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OPTIMIZATION OF PERFORMANCE MANAGEMENT OF LVHM MANUFACTURING

MSc MECHANICAL ENGINEERING

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Table of Abbreviations

Abbreviation	Full Form
AI	Artificial Intelligence
BA	Business Analysis
BI	Business Intelligence
BSC	Balanced Scorecard
CCTV	Closed-Circuit Television
CLV	Customer Lifetime Value
COPQ	Cost of Poor Quality
CRG	Capacity, Resource, Grouping
CW	Calendar Week
DAX	Data Analysis Expressions
DVR	Digital Video Recorder
ERP	Enterprise Resource Planning
GPS	Global Positioning System
HMLV	High-Mix Low-Volume
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
LAN	Local Area Network
LVHM	Low-Volume High-Mix
MIT	Massachusetts Institute of Technology
OKR	Objectives and Key Results
OTD	On-Time Delivery
P&L	Profit and Loss
QDCSM	Quality–Delivery–Cost–Safety–Morale
ROI	Return on Investment
SAP	Systems, Applications & Products in Data Processing
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SME	Small and Medium-sized Enterprise
SORT	Simple Online and Real-Time Tracking

USD	United States Dollar
UV	Ultraviolet
WiFi	Wireless Fidelity
YOLO	You Only Look Once

Abstract

Low-volume high-mix (LVHM) manufacturing environments are characterized by high product variety, variable demand, and complex interdepartmental coordination, conditions that render conventional performance measurement frameworks structurally inadequate. Existing systems, including the Balanced Scorecard, SMART, and OKR frameworks, operate primarily at the strategic level and fail to translate shop-floor operational deviations into real-time, financially interpretable insights at the production department level. This research addresses that structural gap through an empirical case study conducted at Bürkle Hungary Kft., a custom machine assembly located in Debrecen, Hungary.

The study pursued four primary objectives: documenting current KPIs and their tracking methods, developing an integrated operational-financial performance framework, designing a conceptual sensor-based coordination loss tracking system, and delivering a real-time business intelligence dashboard for continuous performance monitoring. A qualitative case study methodology was adopted, combining semi-structured interviews, direct observation, and operational document analysis. Eight key performance indicators were identified and assessed over a 12–13-week period, revealing critical gaps including a supplier on-time delivery rate of 40%, a rework burden reaching 2.4% of productive hours, and qualitative evidence of significant unquantified labor time lost to coordination-related disruptions a category entirely absent from the existing KPI architecture.

In response, a QDCSM-P&L integrated performance framework was developed, directly linking operational indicators across quality, delivery cost, safety, and morale dimensions to production-level profit and loss outcomes. A novel KPI, the Coordination Loss Rate, was introduced to formally capture unproductive labor arising from systemic workflow disruptions. A conceptual sensor and computer vision-based detection system was designed using Pahl's systematic engineering design methodology to enable its future measurement. Finally, a multi-page Microsoft Power BI dashboard was developed as the digital realization of the framework, embedding financially weighted metrics including Cost of Poor Quality and Coordination Loss Cost to support timely managerial decision-making. The findings demonstrate that LVHM performance management failures are fundamentally architectural rather than data-related, and that integrated, low-cost, scalable frameworks can meaningfully close the gap between operational visibility and financial accountability.

Absztrakt

Az alacsony volumenű, nagy mixű (LVHM) gyártási környezeteket nagy termékválaszték, változó kereslet és összetett részlegek közötti koordináció jellemzi, amelyek olyan feltételek, amelyek a hagyományos teljesítménymérési keretrendszereket strukturálisan alkalmatlanná teszik. A meglévő rendszerek, beleértve a Balanced Scorecard, a SMART és az OKR keretrendszereket, elsősorban stratégiai szinten működnek, és nem képesek a gyártóüzemi működési eltéréseket valós idejű, pénzügyileg értelmezhető információkká alakítani a termelési részleg szintjén. Ez a kutatás ezt a strukturális hiányosságot vizsgálja egy empirikus esettanulmányon keresztül, amelyet a debreceni Bürkle Hungary Kft.-nél, egy egyedi gépösszeszerelő kkv-nál végeztek.

A tanulmány négy fő célkitűzést követett: a jelenlegi KPI-k és azok nyomon követési módszereinek dokumentálása, egy integrált működési-pénzügyi teljesítmény-keretrendszer kidolgozása, egy koncepcionális, érzékelőalapú koordinációs veszteségkövető rendszer megtervezése, valamint egy valós idejű üzleti intelligencia irányítópult létrehozása a folyamatos teljesítményfigyeléshez. Kvalitatív esettanulmány módszertanát alkalmazták, amely félig strukturált interjúkat, közvetlen megfigyelést és működési dokumentumelemzést ötvöz. Nyolc kulcsfontosságú teljesítménymutatót azonosítottak és értékeltek 12–13 hét alatt, feltárva a kritikus hiányosságokat, beleértve a beszállítók 40%-os határidőre történő szállítási arányát, a produktív órák 2,4%-át elérő átdolgozási terhet, valamint a koordinációval kapcsolatos zavarok miatti jelentős, nem számszerűsített munkaidő-veszteség kvalitatív bizonyítékait – egy olyan kategóriát, amely teljesen hiányzik a meglévő KPI-architektúrából.

Válaszul egy QDCSM-P&L integrált teljesítmény-keretrendszert fejlesztettek ki, amely közvetlenül összekapcsolja a minőség, a szállítási költség, a biztonság és a morál dimenzióin alapuló működési mutatókat a termelési szintű nyereség-veszteség eredményekkel. Bevezettek egy új KPI-t, a koordinációs veszteség arányát, hogy hivatalosan rögzítsék a szisztematikus munkafolyamat-zavarokból eredő improduktív munkaerőt. Egy koncepcionális érzékelő és számítógépes látás alapú érzékelő rendszert terveztek Pahl szisztematikus mérnöki tervezési módszertanának felhasználásával, hogy lehetővé tegyék a jövőbeni mérését. Végül egy többoldalas Microsoft Power BI irányítópultot fejlesztettek ki a keretrendszer digitális megvalósításaként, amely pénzügyileg súlyozott mutatókat ágyazott be, beleértve a rossz minőség költségét és a koordinációs veszteség költségét, hogy támogassa az időben történő vezetői döntéshozatalt. Az eredmények azt mutatják, hogy az LVHM teljesítménymenedzsmentjének hibái alapvetően architektúrálisak, nem pedig adatalapúak, és hogy az integrált, alacsony költségű, skálázható keretrendszerek jelentősen áthidalhatják a működési láthatóság és a pénzügyi elszámoltathatóság közötti szakadékot

Introduction

In low-volume high-mix (LVHM) manufacturing application, fluctuating customer needs, and product variation present critical efficiency challenges. These difficulties are not limited only to the startup envirnments, it also affect prominent and well established firms (Ex - small, niche manufacturers to large, globally functioning corporations). Companies must continuously change their production systems and improve performance using data-driven decision-making methodologies to stay competitive. According to latest studies reveal LVHM industies has grown drastically in recent years, due to integration of Industry 4.0 and the demand for personalization of the products. Still, there are major gaps in domains such as real-time decision support, lean adaptation, and human-machine collaboration [1].

Nevertheless, mass production business model, characterized by linear processes and predictable performance variations, LVHM manufacturing contends with variable demand patterns, irregular lead times, and recurrent coordination issues within departments. Because of these qualities, planning, cost evaluation, and performance control are all made more difficult. The dynamic character of LVHM industrial operations is sometimes not well represented by evaluation methodologies, which are primarily designed for contexts of repetitive production. Additionally, these approaches occasionally fail to adequately depict the changing nature of LVHM industrial environments [1]. Establishing key performance metrics in unforeseen circumstances may prove difficult. The situation's complexity originated from the numerous production processes, the unpredictability of inputs, and the coordination of operations. The decision-making process is critically important, as abnormalities can rapidly disseminate across the system and affect customer satisfaction [2].

The difficulties are substantial in the current condition of LVHM, which often performs with fewer resources and coordination mechanisms that are less well defined than those of established organizations. Performance evaluations are frequently inconsistent, operational metrics are generally evaluated independently of financial outcomes, and alignment with strategy is seldom sufficiently developed or sustained, even when procedures exist. This explains why firms experience diminished efficiency when they depend on irrelevant operational measures or no longer relevant financial data. However, technical limitations highlight the significance of a comprehensive performance monitoring approach tailored for LVHM environments.

Aim of the thesis

Problems with operations and dependability in finances coexist in LVMH manufacturing. However, there are three major flaws that contemporary methods of evaluating performance highlight most operational frameworks used in lean management, such Quality-Delivery-Cost-Safety-Morale (QDCSM), fail to establish a clear connection between shop-floor performance metrics and financial outcomes. In most cases, QDCSM does not fully translate operational inconsistencies into measurable financial implications, regardless the fact that it provides organized insight into operational performance. Second, hidden productivity gaps are rarely measured in a structured way, especially those that are caused by problems in coordinating between workers and departments coordination delays and disruptions can significantly affect delivery performance, cost structures, and ultimately, profitability. losses largely remain undetected inside traditional KPI frameworks.

Additionally, digital technology and Business Intelligence (BI) platforms provide novel opportunities for real-time performance visualization and data-informed decision-making. Efficacy relies on the presence of a solid foundational measuring framework. In the absence of structural integration between operational and financial metrics, dashboards may devolve into descriptive rather than decision-supportive instruments. Consequently, a research gap emerges in facilitating the development of a comprehensive anchored performance measuring framework, So the comprehensive objectives are,

O1 - To discover and document the KPIs and their tracking methods through the case study that drives the LVHM production environment.

O2 – To design a QDCSM-based performance framework providing both operational and financial visibility.

O3 - To develop a conceptual sensor-based system for tracking coordination losses and improving labor productivity.

O4 – To design/development of decision support real time data visualization method for continuous performance indicators monitoring.

1 Literature Review

1.1 Overview of LVHM Production

The market is shifting from mass production to mass customization, resulting in greater complexity for businesses. Unlike mass production environments, where responsibilities are conventional and standardized, industries that utilize mass customization encounter numerous task result in complex working atmosphere. Promoting sustainability across all industries is critical for humanity's future. As an essential industry, manufacturing has a substantial impact on it. Companies that develop and manufacture new products and technology may pursue unconventional solutions, such as a low-volume manufacturing method. As mentioned in Table 1, these mass customization industries are known as LVHM manufacturing firms because of how they provide divers range of products while maintainng a low number of products [3]. Furthermore, as custormer demand for unique products grows, customization and personalization are becoming increasingly important in this manufacturing model. But small and medium sized industries confront challenges when they shift to LVHM model [4].

Table 1: Difference between Manufacturing System [3]

Manufacturing system	Mass production	Low-Volume High-Mix
Chief Characteristics	Interchangeable parts	Rapid response, minimum warehouse
Lot size	Large	Small
Worker skill	Craftsmen with standardization	High and low
Product life Cycle	Varies, usually long	Very short
Product variability	Restricted	Very high
Manufacturing lead time	Medium	Very short
Work in Process	High	Close to none
Degree of automation	Some	Mixed, with excellent data tracking

LVHM industries, which pay attention to customer demand and rapid changes in the market, will have an upper hand over their competitors [5]. Keen LVHM manufacturing industries concentrate on product customization leveraging advance technologies to fulfil unique consumer demand. Some aspects of agile manufacturing are critical factors, as it involves modular components, partially finished mechanical machines, flexible production, and changeable platforms. These characteristics enable production industries to easily adapt to changing conditions. As a result, improved and empowered manufacturers with technology provide customizable, preconfigured products while reducing their product lead times, manufacturing costs, and finally the setup challenges. Meanwhile, several manufacturing industries are unable to apply any of these above-mentioned strategies to their dynamic environment.

Even though there are many benefits to LVHM production environment, there are also certain issues that need attention to be dealt with to increase operational effectiveness and the profitability of the organization. These challenges include regular changeovers, higher setup cost, inventory management, raw material wastage, Coordination issues, productivity losses and finally the supply chain challenges. As consumers expect more personalized, ready-made items, manufacturers are capitalizing on this trend to separate themselves from competition. However, the LVHM manufacturing environment is not the same as typical mass production's high-volume, low mix setting. First main problem is large variation of distinct items production in very small quantities and demand varies significantly among segments. Also, the usage of different routes for each product, and cycle times vary greatly depending on the product type. These following qualities are challenging to the operations [1]. Moreover, integrating on-demand manufacturing, and efficient supply chains inside the organization reduce lead time and overhead cost, in today's economy, where customer-based product solutions are crucial as automation provides a significant competitive edge for the industries. Businesses must adjust themselves to the ever-changing demands and trends in order to stay in the market [5].

Yet, since manufacturing is a primary cost driver, it has a significant impact on the company's performance. Customers, who typically have significant purchasing power, want timely delivery and great quality. These are also characteristics that are influenced by manufacturing processes. As a result, the company's primary priority in this area is to reduce costs while meeting client expectations in terms of quality and timely delivery[6].

1.2 Productivity in Manufacturing

Any organization's biggest and most difficult responsibility nowadays is "PRODUCTIVITY." The efficiency of the entire production system, the type of raw material inputs, the management's performance, and the combined or integrated efficiency of workers, machines, and other devices and equipment all directly affect organization productivity. However, in LVHM industry, Customization is the execution of tailored orders, necessitating regular design modifications and continuous process variations owing to product differentiation. Main challenge in operating mass customization manufacturing is the variety of difficulties presented by frequent design alterations and recurring process fluctuations and significance of variety coordination from design to manufacturing [7]. At the end it led to delivery slippage in manufacturing businesses. Somehow this is directly connected to the low worker productivity.

It was identified there are problems with coordination in the supply of materials and the availability of tools in production make productivity loss of workers directly. Employees frequently booked "idle" job cards under NO TOOL because they were unable to get the necessary standard tools from the tool counters, which reduced productivity by 2%. Additionally, machining time was impacted by mismatches and delays in the materials that were issued, such as larger or higher-hardness stock. Corrections were only possible for the subsequent production order because this material issue was discovered after the batch was finished. However, maintaining labor productivity is a major challenge because manufacturing heavily relies on labor. Therefore, Finding and comprehending the different elements that affect an organization's growth is crucial for its advancement. The most crucial of these is employee productivity. Each company must keep a close eye on this performance aspect [8].

1.3 Importance of Performance Metrics

Global competition raises substantial challenges for industries attempting for better opportunities. Customer demand for highly complex products and services is rapidly changing. To lower the cost, industries must adapt to the needs of their consumers and the market by providing specialized products and services plus developing flexible procedures and coordinating resources across the inside supply chain of the organization (Figure 1). Management requires readily available and reliable business performance data to address these challenging difficulties.[9].

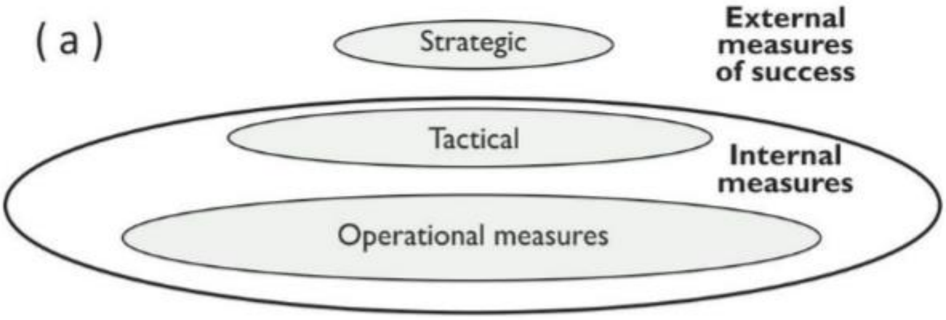


Figure 1: Zones of Measurement in Business [10]

In today's modern era, accurate and reliably measurement of performance indicators is crucial for improving the organization performance and this is where manufacturing industries performance indicators appear. KPIs are essential to success the organization when they assist in making it feasible to monitor the company's performance. Especially, KPIs are particular indicators that accurately depict the main operations of corporate activity internally and externally as shown in Figure 1. To maximize the benefits of the chosen KPIs, they must be achievable, assigned, timely, relevant, and measurable [11].

