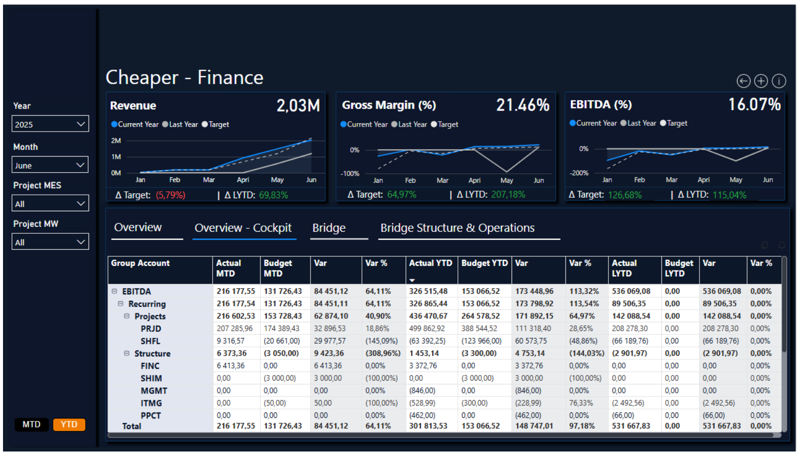

Figure M.7: Detailed table in the "Overview – Cockpit" tab of the Finance display

Figure M.8: Variance charts showing EBITDA variation in the "Bridge" tab of the Finance display

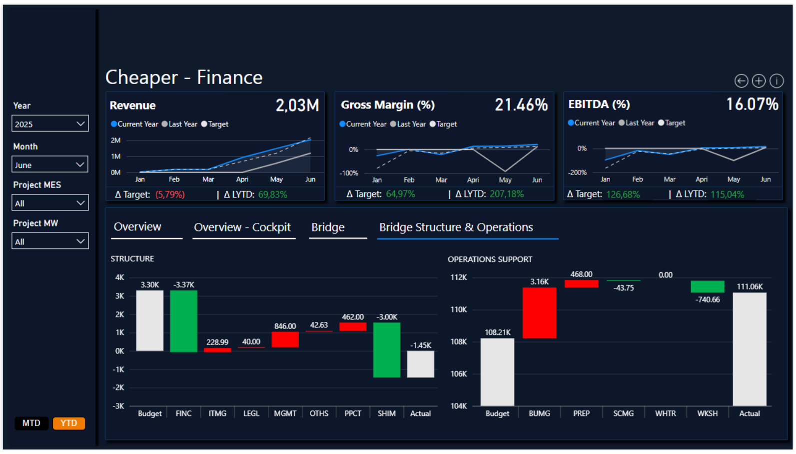

Figure M.9: Variance charts illustrating the variation of structural and operational support costs in the "Bridge – Structure & Operations" tab of the Finance display

Appendix N

Assessment of the Performance Dashboard

Table N.1: Questions employed in the assessment of the developed performance dashboard

#	Question
1	How do you assess the process that was used to select the performance measures, encompassing the identification of CSFs aligned with the strategy and their translation into specific measures?
2	How do you evaluate the definition of the performance measures, with regard to the identified elements such as name, formula, purpose, actions, and frequency of analysis?
3	How do you assess the adequacy of the number of indicators chosen?
4	How would you evaluate the quality of the data incorporated?
5	How would you evaluate the quality of the resulting outputs?
6	How would you rate the organization of the dashboard between the top-level display and the additional detail pages?
7	How do you evaluate the arrangement of the elements in the top-level display?
8	How do you classify the arrangement of the elements in the other displays?
9	How do you evaluate the choice of visual elements (e.g., charts and tables)?
10	How do you evaluate the other interactive elements (e.g., bookmarks, tooltips, navigation buttons, filters, slicers)?
11	How do you rate the potential of this BI-based solution to improve decision-making and support the performance management process of the company?

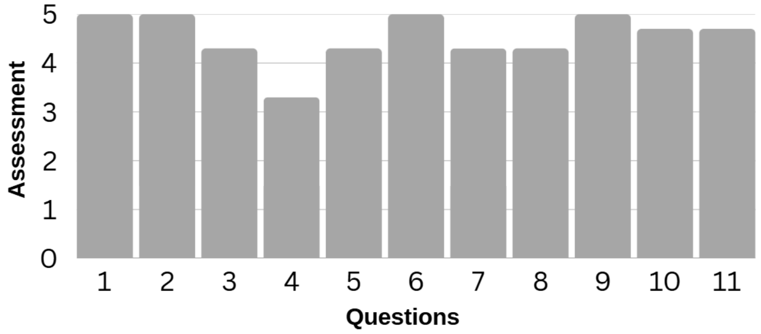

Figure N.1: Results of the closed-ended questions from the performance dashboard assessment