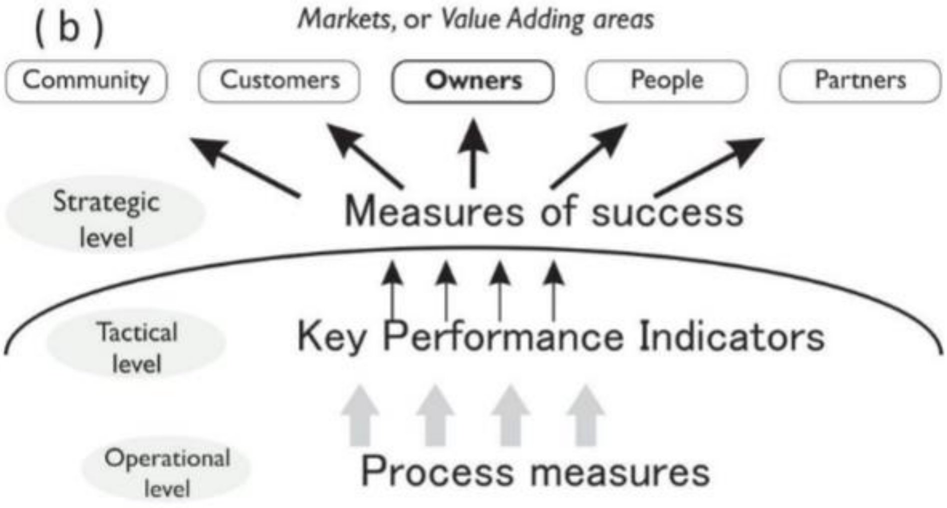


Figure 2: Structure of Measurement [10]

A key concern is to develop effective performance indicators and standards to assit managers in making decisions that improve organizational competitiveness rapidly. In LVHM context also these KPIs are one major insight to indicate defciencies that are covered up. As an example, lengthy change overs, lead time fluctuation and capacity manamegt challenges and etc directly affect for the customer satisfaction and industries profitability. Thats why, when developing the KPIs, above mentioned Figure 2 structure of measurement should be concidered. [12].

Managing daily production in LVHM manufacturing environment can be extremely challenging considering ineffective KPIs like shortest lead time, efficient resource utilization, on time delivery and most importantly unpredictable suppliers could further worsen the issue.[13]. But most importantly poor performance can be defined as organizational waste, which can take many forms. Identifying waste and adopting waste reduction strategies improve performance. Waste can take numerous forms, including energy, raw materials, routing problems, transportation downtime, operation, maintenance, quality, and so on. The following KPIs in Table 02 can be built from waste as mentioned above, and there are many possibilities to build KPIs like below [14].

Table 2: KPIs from the Waste [14]

KPI Type	Specific KPIs
Energy	Input energy/Output energy (Produced Output)
Raw Material	Raw material turnover
Operational KPI	Operation planned time vs actual time
Inventory KPI	Inventory Turnover, Average inventory
Maintenance KPI	Cost of maintenance vs Produced output

However, the most important question is whether traditional performance indicators can still be used, and then which ones should be addressed when monitoring performance in this new era. In this situation, when many behaviors are difficult to detect, some classic indicators may no longer be appropriate in this condition. Decision-making in companies that constantly change demand in an LVHM production environment is extremely difficult. Although mistakes cannot be tolerated under these conditions, negative consequences reach consumers immediately, but the right and most cost-effective answers must be found in a complex network of interconnected options. According to the expert, evaluating intangible and non-financial performance metrics is undoubtedly difficult. Yet monitoring and evaluating these KPIs are critical for firms to operate successfully in modern world [15].

1.4 Performance Measurement Systems

The significant demands for customization, coordination, and volatility are inherent in advanced manufacturing systems, such as low-volume high-mix manufacturing, where performance monitoring is essential. The applicability of traditional performance evaluation methods in dynamic environments is a subject of ongoing discussion. It is essential to examine the most prevalent frameworks used. In advanced manufacturing settings, particularly low-volume high-mix production, performance monitoring is critically important because of the significant levels of customization, coordination, and volatility present. Modern performance Measurement systems can be classified into goal-oriented frameworks, multidimensional strategic models, and standardized industrial KPI systems. Frequently employed approaches encompass the SMART criteria for KPI development, the Balanced Scorecard (BSC), Objectives and Key Results (OKRs), ISO 22400 and the QDCSM standard for industrial performance measurements. Each of these systems offers useful insights. Nevertheless, their relevance to LVHM necessitates cautious assessment.

1.4.1 SMART Framework

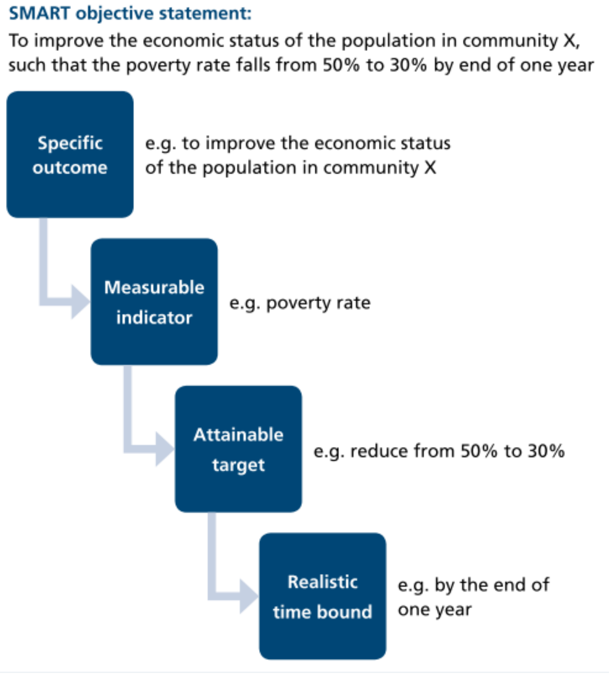


Figure 3: SMART Framework [16]

In the present day, there are requirements for successful establishment of objectives and tasks, such as the goal's uniqueness, tangibility, ability to achieve, and relevance, as well as its timely nature. This strategy for goal planning is known as the SMART-model. At the objective-setting stage, the smart-goal establishing system allows you to consolidate all relevant information, establish an acceptable work time, determine resource sufficiency, and assign clear, precise, and specified tasks to all process participants. The abbreviation SMART is defined as Specific, Measurable, Achievable, Relevant, and Time-bound. Each letter in the abbreviation SMART represents a criterion for the effectiveness of the goals specified [16]. According to Figure 03, there is an example of setting a KPI under this SMART methodology. It shows how manufacturing organization can go beyond and setting KPI in order to achieve their own vision. SMART is primarily a tool for defining goals rather than a comprehensive performance measurement system. It offers direction on formulating objectives but fails to delineate KPI hierarchies, performance dimensions, or the structural integration of measurements. Consequently, it is devoid of systemic architecture.

1.4.2 Balanced Scorecard (BSC) Framework

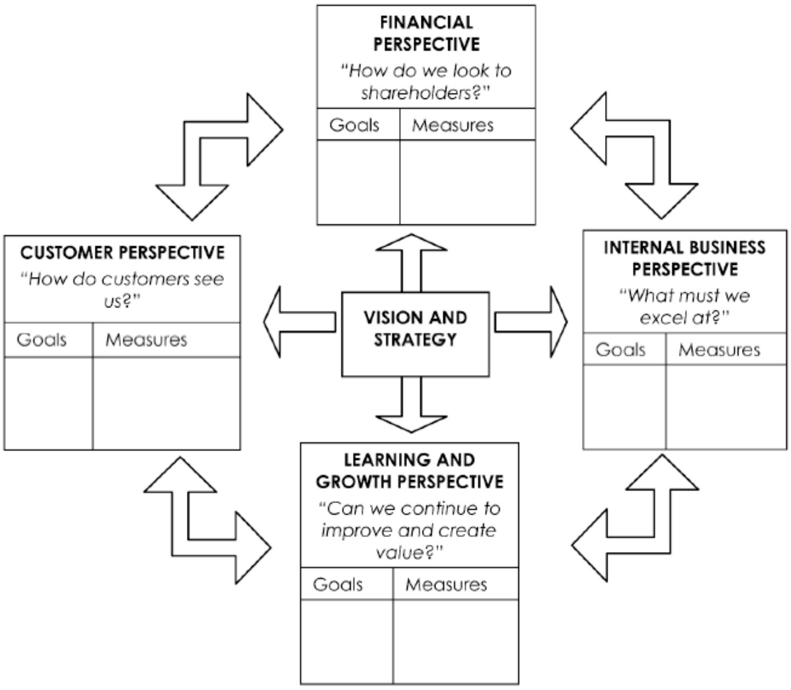


Figure 4: Balanced Scorecard Framework [17]

The BSC methodology, initially suggested by Kaplan and Norton (1992), has been broadly accepted by many businesses and is regarded by scholars as a strategic management tool for establishing a performance management system. It has been established that conventional financial measures do not forecast an organization's future performance because they are trailing indicators based on past performance. By integrating non-financial measures, the BSC hopes to offer managers with more relevant information about the activities they are currently managing than financial measures provide. process and ends that an organization's potential to produce value in the future will be influenced by four key aspects, financial, customer, internal process, and learning and growth as mentioned in Figure 04. In short, the BSC outlines the knowledge, skills, and systems that employees will require in order to innovate and build the necessary strategic capabilities and efficiencies to provide certain benefits to the customers, resulting in higher financial value [17]. While the Balanced Scorecard offers a multifaceted performance framework, its periodic review mechanism may inadequately reflect the real-time production fluctuation characteristic in LVHM systems.

1.4.3 OKR Framework

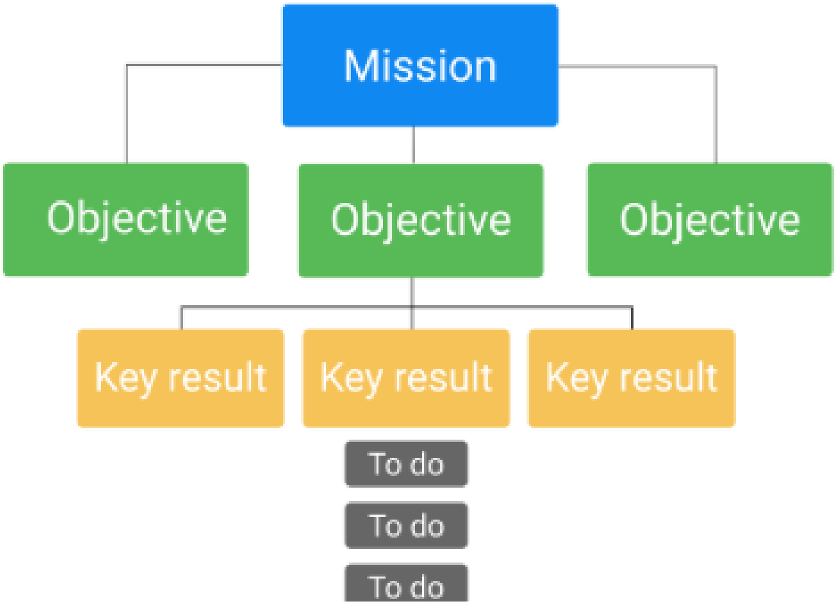


Figure 5: OKR Framework [18]

In order to address the limitations associated with conventional KPIs, industries are increasingly using the Objectives and Key Results (OKRs) framework to better connect day-to-day data to strategic goals. OKRs, originally conceived by Andy Grove at Intel and further popularized by John Doerr within the technology sector, advocate for the establishment of challenging goals and quantifiable key results on a regular basis. However, OKR is widely adopted framework for fostering concentration and integration, as they facilitate the development and communication of goals throughout the business, ensuring that all actions contribute to the same strategic objectives [19].

The basic concept of OKRs involves creating defined objectives and clearly outlining the results required to reach the intended outcome. In general terms, OKRs entail establishing an "Objective" and "Key Results" as shown in Figure 05. OKRs are designed to give a company measurable targets to focus on and then measure their effectiveness in meeting those targets. At the core, OKRs entail establishing an objective, which can then be divided into various Key Results. For instance, the company's objective could be "increase customer satisfaction". Its primary outcomes might include obtaining a specific customer satisfaction rating, optimizing response times, and reaching a certain number of customers [20]. These hurdles of approaches are a lack of organizational maturity and support, as well as an incorrect understanding of organizational objectives[21].

1.4.4 ISO 22400 KPIs Framework

ISO 22400, released by the International Organization for Standardization, is a comprehensive standard. ISO 22400 Part 1 provides an overview, principles, and terminology. In 2017, a modification to the energy KPIs added four new KPIs. The standard attempts to establish "an industry-neutral framework for defining, “Creating, sharing, and utilizing KPIs for managing industrial operations. This method and general concepts for creating KPIs, along with the necessary terms, are explained. Next, KPIs are defined. KPI estimations are based on a mix of basic factors [20]. ISO22400 is meant to be industry and process dependent. This ISO model measures performance using a general equipment structure hierarchy and production orders. KPIs can be used by any manufacturing enterprises, independent of production type (discrete, continuous, or batch). That is a main disadvantage for the different types of organizations since this is a general set of KPIs.

The discussion of the various frameworks demonstrates their method, utilization, advantages and disadvantages. Either these systems are too sophisticated for the organization, or they lack the necessary skill set to execute this framework. According to surveys, only 26% of executives believe their functional KPIs are closely connected with their organization's strategic objectives, highlighting a continuous divergence. A global MIT study revealed that while the majority of businesses use KPIs, there is "no best practice" opinion. Numerous businesses use KPIs as a "tick-box" rather than a driver of change. These constraints underscore the necessity for performance measurements framework and continuous monitoring that not only reflect previous outcomes but also inform future decisions and strategy[19].

1.4.5 Quality–Delivery–Cost–Safety–Morale (QDCSM)

The QCDSM methodology is a framework for organized performance management that is frequently used in manufacturing organizations for the purpose of monitoring and improving an organization's operational effectiveness. It classifies essential performance indicators into five fundamental aspects, which are as follows: quality performance, cost efficiency, delivery reliability, safety performance, and employee morale. The principal aim of QCDSM is to establish transparency in everyday operations and to synchronize shop-floor actions with organizational objectives. primarily used as an operational control instrument within shop-floor management systems, where KPIs are visibly presented and routinely assessed to facilitate prompt corrective measures ongoing improvement efforts [22]. Its implementation generally emphasizes short- to long-term operational stability, process optimization, and performance monitoring, rather than extensive strategic or financial integration. Consequently, QCDSM now operates primarily as a systematic framework for monitoring operational performance and enhancing KPIs at the execution level inside manufacturing entities. Yet financial integration has not been studied.

1.5 Digital Monitoring and Real-Time Performance Systems

Manufacturing and operating modern technology items necessitate knowledge of several disciplines, including mechanical engineering, electrical engineering, and software engineering. Assessing the current state and quality of processes and machines is tough due to their complexity and the need for competence in different engineering fields. With globalization and increased competition, it's crucial to lower production costs while maintaining good throughput and quality. Accurately assessing the health and quality of production processes and machinery is crucial for optimizing production costs. However, it is essential to examine the manufacturing conditions before deciding whether or not to intervene. Allowing decision-makers, production managers, and operators to quickly analyze manufacturing process conditions. That’s where this continuous monitoring is coming to play[23].

As an example, to continuously monitor the relevant KPIs, data collection and analysis is required. Most KPIs are measured against predetermined alert and threshold limits. These limits are recommended by feature designers, although they can often be changed to meet individual client needs or application trends. Furthermore, simple limitations for alarms can be defined based on criteria other than absolute alarm limitations. For example, trends can be tracked, and if there is a significant change from baseline, an alarm can be generated, even if the absolute parameter value is fine. Whatever happens once the alarm is triggered depends on how the remote monitoring system is configured. It is possible to notify the customer's maintenance/operations department as well as the specialists from the equipment manufacturer instantly. Alternatively, the equipment manufacturer's expert can be notified first to analyze the matter before contacting the consumer. This would help to reduce the number of false positives and false negatives. There are several notification alternatives, including e-mail, phone calls/text messages, and direct communication with a plant operating system [24].

1.5.1 Dashboard-Based KPI Monitoring

Today's economy is increasingly focused on data, often known as Big Data. Businesses face a significant problem in managing and extracting value from large amounts of data. Performance dashboards compress complex procedures into small portions, allowing users to focus on daily business operations. As the IT industry becomes more competitive, investments, business directives, and data are rapidly growing. Therefore, business owners should take extra cause and consider all facts while making decisions.

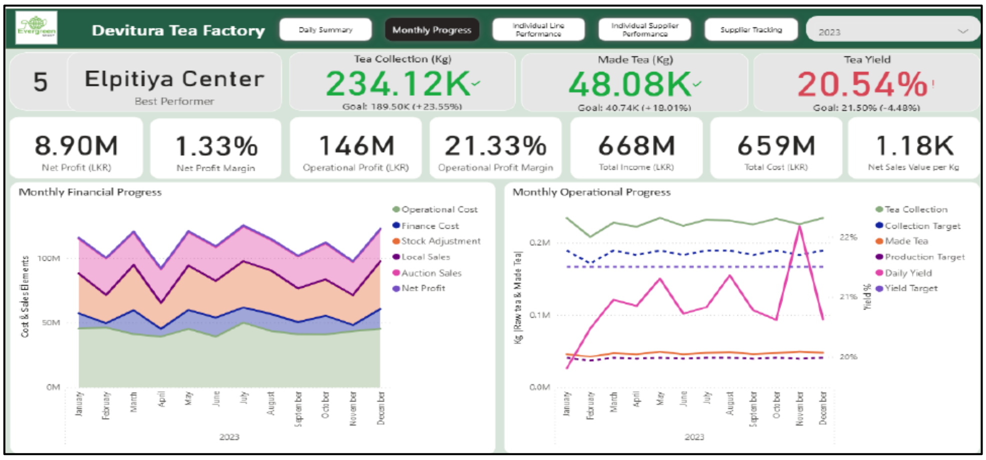
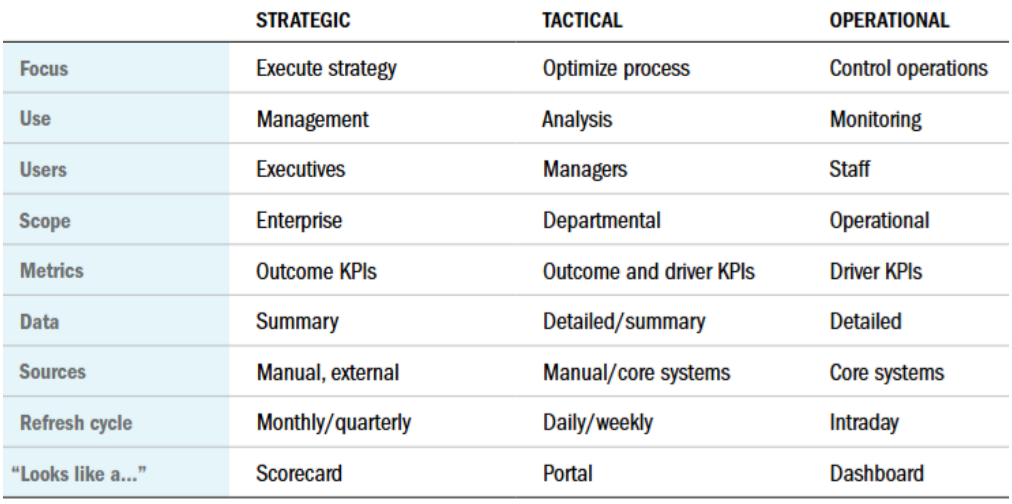


Figure 6: Performance Dashboard Example [25]

Technology that evaluates and tracks business growth is crucial for demonstrating profitability. Existing approaches for measuring firm growth are restricted in their ability to analyze business behavior and give basic information. As a result, business owners may not have entire confidence in their decisions. This performance dashboard provides insights (Figure 6) into business behavior from the beginning. This application manages information by tracking metrics, essential Performance Indicators (KPIs), and other essential aspects relevant to a business or specialized process. Dashboards employ data visualization to provide users with a quick overview of current performance and track the department's capacity to meet service level targets [26].

The main characteristics of dashboard consist of being able to monitor key company operations using metrics and notifications when performance falls below targets, examine the primary causes of problems by exploring timely data from multiple angles and levels of detail, boost performance, and point the organization in the right direction. It thus provides significant benefits, such as improving communication, refining strategy, increasing visibility and coordination, increasing motivation, presenting a consistent view of the business, lowering costs, providing users with actionable insights, and enabling faster and more informed actions to improve overall performance.



	STRATEGIC	TACTICAL	OPERATIONAL
Focus	Execute strategy	Optimize process	Control operations
Use	Management	Analysis	Monitoring
Users	Executives	Managers	Staff
Scope	Enterprise	Departmental	Operational
Metrics	Outcome KPIs	Outcome and driver KPIs	Driver KPIs
Data	Summary	Detailed/summary	Detailed
Sources	Manual, external	Manual/core systems	Core systems
Refresh cycle	Monthly/quarterly	Daily/weekly	Intraday
"Looks like a..."	Scorecard	Portal	Dashboard

Figure 7: Different types of Performance Dashboard [27]

Mainly, there are three types of performance dashboards as shown in Figure 7 In short, Strategic dashboards, often known as scorecards, are intended to help senior executives implement strategy, manage performance, and drive new or optimal behaviors across the company. These dashboards aim to assist executives participate on problem-solving and opportunity-exploration during monthly strategic reviews or operational planning sessions. On the other hand, Tactical dashboards enable mid-level or departmental managers to optimize the performance of their employees and procedures. These dashboards collect summary and detailed data on a daily or weekly basis, primarily from operational systems, allowing managers and analysts to detect problems and design solutions to ensure they meet short- and long-term goals.

Ultimately, Operational dashboards allow employees on the front lines to monitor and control essential operations on an ongoing basis. These dashboards provide extensive data from operational systems, including driver KPIs and operational measures, many of which influence higher-level KPIs, as previously stated. These dashboards, which commonly resemble automotive dashboards, send out notifications when predetermined thresholds are surpassed. They may be continuously updated as events occur, causing dials and gauges to "flicker" in real time [27].

1.6 Problem Formulation

Low-Volume High-Mix manufacturing settings are distinguished by dynamic routing, frequent job changes, significant product variability, robust task and departmental interdependence. In these settings, the efficiency of the coordination between operators, processes, and functional units is just as important as machine efficiency or defect rates in determining productivity. Failures like Workflow interruptions, delays between activities, incorrect job sequences, and communication failures can significantly reduce productive time.

In this business context, productivity losses linked to coordination are never explicitly established as clear Key Performance Indicators (KPIs), notwithstanding their practical significance. Instead of being measured and evaluated as financially accountable performance indicators, they are often seen to be hidden organizational challenges. Current performance measurement systems fall short in filling this gap and offer inadequate answers. Although finance structures, especially Profit and Loss (P&L) reporting, give total costs and revenue results, they don't explain the operational reasons behind performance variations. Conversely, operational KPI systems, whether strategic, goal-oriented, or standardized production frameworks, generally focus on quality, cost, delivery, and equipment efficiency, while largely overlooking coordination inefficiencies as a distinct measurable factor.

Although the above frameworks are potentially allowing for the inclusion of additional KPIs, firms do not frequently use formal coordination-loss indicators, particularly in LVHM contexts marked by considerable variability and complex human interactions. Additionally, when occurrences of idle time or delays are identified, there is no structured system that methodically translates coordination-related operational losses into a distinct financial effect within the profit and loss framework. Thus, managers are unable to ascertain the precise ways in which inefficient coordination impacts wage costs, productivity, corporate expenditures, and, ultimately, income production. When operational monitoring and financial outcomes are not in sync, it becomes more difficult to make informed decisions and improvement initiatives.

Constant innovation in digital monitoring techniques has made it possible to gather data in real-time using tracking devices, visual monitoring tools, and sensors. Although these technologies have the potential to revolutionize performance assessment frameworks, in most implementations they mainly serve to present traditional production indicators. At present, there isn't a stand-alone solution that combines three components: (1) a coordination-loss key performance indicator; (2) a way for systematically translating operational KPIs into financial value; and (3) real-time visualization within a consolidated performance framework designed for LVHM scenarios. This research focuses on the lack of a structured and operationalized Key Performance Indicator (KPI) for measuring coordination-related productivity loss in LVHM and a framework that connects these operational measures to financial outcomes and allows real-time monitoring. The overarching goal of this study is to improve accountability decision-making and productivity management in LVHM industrial settings by identifying and quantifying previously inaccessible operational bottlenecks.

2 Research Approach

2.1 Design of the Study

This chapter outlines a case study approach to systematically study the selected research objectives with strong emphasis on secondary data analysis combined with design and development research.

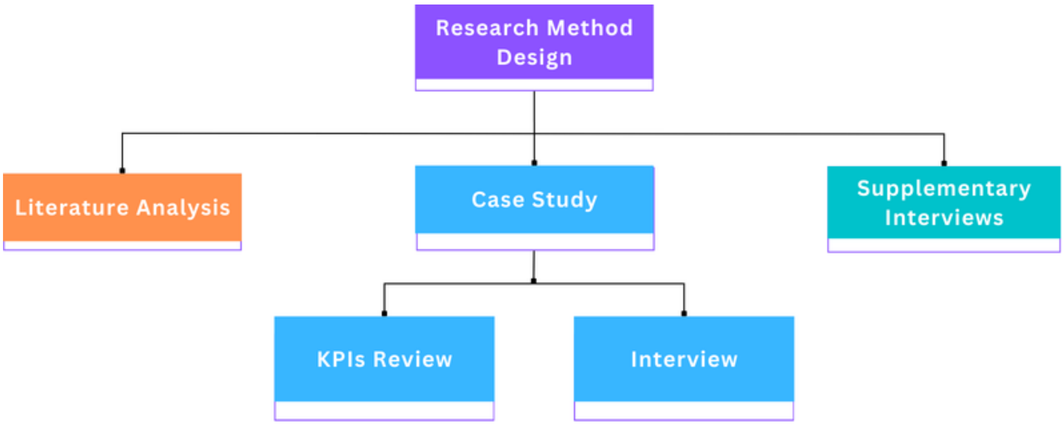


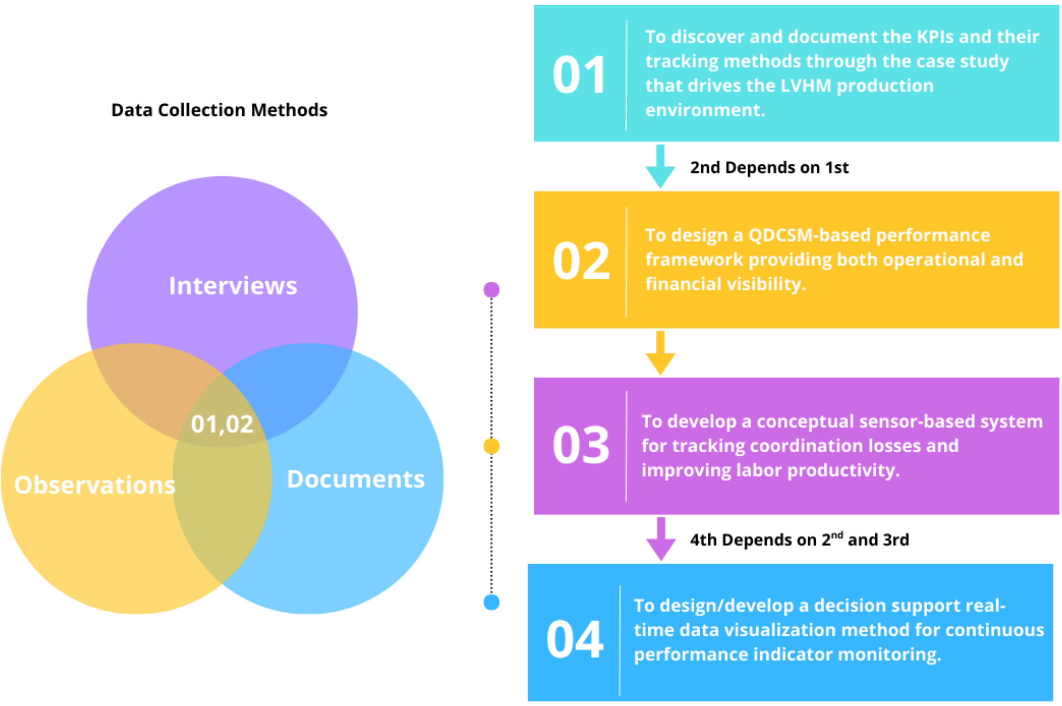
Figure 8: Research Design (Source: Developed by the author)

Multiple research approaches are ideally designed to fulfill the aims of this study. Literature research was performed to discover current methodologies that amalgamate financial and operational performance information within shop floor settings. This phase aimed at analyzing prior research, reports, standards, and recommendations regarding performance monitoring systems to understand their application in industrial contexts, particularly in LVHM manufacturing. A Case study methodology was used to analyze the existing approaches employed in the business, subsequent to a literature review. case study analyzed the performance indicators (KPIs) used in LVMH production and the methodologies employed to assess and monitor these KPIs on the shop floor. Findings from this study provided useful information for putting operational and financial indicators to use in real-world manufacturing settings.

To expand the study's scope beyond a singular organization, it’s also consulted more experts in the sector to enhance the case studies. The interviews sought to investigate the existence of integrated financial and operational performance insight systems in shop floor contexts and to collect expert perspectives on the proposed performance measurement framework. case study and supplemental interviews were employed to examine the methods by which coordination losses are currently recognized and monitored in production processes.

Finally, conceptual KPI for monitoring coordination losses was established based on insights from the literature analysis, case study findings, and expert interviews to address a gap in existing shop floor performance monitoring procedures. proposed performance framework and the newly established KPI were incorporated into a conceptual real-time decision-support dashboard aimed at facilitating shopfloor decision-making by merging financial and operational performance details.

2.2 Data Collection



01 To discover and document the KPIs and their tracking methods through the case study that drives the LVHM production environment.

02 To design a QDCSM-based performance framework providing both operational and financial visibility.

03 To develop a conceptual sensor-based system for tracking coordination losses and improving labor productivity.

04 To design/develop a decision support real-time data visualization method for continuous performance indicator monitoring.

Figure 9: Data Collection Map (Source: Developed by the author)

Acquiring data or information is a key feature of this research study because it will examine the current status of LVHM manufacturing while also indicating areas for development. All research objectives are directly or indirectly combined with the data collection method according to the Figure 9 data collection map. Data collection and consulting process start from the middle of October 2025 until March 2026. First objective is the most important objective from data collection. Because 3rd and 4th objectives directly depend on the 1st objective data collection. However, data collection process is supported by interviews, observations and the organization documentation.

2.2.1 Interviews

The interviews follow a planned framework to ensure uniformity and comparability between participants as stated in Table 03. The structured interview approach consisted of predetermined questions concentrating on major areas including as, Companies main production challenges, KPI data, competitors and market position. Organizational structure and decision-making procedures, Strategic planning and future innovation objectives. Each interview lasted about an hour and was performed using both physical and video conferencing depending on the interviewees' geographical regions.

Table 3: Summery of Interview Details

Interviewee	**Status**	**Format**	**Length**	**Recording**
Primary Case				
Factory Manager	29/10/25	Semi Structured	60 min	Concurrent Notes
	17/11/25	Semi Structured	85 min	Concurrent and Supplementary Notes
	16/12/25	Semi Structured	45 min	Concurrent and Supplementary Notes
	21/02/26	Semi Structured	45 min	Concurrent and Supplementary Notes
	02/04/26	Semi Structured	50 min	Concurrent and Supplementary Notes
Secondary Cases (Outside the main case)				
Business Owner (SME)	18/12/25	Semi Structured	40 min	Concurrent Notes
Manger – Business Excellence	19/12/25	Semi Structured	40 min	Concurrent Notes
Industrial Engineering Executive	23/12/25	Semi Structured	40 min	Concurrent Notes
Supervisor	29/12/25	Semi Structured	40 min	Concurrent Notes
Operator Level	30/12/25	Semi Structured	40 min	Concurrent Notes
Business Owner (Large Scale)	03/12/25	Semi Structured	40 min	Concurrent Notes

(Source: Design by the author)

2.2.2 Observations and documents

Direct observations were made on the factory floor on three distinct occasions, each with the author present and taking written notes. The first visit was conducted to gain a general grasp of the manufacturing process and was guided by the plant manager himself. The second visit was to obtain a thorough grasp of the manufacturing processes. Beginning with the third visit, self-led visits were conducted to observe processes and examine specific actions. Additionally, Document analysis is an important data gathering tool to use in case studies where the goal is to obtain detailed information. To answer both RQs, KPI-related materials were examined, including company reports, presentation slides, and ERP System documentation. These documents were acquired from interviews. Documents used to verify the data gathered from interviews and observations.

2.3 Company

Bürkle GmbH was created in 1920 by Robert Bürkle with the purpose of curing timber surfaces. Initially, a facility that was one hundred square meters in size was used to construct spindle and fume presses. The finished machines had been sold to a significant number of customers all over the world by the 1930s. The current headquarters are in Freudenstadt, Germany. Bürkle GmbH began manufacturing printed circuit boards in the 1960s. In the 1980s, the number of product categories grew, including plastic card lamination.

In 1990, they purchased their long-term partner, WM Wild, and Bürkle constructed its second production in Mastholte. In 1998, they established Bürkle North America Inc in California, so entering the American market. In 2003, they established Bürkle Machinery Co. Ltd. in Shanghai, thereby entering the Asian market. In 2008, they introduced the world's first multi-level laminating machine line into the solar laminating market. The 2009/2010 crisis decimated the solar business, forcing Bürkle to emphasize traditional woodworking machinery once more to survive. Thanks to new inventions, the company was also able to join the insulation material production sector with the thermal bonding technique. This was extremely beneficial to the company's survival during the crisis.

In 2019, Bürkle Hungary Kft. was established in Debrecen to boost competitiveness. Initially, only roller coating and UV gloss drying/paint burning machines were handed over to Hungarian experts. Bürkle Hungary Kft currently has 71 employees. The workforce is divided between 17 office workers, indirect 21 support workers and 33 direct mechanics. The primary scope of operation is custom machine manufacturing. The company primarily manufactures custom machines using purchased parts and only performs assembly work. Bürkle Hungary kft has grown steadily since its inception in 2019. Two further halls will be added to the site in 2022, followed by a new building and expanded warehouse in 2024. The factory space has been separated into three components. The first is the SSB area, which is in charge of switch cabinets and has its own electronics warehouse. The remaining two areas are the woodworking machine line and the largest press area. Bürkle Hungary Kft's current product line includes woodworking, press, and conveyor machines, as well as solar press machines starting in 2023. The company's primary customers include IKEA, Apple, Meyerburger, Bottero, and Riwag [28].

Figure 10: Bürkle Hungary Kft's Debrecen Plant [29]

3 Case Analysis and Framework Development

This chapter provides an empirical investigation of the chosen LVHM case company and formulates the proposed performance measurement system. Assessing the company's current operational KPIs is crucial for formulating a more efficient measurement plan. This chapter presents a summary of the company's existing performance metrics, encompassing operational standards. The post clarifies the methodology for quantifying the established coordination loss KPI and subsequently displays the findings. Ultimately, the chapter incorporates this KPI into a systematic framework that merges QDCSM operational dimensions with Profit and Loss (P&L) indicators and illustrates its execution via real-time dashboard monitoring in late chapter.

3.1 Identified Performance Metrics and Measurement System

The organization's operational performance has been analyzed over a period of 12 weeks. The current KPIs utilized by the organization are shown in the following images. The organization's ERP system updates all of these KPIs twice every day. All data is entered into the system manually.

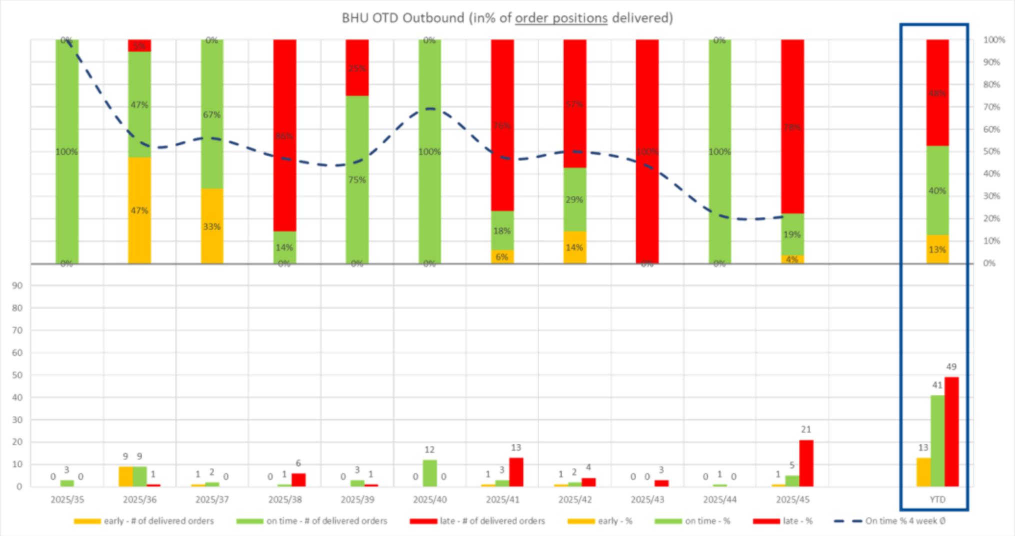


Figure 11: OTD Outbound KPI Data [30]

As a customized manufacturing company, Bürkle have designated OTD Outbound as a KPI, since it takes time for the company to receive the product from the supplier on time, also affects the performance of their company as shown in Figure 11. The Most significant issue currently confronting LVHM companies is the 40% tendency of suppliers to deliver raw materials on time during the analyzed period. The company's whole operation relies on this KPI. Instance, if a supplier delays the delivery of raw materials, the entire production process will be thoroughly affected. Likewise, if they manage to fulfill this order in advance, it will escalate the company's warehousing expenses, presenting an additional issue. This affects the company's financial flow. Furthermore, employing this form of KPI enables a firm to rate their suppliers. Therefore, Outbound KPI holds significant value even for a business at a fundamental level.

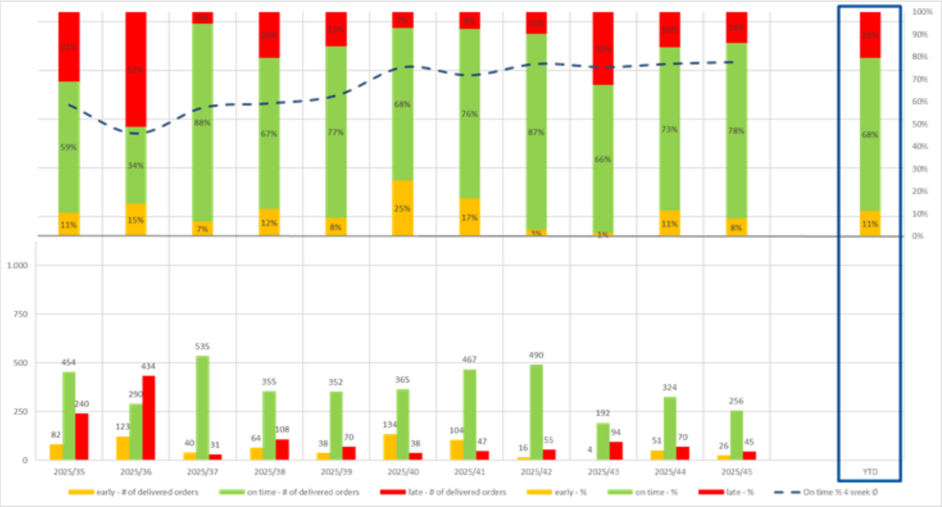


Figure 12: OTD Inbound KPI Data [30]

Furthermore, as illustrated in Figure 12, Bürkle's productions must be delivered to their customers on time, to maintain customer satisfaction. This indicates that their products were delivered to customers 11% ahead of schedule, 68% on time, and 21% late. Nevertheless, it is also a crucial KPI for the organization. Manufacturers that produce unique goods have a minimal likelihood of retaining the same customer. However, an organization must do specific actions to achieve client satisfaction. That's why OTD Inbound KPIs are important. However, what a company requires in its initial phase is a robust long-term connection. On the other hand, Benefits for the organization include efficient cash flow management, reduced operational expenses, and systematic production planning and etc.

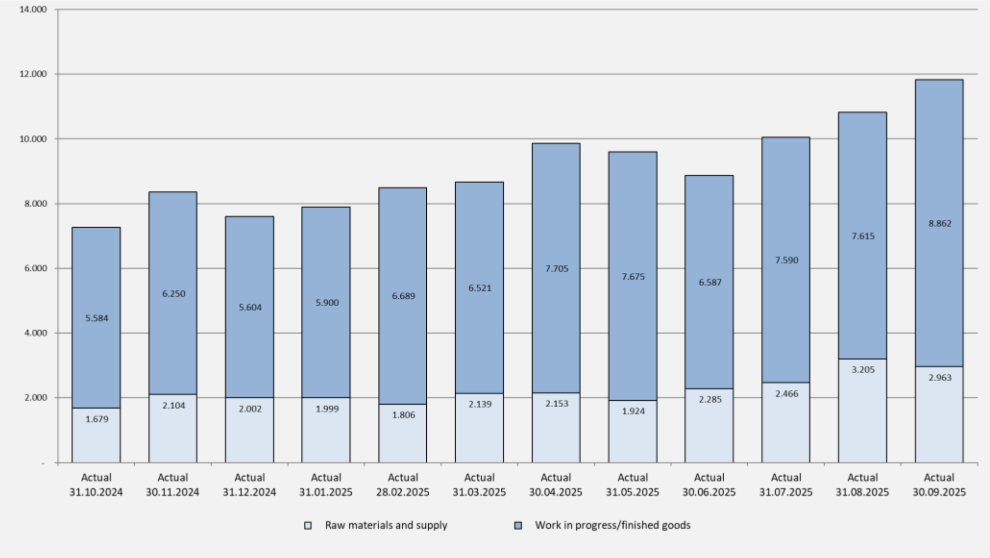
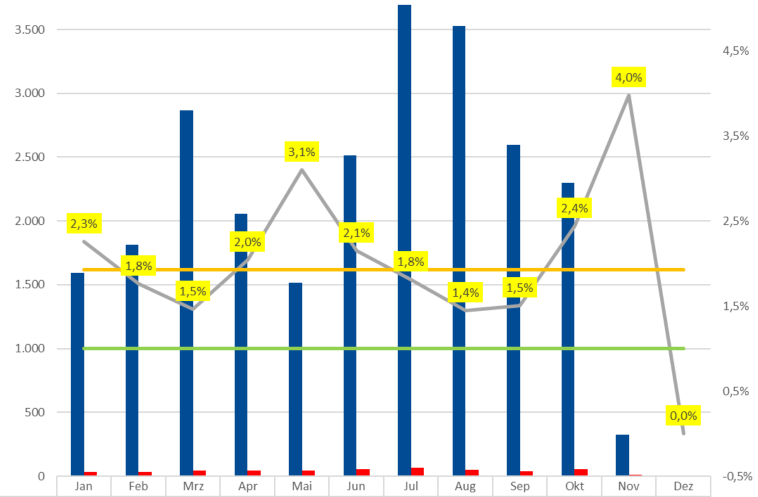


Figure 13: Order Inventory Leve KPI [30]

Inventory level is also one of the major KPIs used in these LVHM production environments since it blocks the cashflow of the organization as mentioned above. Bürkle also sets order inventory as a main KPI as shown in Figure 13. The data indicated that the company was sustaining a stable inventory of raw materials. Organization must examine inventory KPIs from a different perspective. If these firms opt for software solutions such as ERP, which entail greater operating expenses, the necessity of employing a laborer to manage inventory levels is an increase in expenditure. The discrepancy between the ERP system and the accurate inventory level poses a significant challenge for Discrepancy between the ERP system and the accurate inventory level poses a significant challenge for organizations.



	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
■ # Order Positions delivered	1.596	1.816	2.868	2.054	1.517	2.513	3.694	3.529	2.594	2.297	327	-
■ # Order Positions with Quality defect	36	32	42	42	47	54	67	51	39	56	13	0
— Quota	2,3%	1,8%	1,5%	2,0%	3,1%	2,1%	1,8%	1,4%	1,5%	2,4%	4,0%	0,0%
— Avg. Quota YTD	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%	1,9%
— Target	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%

Figure 14: Supplier Quality KPI [30]

As well as OTD outbound KPI, quality of the supplier is more important, because it can negatively impact the organizations from the customer side. Therefore, Supplier quality is also monitored by Bürkle (Figure 14). The supplier quality KPI aim stipulates that 1% of the obtained raw materials may exhibit quality issues. Over analysis period, the average has increased to approximately 1.9%. The minimum value recorded is 1.5%. This has sometimes led to high quality issues such as 3.1%, 4%. Also, this is a very unfavorable situation for the organization.

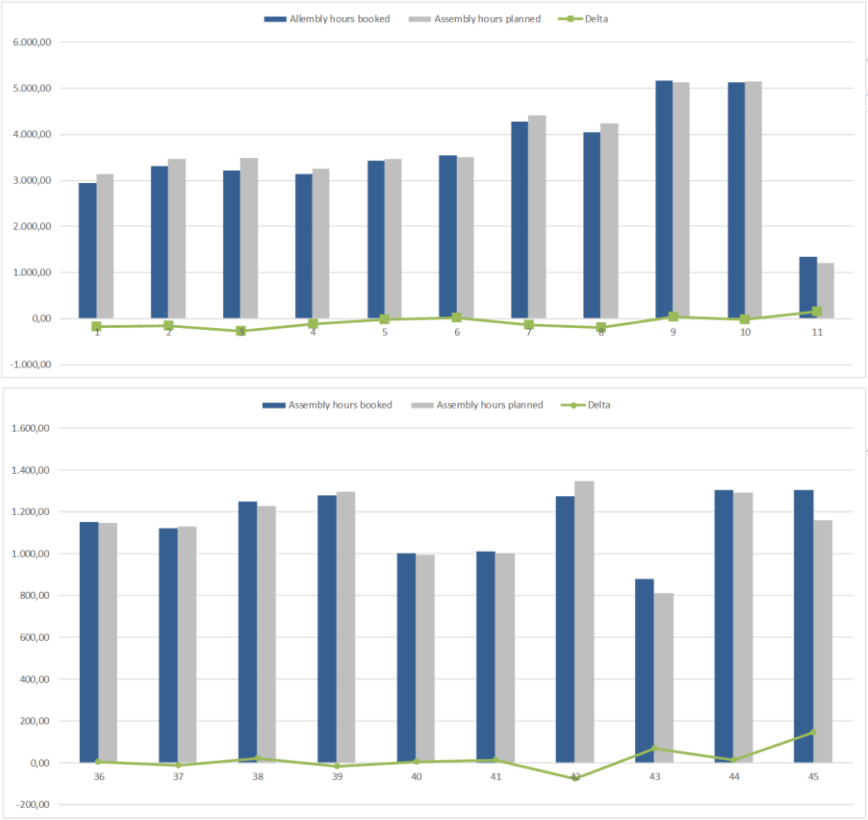


Figure 15: Efficiency of Planning Hours [30]

Organization efficiency is also compared by using planned hours vs actual time spent on production as shown in Figure 15. The data shown in the image illustrates scheduled and actual order-related labor hours over multiple production weeks, emphasizing the difference between these two metrics. The first graph above shows data from week 1 to week 11. The difference between planned hours and booked hours is -2%. Similarly, it is 2% in weeks 36-45. This represents a very good planning opportunity within the LVHM organizational structure. In most instances, the projected and actual hours are well aligned, suggesting that the production planning system offers a fairly precise assessment of the labor needs for order-related tasks. Nevertheless, substantial variations may still be evident in specific weeks, when actual hours exceed or fall short of the projected numbers.

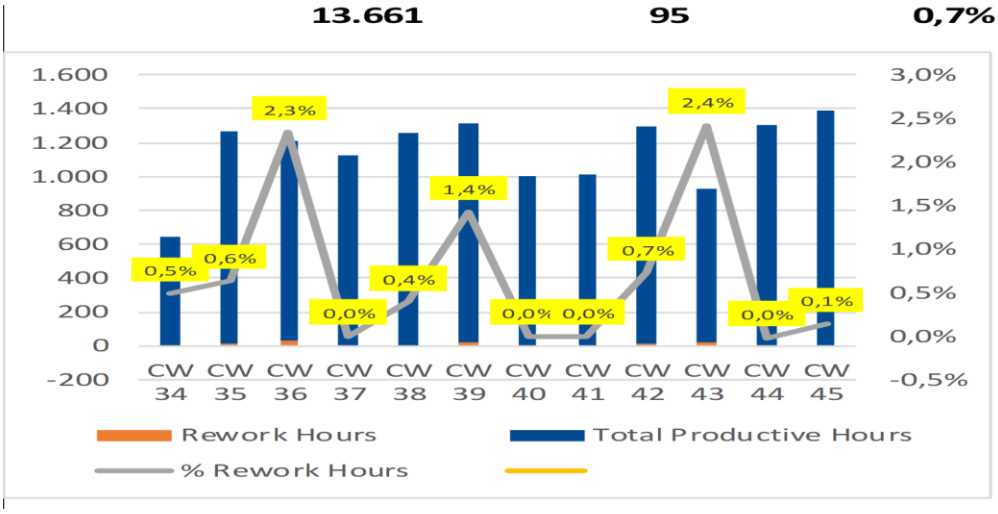


Figure 16: Rework KPI [30]

In this organizational structure, rework represents significant expense. Consequently, the rework KPI is assessed in multiple components. There are primarily two types of reworks KPIs. The first occurs during production, while the second transpires post-delivery to the relevant client (Figure 16). This rework KPI also analyzed data over a nine-week period. Rework is calculated as a percentage value of total productive hours. Here, too, 4 weeks of production were completed without any rework. The highest value reported was 2.4%, but an approximate average of 0.7% can be taken as an estimate.

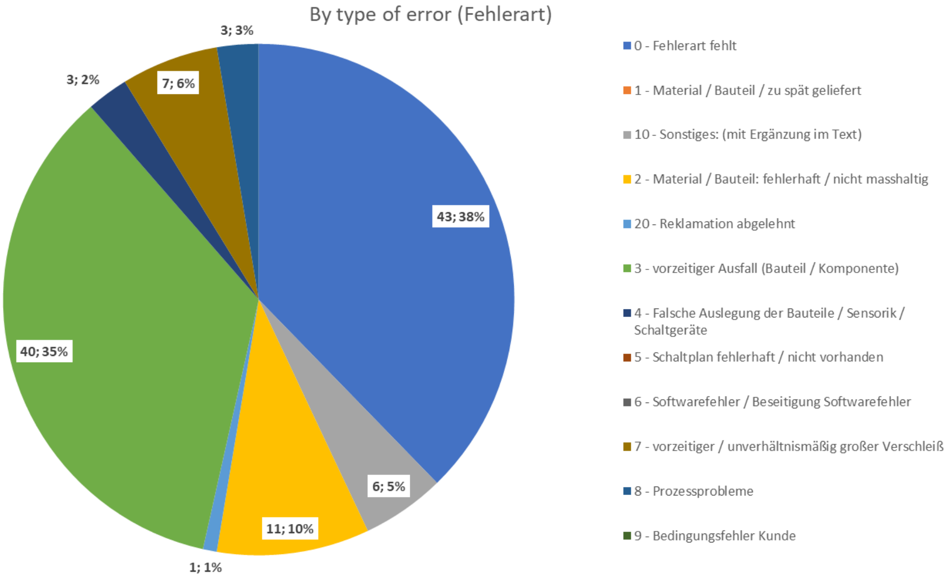
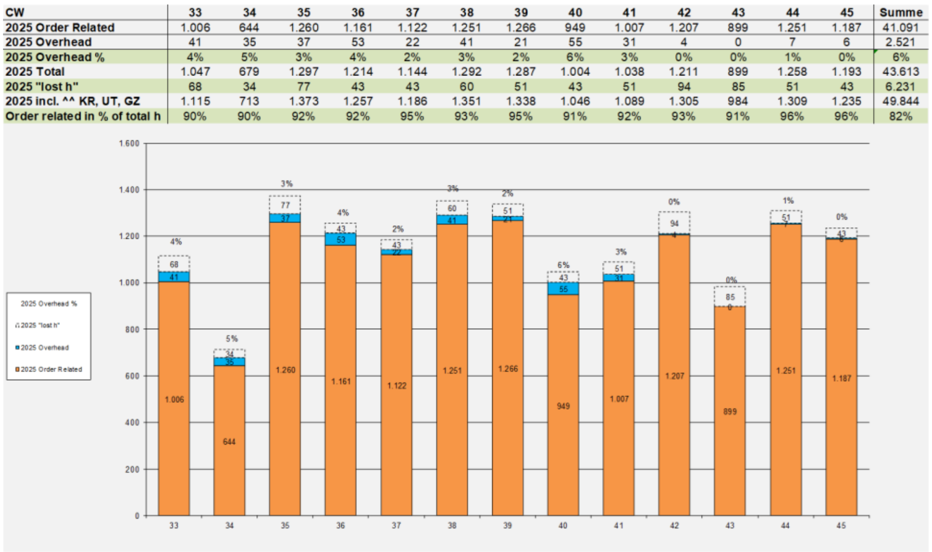


Figure 17: Customer Complain KPI [30]

Customer satisfaction determines the future of the organization, so a relevant KPI has been provided for monitoring it as shown in Figure 17. Customer satisfaction metric serves as an independent KPI aimed at reducing complaints associated with these products.



CW	33	34	35	36	37	38	39	40	41	42	43	44	45	Summe
2025 Order Related	1.006	644	1.260	1.161	1.122	1.251	1.266	949	1.007	1.207	899	1.251	1.187	41.091
2025 Overhead	41	35	37	53	22	41	21	55	31	4	0	7	6	2.521
2025 Overhead %	4%	5%	3%	4%	2%	3%	2%	6%	3%	0%	0%	1%	0%	6%
2025 Total	1.047	679	1.297	1.214	1.144	1.292	1.287	1.004	1.038	1.211	899	1.258	1.193	43.613
2025 "lost h"	68	34	77	43	43	60	51	43	51	94	85	51	43	6.231
2025 incl. ^^ KR, UT, GZ	1.115	713	1.373	1.257	1.186	1.351	1.338	1.046	1.089	1.305	984	1.309	1.235	49.844
Order related in % of total h	90%	90%	92%	92%	95%	93%	95%	91%	92%	93%	91%	96%	96%	82%

Figure 18: Employee Productivity KPI [30]

Productivity KPI is kind of a common KPI in production industry presently. Indeed, Bürkle also monitors the productivity of the employees through this productivity KPI (Figure 18). This dataset shows how the work hours were split up each week in a production setting from weeks 33 to 45 of 2025. The hours were broken down into three groups: order-related work, overhead tasks, and lost hours. There was a total of 43,613 production hours during this time, with 2,521 hours spent on overhead responsibilities and 41,091 hours spent on order-related operations, this amounts to around 6% of the overall production time. With the addition of 6,231 hours that were recorded as lost, the total working hours recorded reached 49,844. In other words, value-added production activities take up the vast majority of an employee's time (around 82% of total working hours). Time lost in the production system can occur for several reasons, such as issues with coordination, lengthy waiting times, inadequate communication, stopped procedures, or inadequate planning.

3.2 Discussion of KPI Performance Against Targets

The operational KPIs were assessed over a 12-week duration with their corresponding target values to gauge overall performance. The OTD Outbound KPI, assessing supplier delivery performance against the scheduled supply date, reveals a modest average success rate of 40%, highlighting issues with supplier delivery reliability. The OTD Inbound KPI, indicating the company's capacity to deliver products to consumers punctually, demonstrates a 68% success rate against the target. This performance, while superior to supplier delivery performance, indicates possible opportunities for enhancement in fulfilling customer delivery commitments. The Order Inventory Level KPI exhibits robust performance, mostly attributable to the existence of buffer stock, which ensures material availability and mitigates the risk of production disruptions. The Supplier Quality KPI, with a target of 1%, now averages 1.9% of every order, signifying a divergence from the anticipated quality standard. Planning Hours Efficiency KPI indicates a performance level exceeding 90%, reflecting effective utilization of planning resources. The Rework KPI, assessed over the identical 12-week duration, indicates a peak value of 2.4% of total productive hours, implying that rework activities are largely managed.

KPI monitoring reports are generated solely once a week, thus hindering the prompt discovery of operational difficulties. Consequently, real-time decision-making and financial performance insights remain underutilized, underscoring the advantages of adopting enhanced real-time KPI monitoring solutions.

3.3 Gap Analysis

A Comprehensive analysis of contemporary performance evaluation techniques within a standard organization reveals institutional limitations that hinder managers' capacity to acquire insights and make effective judgments. indicators constitute components of the integrated performance architecture; nevertheless, they function as a distinct measurement framework. Although operational control systems and production cost analysis tools are widely used to assess financial performance, research on the examined company indicates that these tools inadequately convert the operational KPIs of the production department into comprehensible real-time metrics. In low-volume, high-mix manufacturing settings, where the variety of products and interdependencies across processes enhance workflow complexity, coordination issues also operate as a substantial bottleneck. and research, however, reveal that operators abandon their workstations when faced with improper instructions, process problems, communication delays, or a lack of materials, all of which have a major influence on productivity. Notwithstanding its Practical significance, current performance assessment approaches are deficient in a definitive key performance indicator that directly identifies losses owing to coordination failures. Consequently, these problems endure during manufacturing and are not systematically monitored or rectified.

3.4 Development of Coordination Loss KPI

3.4.1 Definition of Coordination Loss

Constant alterations to production processes are necessary in LVHM settings due to the high degree of product variety and the frequency of order changes. There is a learning curve associated with every new or modified product that requires adjusting layout parameters, work instructions, material flows, and task sequences. Managing the relationship between interconnected systems and the people working on the production floor became more difficult due to these ever-changing elements. As a Result, a significant amount of productive working time is impacted by coordination-related interruptions. These include interruptions due to contradictory guidelines delays in obtaining materials or approvals, temporary disconnection of workstations to resolve workflow issues, modifications in planning, and synchronization lags between operations. It is important to emphasize that these time losses exclude personal rest periods and are mostly assigned to system.

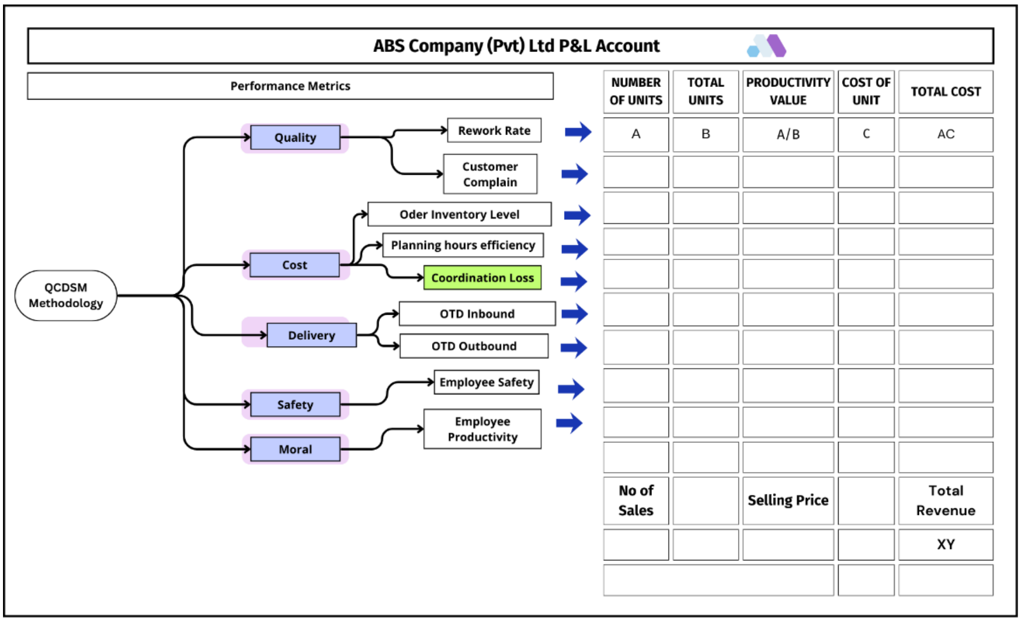
Regardless of their widespread presence and importance, these coordination-related time losses are rarely recognized in conventional productivity or financial indicators. However, they are included in standardized business performance metrics, resulting in a lack of transparency. The following subsection characterizes coordination loss as ineffective working time caused by systemic coordination limitations in LVHM production settings. This period indicates a measurable drop in productivity that immediately affects operational efficiency and financial performance.

3.4.2 Measurement Logic

An effective proxy for coordination loss is the duration that workers remain unproductive during designated production hours due to coordination issues. This examination exclusively addresses systemic issues within the work process, excluding authorized breaks and personal-time breaks. The data is acquired by systematic monitoring enabled by CCTV cameras and sensor-based activity detection. Coordination time includes delays caused by awaiting materials or instructions, planned modifications, workflow interruptions, coordination lags across operations, and transient voids in workstations due to operational contradictions. However, the entire allocated production time is thereby segmented into productive time, nonproductive, and personal break time. The coordination loss rate is calculated by comparing the proportion of coordination loss duration to the overall planned production time, as per this classification. The defined coordination loss time is transformed into monetary value using the applicable labor cost rate in order to simplify financial integration. This allows for an evaluation of the direct economic consequences of coordination inefficiencies in the production department.

3.5 Development of Integrated Perforamcne Framework

Often, businesses fail in the early stages not because their product is not marketable but rather because they are unable to compete with the current market price. At present, even large firms implement techniques to minimize costs while offering competitive prices. Therefore, to minimize expenditures, companies must continuously oversee both direct and indirect costs. The primary goal of this purpose is to offer the most direct and effective method for LVHM industries to develop KPIs. The study reveals that numerous corporations prioritize profit as their principal performance metric. Therefore, a framework has been presented based on this essential concept and the combination of the expert's worldview.



NUMBER OF UNITS	TOTAL UNITS	PRODUCTIVITY VALUE	COST OF UNIT	TOTAL COST
A	B	A/B	C	AC
No of Sales		Selling Price		Total Revenue
				XY

Figure 19: Proposed Integrated Framework (Source: Developed by the author)

The framework incorporates the QCDSM methodology with the organization's profit and loss statement as illustrated in Figure 19. Findings suggest that LVHM enterprises are hesitant to utilize a large number of KPIs in their manufacturing processes. Companies view it as a distraction from their core mission. The principal aim of most starting companies is to increase profitability. The framework highlights the suitable approach for setting up performance metrics within the organization, without undermining its objectives. This strategy allows LVHM firms to focus on their production while reducing resource use. However, the performance indicators utilized in this framework can be adjusted in accordance with corporate needs. The QCDSM component is unaltered as it serves as the system's foundation.

Research suggests that almost all KPIs at the primary operational level should be quantified in financial metrics. For example, the number of defects and the volume of rework can be easily included in the unit count columns. Additionally, related expenses can be handled proportionately. Therefore, integrating these details and calculating the cost is a straightforward endeavor. Through the process of adding up all of the costs, you will arrive at a straightforward but comprehensive statement of profit and loss for the manufacturing process. A prominent feature of architecture is the provision of real-time data monitoring. It enhances efficiency and precision of decision-making inside the organization. However, despite the lack of particular investment, the enhancement of the knowledge that real-time data monitoring provides for decision-making within growing businesses is pursued as a separate goal.

3.6 Comparison between Frameworks

SMART, OKR, and the Balanced Scorecard are examples of well-known performance systems that offer organized methods for goal setting, strategic alignment, and multifaceted performance evaluation. It is important to note that these frameworks are mostly utilized at the managerial or strategic level. Furthermore, they do not particularly connect operational shopfloor key performance indicators (KPIs) with profit and loss structures in a manner that enables financial insight at the production level monitoring of production performance often does not explicitly incorporate these measurements into calculations. Rather, it makes use of aggregated accounting procedures. This is despite the fact that operational indications may have an implicit influence on financial outcomes.

The presented framework is unique as it integrates the financial rationale of the profit and loss statement at the production department level with operational performance metrics derived from QDCSM. The structure's capacity to link operational indicators to their financial impacts inside the same performance architecture lets manufacturing leadership teams evaluate operational deviations technically and financially. Therefore, financial information immediately integrated into production visibility increases decision-making instead of limiting financial analysis to accounting reports provided after the event. The operationalization of this production-level financial translation within an integrated monitoring environment is inadequately addressed by existing performance frameworks in terms of structural analysis. Eventually, this research helps improve the field by including operational key performance indicators (KPIs) in a system that allows for financial analysis and is tailored to the complicated manufacturing processes of LVMH. The evaluation has been done for better understanding and is below Table 4.

Table 4: Framework Comparison

Criteria	SMART Framework	OKRs Framework	Balance Scorecard Framework	Proposed Framework
Manufacturing Organization Maturity Level	Medium	High	High	Low
Implementation Cost and Time	Low	Low	Low	Low
Skill Requirement	Medium	Medium	Low	Low
Real Time Monitoring	Low	Low	Low	High
Decision Making Support	Low	Low	Low	High

Source: Comparison by the author based on the discussed literature sources

4 Conceptual Design of the Measurement Architecture of the Coordination Loss

This chapter describes the conceptual design technique used to construct the Coordination Loss Tracking system. The system was developed using Gerhard Pahl's conceptual design process, which outlines organized engineering design concepts [31]. The tracking architecture was not developed as a simply technological solution. Rather, it was established in a methodical manner through recurrent phases of problem identification, functional deconstruction, concept creation, and assessment phases. The design approach, which involved brainstorming sessions, relied heavily on collaboration with customers, product managers, business analysts, and experts in the field and it ensured the design was usable and suitable in the LVHM industrial scenario. To ensure the necessary functional requirements, system constraints, and measurement targets, the interaction was considered crucial.

In the concluding section of this chapter, it presents a conceptual framework for tracking architecture. This architecture establishes a framework for systematically identifying, categorizing, and preparing productivity losses associated with coordination to enable quantitative and financial analyses. Thus, the chapter lays the groundwork for the tracking mechanism's operational implementation and codifies the design logic underlying it.

4.1 Structural Architecture of the Measurement System

Nearly all firms that manufacture customized products experience a learning curve. In other words, adaptation to that product requires time. This is an inevitability that cannot be bypassed under any circumstances. Companies must adapt to these changes and progress competitively. The matter of productivity is paramount here. As mentioned before, there are multiple factors contributing to a decline in employee productivity. Fatigue is an inherent aspect of human nature. Likewise, owing to the allocation of specific brakes and human variables, investigations have determined that during the planning process, an employee's productivity or efficiency is frequently regarded as 85%.

However, certain factors may lead to a decline in employee productivity as a result of the organizational side problems as well. These encompass unsuccessful strategies, communication issues, resource deficiencies, and prolonged decision-making periods. Calculating an employee's productivity is challenging without these inquiries. Despite the existence of time studies in industrial engineering to quantify employees' productivity, it remains exceedingly challenging and costly to have an additional individual monitor the entire duration of another job.

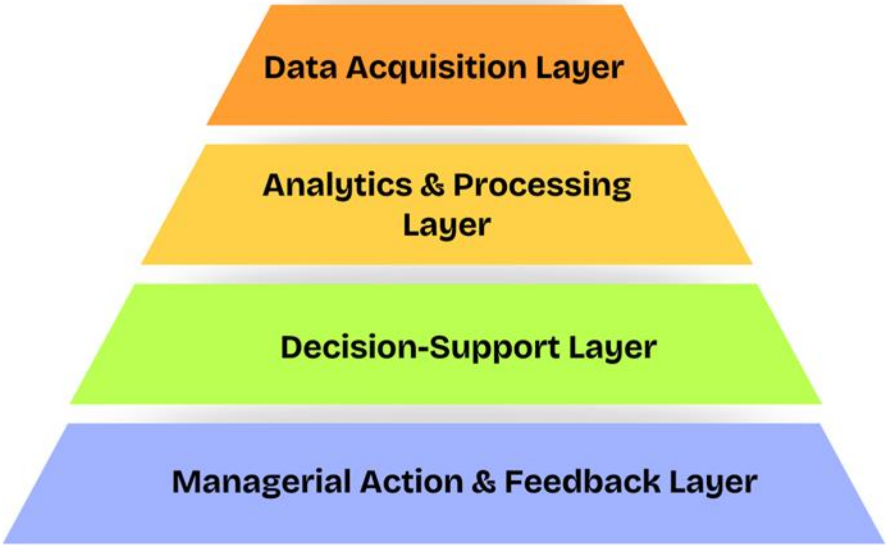


Figure 20: Develop Structural Architecture (Source: Developed by the author)

The primary goal of this objective is to analyze the coordination issues, unexpected disruptions, and fragmentation of workloads that the organization confronts to enhance decision-making. The subsequent section on conceptual design outlines the methodology for data collection utilizing sensor technologies and selecting a strategy to enhance employee productivity by refining the LVHM organizational structure during the learning curve phase. The design process has commenced in accordance with the hierarchy outlined in Figure 20 and the precise and renowned Pahl [31] standards were utilized in the Conceptual Design Process.

4.2 Design Principles of the System

Conceptual design is the phase of the design process that involves identifying fundamental problems through abstraction, establishing functional structures, exploring suitable working principles, and integrating these into a cohesive framework, thereby delineating the foundational solution pathway through the development of a solution principle. This design process is a very sophisticated method consisting of 6 steps. They are followed in a sequence as shown below.

Step 01 - Plan and clarify the task
- Analyze the market
- Create the requirement list (Design Specification)

Step 02 - Abstracting to Identify the Essential Problems
Step 03 - Establish function structure
Step 04 - Working principles and working structure identification
Step 05 - Combine and firm up into concept variants
Step 06 - Evaluation against technical and economic criteria

4.2.1 Step 01 - Plan and clarify the task

The task clarification includes not only declaration on the product's functionality and performance but also specifications concerning timeframes and financial objectives. The design and development phase encounters difficulties in systematically identifying, organizing, and statistically outlining the requirements that inform the solution concept. Consequently, strong Engagement with the client's designers is essential for understanding expectations and convert them into quantifiable system specifications. In order to achieve this, the following questions need to be answered in close cooperation with the clients and the designers.

1. What are the objectives that the intended solution is expected to satisfy?
2. What properties must it have?
3. What properties must it not have?

So, in Table 03 it illustrates the gathered design inputs obtained from brainstorming sessions with Designers and Support (Business Analysis), along with Stakeholder Requirements defined through consultations with Industry experts. These inputs ensure that a full understanding of the system requirements is achieved by reflecting the expectations and viewpoints of both internal design contributors and external stakeholders with regard to the system. Subsequently, the gathered inputs identified in Table 3 were methodically organized into categorized client requirements, as referenced in the subsequent section's Table 4. This classification enables the systematic transformation of stakeholder expectations into clearly defined and actionable design requirements. However, the outcome of this approach is a list of requirements. Requirement list serves as the specification against which the success of the design project can be judged.

Task Clarification – Find a most possible way to track coordination loss of the labors.

Table 5: Integrated Design Inputs from Business Analysis and Industry Stakeholders

Designer and Support (BA) Business Analysis Brainstorming	**Stakeholder Requirements (Derived by industry expert)**
Target Industry	Low price
Manufacturing Cost < 300 USD	5 years warranty
Selling Price < 2000 USD	Easy instructions/trainings < 45 min
Troubleshoot Chargers	Minimal disruptions to current workflow
Diagnosing Time < 20min	Ability to differentiate disruptions to workflow
Warranty – Lifetime	Real time data acquisition without manual data input

ROI Value	Ability to recreate historical data set
Easiness of usage	Worker's presence detection accuracy >85%
Data Protection	Resilient data transmission
Integration (SAP, ERP etc.)	Integration (SAP, ERP etc.)
Accuracy < 90%	Enables to turn off monitoring during downtime and off-shift hours.
Data Storage (Local hard drive /Cloud)	In accordance with labor regulations
Connection Method (Wi-Fi, GPS, Bluetooth etc.)	
Real Time Monitoring	
Failure handling	
Training requirements	
Sensor types	
Automatic daily productivity reports	

(Source: Developed by the author)

Table 6: Classifying Customer Requirements

Expecters (Essential Features)	**Spokens** (Customer might clearly asked for)	**Unspokens** (Customer may not request but they will appreciate)	**Exciters** (Beyond the expectations of the stakeholder)
Resilient data transmission	Easy instructions/trainings	Sensor types	Less energy usage
Accuracy	Low operational cost	Connection method	Predictive alerts for possible delays in job completion
Integration (SAP, ERP etc.)	ROI Value	Data protection	
Real Time Monitoring	Enables to turn off monitoring during downtime and off-shift hours.	Data storage	

Easiness of usage	Ability to recreate historical data set	Diagnosing Time < 20min	
Resilient data transmission			

(Source: Developed by the author)

Requirement list is a specification which should be included in the product as mentioned above. Standard template proposed by Pahl has been used to formulate the requirement list. Here, the Demands (D) are non-negotiable requirements that must be satisfied under all conditions; thus, failure to fulfill any of these requirements renders the solution unsatisfactory. On the other hand, Wishes (W) denote desired although non-essential criteria that improve the system's performance or usefulness. They should be evaluated if their implementation does not substantially elevate development expenses and should be categorized based on their significance (major, medium, or minor). Nevertheless, requirement list has been made based on the classification of customer requirements.

Table 7: Requirement List

Designer - Sajith		Requirement List for Design and development of sensor-based data accusation system to track coordination loss to improve labor productivity.	Issues on 08/01/2025 Page no 01
Changes	D W	Requirements	Responsible
		1. Function	Sajith
05/01/2025	D	• Detect employees' presence at workspace. • Identify number of disruptions to the work. • Identify duration of absence. • Real time monitoring	
		2. Performance	
05/01/2025	D D	• Worker's presence detection accuracy >85% • Diagnosing Time < 20min	
		3. Storage Requirement	

05/01/2025	D	• Data Storage (Local hard drive /Cloud) • Integration (SAP, ERP etc.)	
		4. Cost	
05/01/2025	W	• Sensor unit cost <150 USD • Dashboard Development < 100 USD • ROI < 4 months • Minimum Installation cost	
05/01/2025		5. Maintenance	
	D D	• Diagnosing Time < 20min • Troubleshoot easiness	
		6. Safety	
05/01/2025	W W	• Electrical safety regulations • No physical risk to employees	
05/01/2025		7. Energy	
	W	• Low energy consumption < 5W	
05/01/2025		8. Materials	
	D D	• Built in lighter < 0.1 lb. • No rusting <0.0001 ^m2 • Storing Temperature - -5/60 c	
05/01/2025		9. Environmental Impact	
	W	• Recycling • Functioning under industrial circumstance (-5 – 60 c)	
05/01/2025		10. Number of components	
	W	• Component should be exactly 01.	

05/01/2025	W	11. Portability requirement	
05/01/2025	W	12. Aesthetic Requirement	
05/01/2025		13. Ethics	
	W	• In accordance with labor regulations • No biometrics data requirement	

(Source: Developed by the author)

4.2.2 Step 02 – Abstracting to Identify the Essential Problems

In conceptual design, abstraction helps to uncover the true essence of an issue by eliminating aspects that are specific to a solution and concentrating on the primary purpose and limitations. Designers are frequently impacted by conventional approaches, prior experiences, and pre-existing solutions. These influences have the potential to stifle originality and keep better options from being explored. Additionally, the designer may be unintentionally led in one direction by requirement lists that already indicate specific solutions.

The designer reformulates the problem at a more general level and eliminates superfluous details by employing abstraction. Without being bound by a particular solution, this aids in precisely defining the main function as well as the important limitations, including cost, space, performance, production techniques, and delivery time. Define the key subproblems and investigate several solution concepts more easily after the main issue has been recognized. As a result, abstraction encourages the creation of more creative and efficient solutions by assisting designers in avoiding obsession with traditional concepts. Therefore, abstraction process has followed below 5 stages.

Stage 1. Eliminate personal preferences.

Stage 2. Omit requirements that have no direct bearing on the function and the essential constraints.

Stage 3. Transform quantitative into qualitative data and reduce them to essential statements.

Stage 4. As far as it is concerned, generalize the results of the previous step.

Stage 5. Formulate the problem in solution-neutral terms.

Results of Stage 01 and Stage 02

The abstraction process was executed to the requirement list to determine the task's primary constraints and functionalities. In order to ensure an objective approach to work, personal preferences, past experiences, and regular ways of thinking are deliberately removed in the first stage of abstraction. Designers tend to become attached to solutions they are comfortable with, which can inadvertently restrict originality. In second stage, needs that are not directly related to the primary function or necessary constraints are left out. Removing subjective influences and non-essential needs helps you focus on the core elements of the issue. This aids in precisely determining what is required to complete the main task. Therefore, below points has abstract from the requirement list.

- Detect employees’ presence at workspace.
- Identify number of disruptions to the work.
- Identify duration of absence.
- Worker’s presence detection accuracy >85%
- Data Storage (Local hard drive /Cloud)
- Integration (SAP, ERP etc.)
- Built in lighter < 0.1 lb.
- No rusting <0.0001 ^m2
- Storing Temperature - -5/60 c
- Functioning under industrial circumstance (-5 – 60 c)
- Low energy consumption < 5W
- Sensor unit cost <150 USD
- Dashboard Development < 100 USD
- ROI < 4 months

Results of Stage 03

In the third stage of the abstraction process, quantitative information like time constraints, costs, dimensions, or numerical limits was transformed into qualitative descriptions. By eliminating redundant specificity and emphasizing the core meaning of each need, this transformation expanded the possible solution space. Simple terms, stage 1 and 2 summarize by removing numerical values like below.

- Detect employees’ presence at workspace.
- detection accuracy
- Low energy consumption
- Integration
- Built in lighter
- Functioning under industrial circumstance
- Data Storage
- Low cost

Results of Stage 04

The outcomes of the qualitative transformation were subsequently extrapolated to a more comprehensive functional level in Stage 4 as stated below. To broaden the scope of potential solution concepts, specific technical explanations were reformed into more general functional assertions.

- Detect employees' presence at workspace.
- detection accuracy
- Integration
- Data Storage
- Low cost

Results of Stage 05

In the concluding phase of the abstraction process, the task was articulated in non-solution-focused terminology. All mentions of particular technologies, methodologies, or components were eliminated, retaining solely the fundamental aims and limitations. This method guarantees a thorough comprehension of the problem's essential goal, allowing designers to produce a variety of innovative solution principles.

Abstraction Outcome - Design and develop a cost-effective data acquision system with better detection accuracy, data storage facility and possibility of integrating into enterprise rescourse planning system (ERP) to improve current status of labor productivity.

4.2.3 Step 03 - Establish function structure

The requirements establish the function that reflects the anticipated overall relationship between the inputs and outputs of the intended data acquisition system, according to the abstraction's outcome.

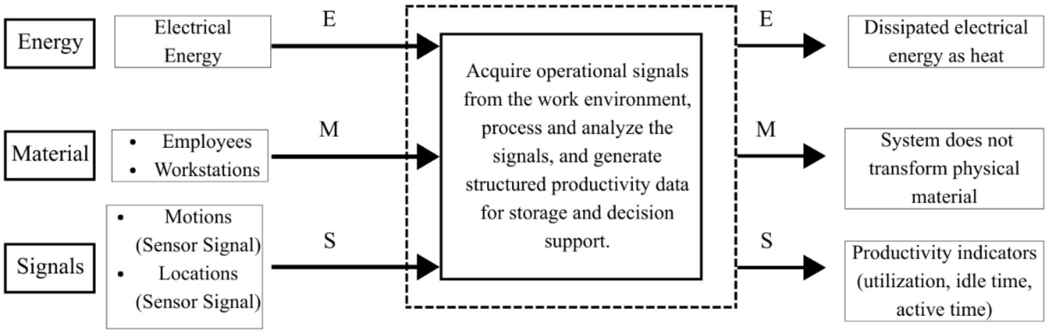


Figure 21: Overall function structure (Source: Developed by the author)

Establishing Sub Function Structure

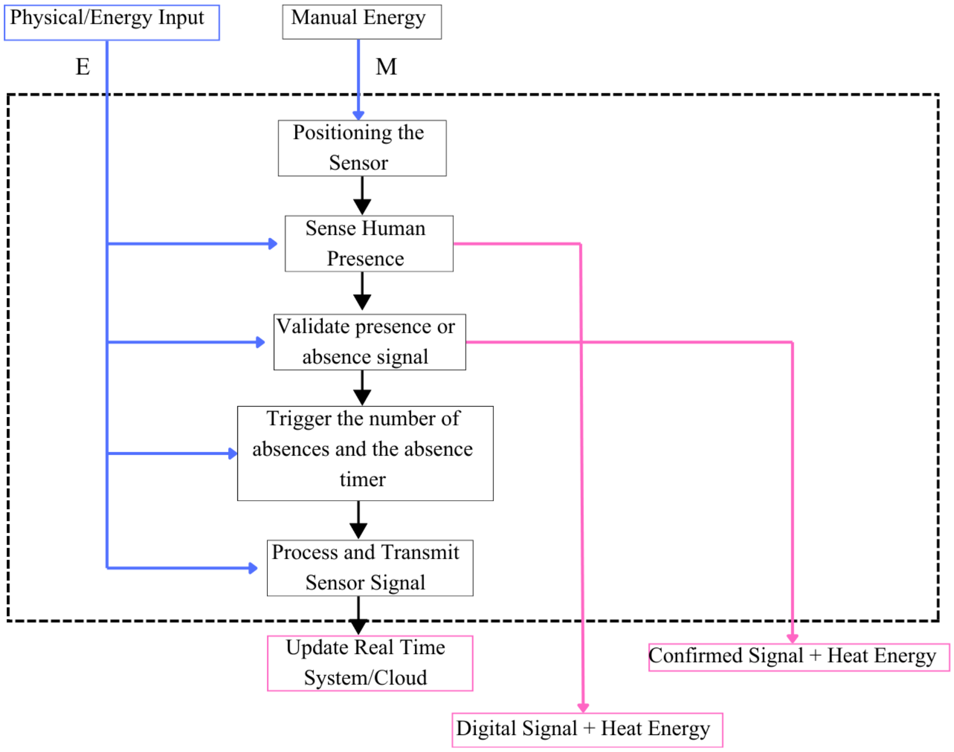


Figure 22: Sub Function Structure (Source: Developed by the author)

A complicated or general function can be separated into simpler subfunctions of lesser level of complexity, just as a technological system is capable of being divided down subsystems and elements as presented in Figure 22. A function structure that represents the entire function is created by combining the many subfunctions. Determining subfunctions that aid in the future search for solutions and combining these subfunctions into a straightforward and clear function structure are the goals of decomposing complex functions.

1. **Energy Flow**
    - Input Energy - Electrical energy applied to sensor
    - Energy Conversion
    - Output Energy - Heat

2. **Material Flow**
    - Input Material – Workers Presense
    - Transformation
    - Output Material – Digital Signal

3. **Signal Flow**
    - Input Signal – Sensor
    - Output Signal – Visual Feedback

4.2.4 Step 04 - Working principles and structure identification

The exploration of operational principles entails recognizing potential methods to accomplish each subfunction of a product and integrating them into a functional framework, ultimately resulting in a principled solution. A working principle embodies the essential physical effect, coupled with the requisite geometric and material attributes. In many cases, pre-existing physical effects can be used, but the main problem is how the shape is designed. Designers often combine physical impacts and form features when they create several versions of a solution. This creates a solution space that looks at a Lots of different options. Literature reviews, intuition, classification techniques, design catalogs, and the analysis of natural and technical systems are employed to ensure functioning principles. It is possible to arrange the solutions for a variety of subfunctions in a methodical manner in categorization Table 06, as will be demonstrated below.

Table 8: Working Principles

Solution Principles		1	2	3	4
Subfunctions					
1	Positioning the Sensor	Automatic Move A	Manual Move B		
2	Sense Human Presence	GPS Module C	Bluetooth Module D	Camera Module E	Break beam Module F
3	Validate presence or absence signal	Arduino G	ESP32 H	Raspberry PI I	DVR Module J
B	Trigger the number of absences and the absence timer	Arduino	ESP32	Raspberry PI	DVR Module
5	Process and Transmit Sensor Signal	GPS P	WIFI Q	Bluetooth R	Cable S
6	Update Real Time System/Cloud	Local Hard Drive T	Cloud System U		

(Source: Developed by the author)

4.2.5 Step 05 - Combine and firm up into concept variants

It is vital to generate comprehensive solutions by combining the operational principles into a coherent framework called systems synthesis in order to accomplish the primary purpose. This is the only way to achieve the primary objective. This integration rests on the previously established functional structure, which physically and conceptually reflects the subfunctions beneficial connections. Finally, in order to achieve the overall function, it is necessary to conduct system integration, which entails combining the operational principles into a functional framework, in order to generate comprehensive solutions. The developed function structure is stated in Table 07.

Table 9: Type of solutions

Solutions	**Combinations Solutions**
A	A-C-G-P-T
B	A-D-I-Q-T
C	B-E-J-Q-U
D	B-E-H-R-U
E	A-F-I-S-T

(Source: Developed by the author)

4.2.6 Step 06 - Evaluation against technical and economic criteria

The requirements list is the primary source for determining the evaluation criteria. During the preliminary selection process, variations that did not satisfy essential criteria were eliminated from consideration. While the ideas are being developed into primary solutions (Table 07), it is of the utmost importance to make certain that all of the remaining alternatives are in accordance with the requirements Since information is scarce, not all decisions can be made with confidence, therefore the probability of satisfying criteria may serve as an extra evaluative benchmark.

The study's evaluation criteria were organized in a systematic way after being retrieved from the requirements list. Table 09 summarizes the criteria, which include technical, economic, and safety aspects, and provides a clear framework for comparing and contrasting different conceptual design options. In addition, each assessment criterion was assigned a weighting variable in order to prioritize the core components of the possible combinations of conceptual designs. Despite the fact that the weightings were only preliminary due to the lack of sufficient information, they allowed for the prioritization of the most essential functions and requirements while considering the various potential solutions. The specifics of the weighting criteria are presented in Table 08.

Table 10: Rating Structure

Description	**Rate**

Poor	1
Average	2
Good	3
Very good	4
Excellent	5

(Source: Developed by the author)

Table 11: Evaluation Process

Solution Technical Criteria		A	B	C	D	E
1	Simple Construction	5	5	4	4	5
2	Accuracy	3	2	5	3	3
3	Low Cost	3	4	4	4	2
4	Maintenance/Calibration	2	4	5	3	4
5	Reliability of DATA	3	2	4	4	1
Total		16	17	22	18	15
$R=\frac{\text{Total}}{25}$		0.64	0.68	0.88	0.72	0.6

(Source: Developed by the author)

Following a comprehensive technical analysis, Solution C seems to be the best option. As a result, the finished product of the conceptual design process is shown below.

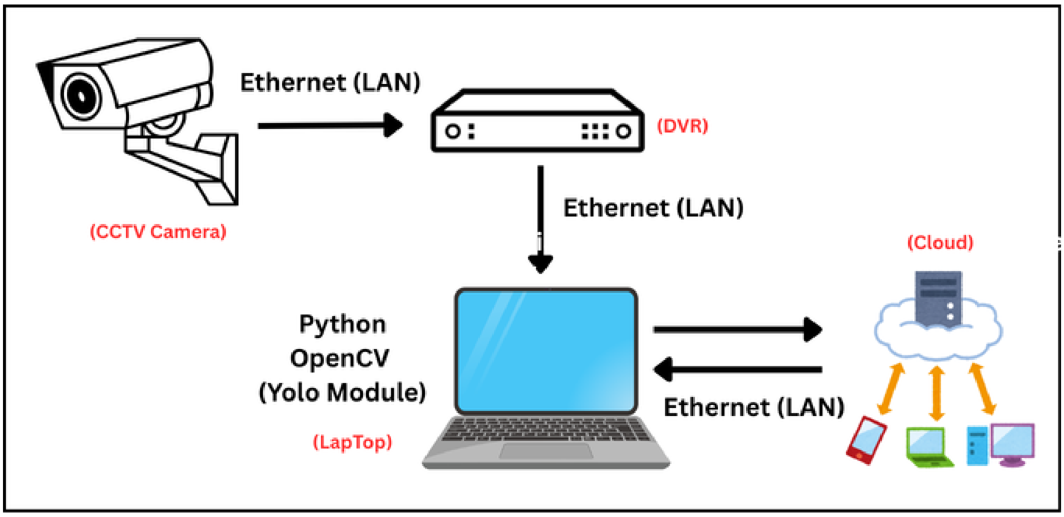


Figure 23: Conceptual Design of Proposed Method (Source: Developed by the author)

The suggested conceptual approach seeks to identify potential coordination loss by observing the presence of individuals inside a specified camera field of identify potential coordination loss by observing the presence of individuals inside a specified camera field of view. system incorporates a CCTV camera, digital video recorder (DVR), processing unit, and cloud connectivity to facilitate real-time monitoring data analysis. suggested architecture transmits video footage acquired by CCTV cameras across the local network (Ethernet LAN) to a DVR. DVR archives and transmits the video stream to a processing unit (laptop) for data processing. processing unit operates a computer vision detection system created with Python and OpenCV, incorporating the YOLO (You Only Look Once) object detection module. Module perpetually examines incoming video frames to identify and monitor individuals within the seen environment.

The Identification of coordination loss relies mostly on observing the visual presence of persons within the camera's field of vision. The system categorizes an identifiable subject's exit from the camera's field of view as a probable loss of coordination event. result from spots or transient movements beyond the frame. This strategy accounts for coordination loss if the individual is unobserved for a designated duration (e.g., several seconds), hence excluding disruptions in letter detection. Combining numerous Cameras with overlapping fields of vision improves detection reliability and allows for ongoing surveillance even when a person walks out of range of a single camera. To further ensure that human detection remains intact across frames, the system can further use multi-object tracking techniques like DeepSORT or SORT (Simple Online and Real-Time Tracking). By maintaining continuous Tracking of individuals even during abrupt obstructions or transitions across camera boundaries, these tracking techniques reduce misidentification caused by coordination loss.

4.3 Economic Feasibility Assessment

The preceding conceptual design approach shows that it is not technically feasible to measure an employee's productivity with minimal technical instruments. Therefore, the intent of this piece is to help a business better comprehend the benefits and drawbacks of implementing this technology. This is an illustration of an 8-hour workday in a machine assembly facility. Rest intervals are completely abolished for one hour. One worker is the subject of computations. Additionally, the organization attributed the decline in employee productivity to problems with coordination, unanticipated interruptions, and workload fragmentation. For better understanding of the calculation process below assumption has been taken into consideration.

Assumptions

- The direct employee's current productivity is 85% relative to planned output.
- Employee productivity has decreased by 5% (out of available time) as a result of organizational coordination issues.
- Operational improvement coefficient (β) is 5%

Data synthesis from case study

The data included in this analysis was gathered from the case study organization. which was formed to demonstrate the possible economic advantages of implementing a coordination loss tracking system, based on these empirical inputs.

Total shift time (T_T) - 480 minutes
Planned rest time (T_P) - 60 minutes
Available time (T_A) - 420 minutes
Average workdays per month – 20 days
Hourly wage – 10 €
Planned Annual hours per employee – 1920 hours

Daily Productivity Loss

This computation determines the average daily productive time lost due to coordination-based inefficiencies in the production context. from the case study were used to aggregate lost minutes per operator over shifts, thereby estimating the total daily productivity impact. This establishes a concrete operational baseline demonstrating the extent of unstructured coordination disruptions in the existing system.

$P = 1 - (L_o + L_x + L_f)$ where, ------- (1)

P - Productivity
L_o – Operational losses
L_x – Coordination Problems
L_f – Fatigue relates losses

Productivity Loss (P_T)= 420 * 0.05 = 21 minutes

According to the assumptions, 21 minutes are lost for the reasons listed above per day.

Annual Economic Loss

Annual economic impact was determined by projecting the calculated daily productivity loss over company's annual operation schedule. approach quantifies operational inefficiencies by turning lost time into monetary value using the average labor cost rate. The aim is to illustrate the economic impact of unquantified coordination loss in the production department.is to illustrate the economic impact of unquantified coordination loss in the production.

$Ae_L = N * W_h * P_l * A_h * \beta$ Where, -------- (2)

Ae_L - Annual economic loss
N – Number of employees
W_h – Hourly wage per employees
P_l – Productivity loss (minutes)
A_h – Planned Annual hours per employee

Annual economic loss (Ae_L) = 1 * (10/60) * 21 * 1920 = 6720 €

Annual Operational Improvement

Under conservative improvement assumptions, the Introduction of a coordination loss tracking system is anticipated to increase operational efficiency by roughly 5%. This assessment indicates attainable performance enhancements through enhanced visibility, systematic interruption oversight, and data-informed managerial action. used to simulate possible recovered productivity and related financial advantages, rather than to signify assured results.

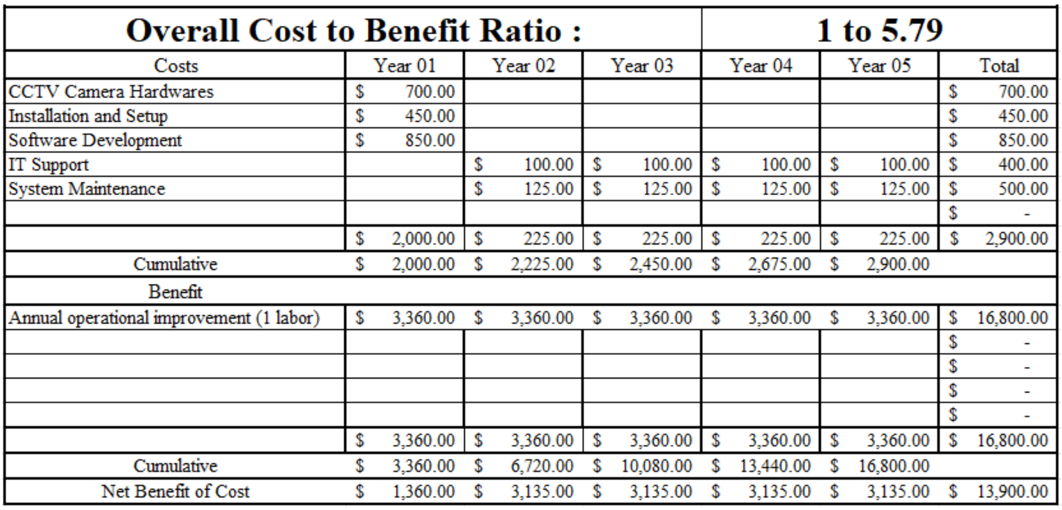
Annual operational improvement = $Ae_L * \beta$ Where, --------- (3)
β - Operational improvement coefficient

Annual operational improvement = 6720 * 0.05 = 336 β

4.3.1 Cost benefit analysis

The cost information shown below is derived from an official quotation received from Rysera.lk for the suggested CCTV-based tracking solution. The quotation includes the upfront cost of installation as well as ongoing service fees and anticipated maintenance costs for a period of five years. The economic assessment takes into consideration all expenses, whether they are operational or capital. This analysis incorporates the previously determined annual operational improvement to guarantee the cost-benefit ratio for the same five-year period. Using this approach, it is possible to systematically weigh the expected financial benefits driven by productivity against the total investment required.

Table 12: Cost benefit analysis



Overall Cost to Benefit Ratio :				1 to 5.79		
Costs	Year 01	Year 02	Year 03	Year 04	Year 05	Total
CCTV Camera Hardwares	$ 700.00					$ 700.00
Installation and Setup	$ 450.00					$ 450.00
Software Development	$ 850.00					$ 850.00
IT Support		$ 100.00	$ 100.00	$ 100.00	$ 100.00	$ 400.00
System Maintenance		$ 125.00	$ 125.00	$ 125.00	$ 125.00	$ 500.00
						$ -
	$ 2,000.00	$ 225.00	$ 225.00	$ 225.00	$ 225.00	$ 2,900.00
Cumulative	$ 2,000.00	$ 2,225.00	$ 2,450.00	$ 2,675.00	$ 2,900.00	
Benefit						
Annual operational improvement (1 labor)	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 16,800.00
						$ -
						$ -
						$ -
						$ -
	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 3,360.00	$ 16,800.00
Cumulative	$ 3,360.00	$ 6,720.00	$ 10,080.00	$ 13,440.00	$ 16,800.00	
Net Benefit of Cost	$ 1,360.00	$ 3,135.00	$ 3,135.00	$ 3,135.00	$ 3,135.00	$ 13,900.00

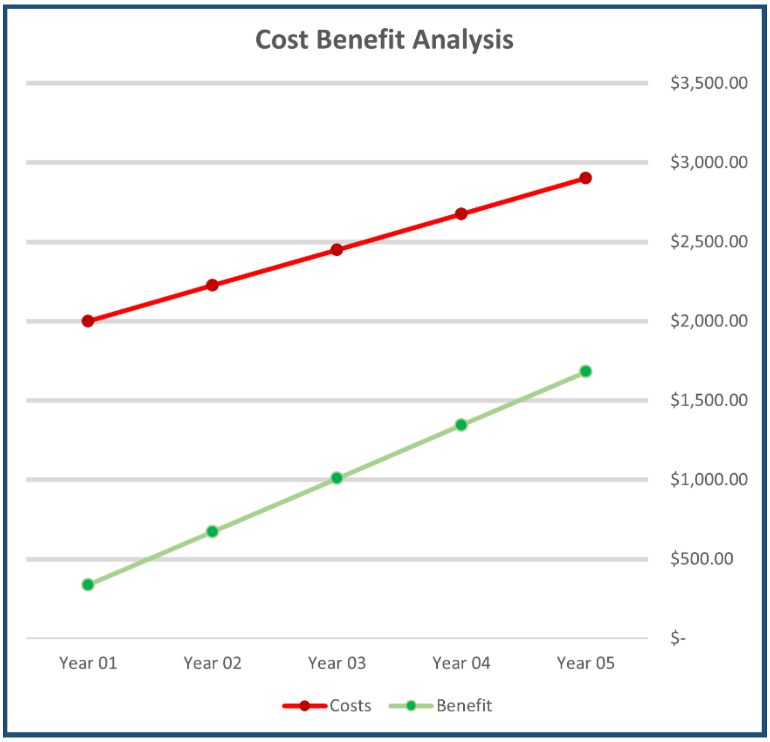


Figure 24: Cost to benefit ratio (Source: Calculated by the author)

The techno-economic analysis shows that over the evaluated time period, the Calculated cost-to-benefit ratio is 1.73:1 in an operational scenario with a single person. Consequently, this suggests that the financial return does not immediately surpass the investment in conditions of minimal workers. Nevertheless, the investigation further illustrates that as the quantity of operators escalates, the economic feasibility markedly enhances. settings with over five workers, the anticipated productivity enhancements are adequate to recoup the expenditure within the initial year of execution. The scaling impact demonstrates that the suggested coordination loss tracking system becomes progressively more economically advantageous in multi-operator production environments.

5 Design and Development of BI Dashboard

Previous chapters of the thesis explain the theoretical foundations and the conceptual foundation of the research. Chapter 2 discusses the limitations of current performance management systems and mainly their operational and financial visibility. Then case analysis also confirmed these limitations. Chapter 04 developed the conceptual performance measurement framework by integrating QDCSM parameters and the profit and loss accounting method, creating a dual-lens model in which these two insights can be measured. However, this chapter introduced the realization of the conceptual framework as functional through the digital integration to the framework. In this framework, dashboard is not act as a reporting tool, it is the digital representation developed framework though this research. Though the digital representation framework becomes a deployable management instrument. Therefore, this chapter documents the design and development process with technical and methodological support to build replication. The chapter includes rationale behind the selection of Power BI as design platform, overall dashboard architecture and design principle, and detailed design and construction of each section.

5.1 Platform Selection – Microsoft Power BI

5.1.1 Evaluation Criteria

The selection of the Business intelligence platform is not just a simple decision. It carefully chooses based on the organization function and contextual requirements that directly combine with the research main goals. Evaluation criteria include (1) real time or near real time data refresh rate or capability, (2) Capacity include different data sources (operational and financial), (3) dynamic visualization with user drilldown to navigate data without further technological expertise, (4) institutional strategic alignment and capability.

5.1.2 Comparative Assessment

Multiple competitive platforms were considered in this development including Power BI, Tableau, and SAP Analytics Cloud as mentioned in Table. Each platform offers different types of aspects and capabilities. Power BI was selected based on organization compatibility and better response to the evaluation criteria of the research work.

Table 13: Multi Comparison of BI platforms

Criterion	Power BI	Tableau	SAP Analytics Cloud
Microsoft 365 / ERP integration	Native, seamless	Via connectors	SAP-native only
Real-time data refresh	Supported (streaming + scheduled)	Supported	Supported
Licence cost	Included in M365 E3/E5	Additional licence	Additional licence
Cross-page navigation	Full support	Limited	Limited
DAX-based calculated measures	Native	Not available	Limited
Deployment within LVMH ecosystem	Compatible	Requires additional setup	Requires SAP stack

(Source: Comparison by the author based on the literature sources)

Power BI’s natural support with Microsoft 365 is a key advantage here. Availability of the Data Analysis Expressions (DAX) has enabled to construct and derive customized metrics as per the requirements without separate analytics environment. Furthermore, its cross-page navigation support system developed though the bookmarks and page navigation buttons allow the function of multimodule dashboard for clear architecture of the framework. Additionally, Power BI is included in Microsoft 365 Enterprise License, it already added subsidiary to the organization. These practical considerations allow Power BI to act as the sustainable operational management tool within the organization.

5.2 Overall Dashboard Architecture and Design Principles

5.2.1 Structural Architecture

This dashboard comprises 4 pages and each page dedicated to separate KPI categories with three analytical pages and main page which serve as the navigation hub for the three analytical pages. Delivery, Quality, Resource and Planning are the analytical models provided here. According to the organization's existing KPI structure, these analytical models have been categorized. The structure was built based on the end user utilization in mind. In manufacturing environment, different performance domains are reviewed by different members of the organization. Production department mainly focuses on delivery and resource metrics, quality department engages with defects and rework KPIs mainly, financial department controls the cost and the revenue indicators. However, the architectural modular design supports various user orientations while preserving a single model of data and consistent visual language, hence ensuring the accessibility of cross-domain insights.

5.2.2 The Dual-Column Design Principle

The standout design decision in the dashboard was systematic application of a dual-column design layout throughout all three analytical pages. Starting from first analytical page, the left column is devoted to operational performance metrics. The right column is devoted to financial insights of the corresponding operational metrics. This dual column principle is the direct visual representation of the conceptual framework which combines QDCSM vs P&L. Most importantly, operational metrics and the financial performance of the same metrics are not different entities in the manufacturing context. Whole idea behind this conceptual idea and the visualization method is to integrate immediately appear to any user, regardless of their professional background.

5.2.3 Color Coding and Visual Language

A standardized and systematic color coding was developed across all pages. The blue color schemes are solely used for operational performance panels and green color schemes are restricted to the financial insight panels. These color tones are interpretation of the cognitive understanding. It supports users to align themselves with performance instantly without reading the title of the labels. Additionally, it clarifies both difference and the relationship between operational and financial dimensions of the framework. The dashboard integrates burkle’s official color branding into dashboard header and branding elements. This positioned dashboard as the internal organizational tool rather than prototyping tool. The design was intentional and it reflects the sustainability of the users if branding alignment was treated as functional structure of day-to-day usage.

5.2.4 Development of the Main Page

The main page as shown in Figure 25 serves as the primary interface and the navigation center of the dashboard. It has several crucial roles including corporate identity, support its user to understand the structure of the tool, and directed to intuitive navigation across the analytical pages.

Figure 25: Main Page (Source: Developed by the author)

The primary page features a full bleed backdrop image of the Burkle manufacturing site, with a semi-transparent text panel at the top with the dashboard title “Operational and Financial Performance Dashboard”. The use of the title's name is deliberate and illustrates the two categories of performance review. The left side navigation panel shows all the analytical performance pages, Main Page, Delivery, Quality, Resource and Planning. All these pages are navigated as Power BI navigation buttons and directed to the corresponding page based on the selection of the button. Active analytical pages represent by the lighter background featuring shade. However, it furnishes positional awareness to its users easily. This navigation strategy was chosen over tab-oriented navigation due to its provision of constant transparent orientation, ensuring users are consistently aware of their location and available options, a crucial usability aspect in a multi-module performance tool utilized under time constraints.

5.3 Design and Development of the Delivery Performance Page

5.3.1 Conceptual Framing

The delivery performance page as shown in Figure 26, is the first analytical page which comprises the conceptual frameworks delivery dimension as per combination of the QDCSM frameworks ‘D’ Delivery, category and its financial insights. This delivery performance page accounts for both aspects of the supply chain: from supplier to company and from company to customer. This both directional idea is lacking in the majority of QDCSM approaches implemented in production settings, which often emphasize the company-to-customer perspective.

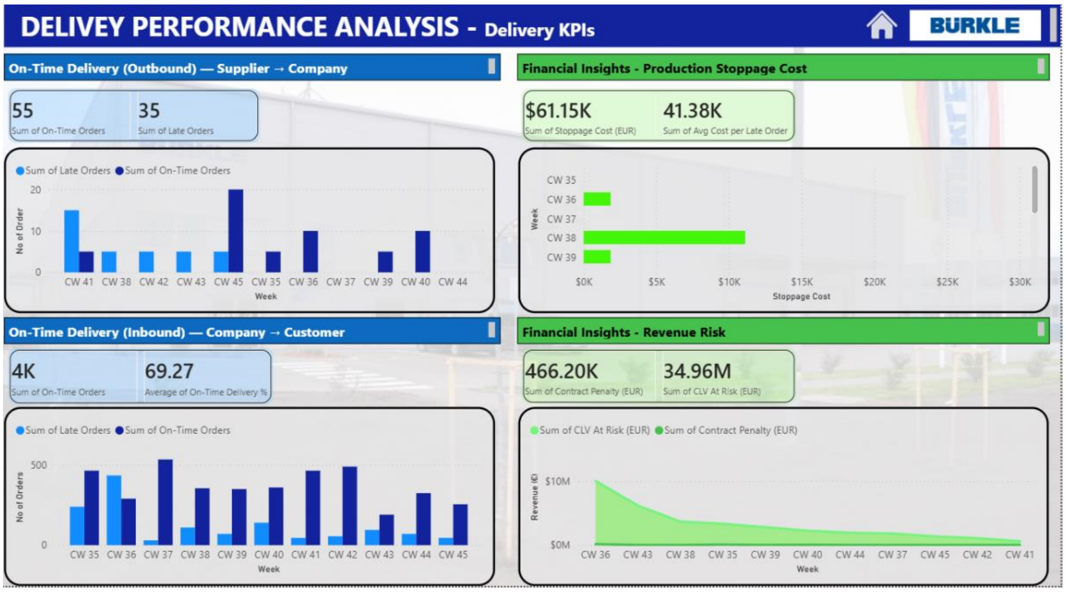


Figure 26: Delivery Performance Page (Source: Developed by the author)

5.3.2 Panel 1 – On Time Delivery (Outbound): Supplier to Company

The top left corner of the panel tracks OTD Outbound performance metric from supplier to the company facilities. Two KPI cards were utilized to display all on-time orders and all late orders within the 12-week period. This is located at the top end of the clustered bar chart. Bar charts consist of two data categories: late orders represented in light blue and on-time orders depicted in dark blue for comparative visualization. All panels on the pages utilize calendar week (CW) as the major timeframe dimension, consistent with Burkle's current performance metrics assessment process. The monthly review procedure in financial reporting is prevalent, yet it may hinder timely decision-making in the production environment. The weekly granularity provides an opportunity and sufficient time for decision-making through trend identification.

The DAX algorithm is utilized to calculate the on-time delivery statistics, based on the ratio of promised delivery dates to proven delivery dates. Nevertheless, by evaluating the external and internal aspects, a tolerance threshold can be implemented in the process. This categorization logic was established in collaboration with the operational data derived from the case study and embodies the delivery performance standards implemented inside the organization.

5.3.3 Panel 2 - Financial Insights: Production Stoppage Cost

The top part right panel is devoted to financial insights, translating late supplier deliveries into their financial repercussions for the organization. Resulting from an interruption of the production line. The two main performance indicator cards on this board exhibit the average cost per delayed order over a 12-week duration and the expense associated with production downtime. The costs associated with manufacturing line downtime are illustrated each calendar week in the horizontal bar chart. The average daily production output value can be determined by analyzing the current or anticipated downtime of the manufacturing line. The algorithm aligns with the foundational principles of simplified profit and loss accounting and DAX expression formulas, enabling the conversion of hourly output loss into a monetary financial impact. The fundamental principle of the QDCSM-Profit and Loss architecture executed in DAX is the causal relationship between operational events and financial outcomes.

5.3.4 Panel 3 - On-Time Delivery (Inbound): Company to Customer

The lower left corner's operational performance panel is quite similar to the upper left corner's structure. Nevertheless, the focus is on the efficiency of customer deliveries. The total number of orders delivered to clients on time and the average percentage of orders delivered on time were the basis for developing the key performance indicator cards. Following the supplier delivery panel's double-row structure, the bar chart shows these metrics by calendar week. A visual representation of the correlation between supplier delivery variance and customer delivery performance is provided by the operational panel, which is situated below the supplier delivery panel. This panel gives users the ability to visually understand the relationship between the two. Consequently, this results in the production of an alarm signal that has a quick cascade effect throughout the supply chain.

5.3.5 Panel 4 - Financial Insights: Revenue Risk

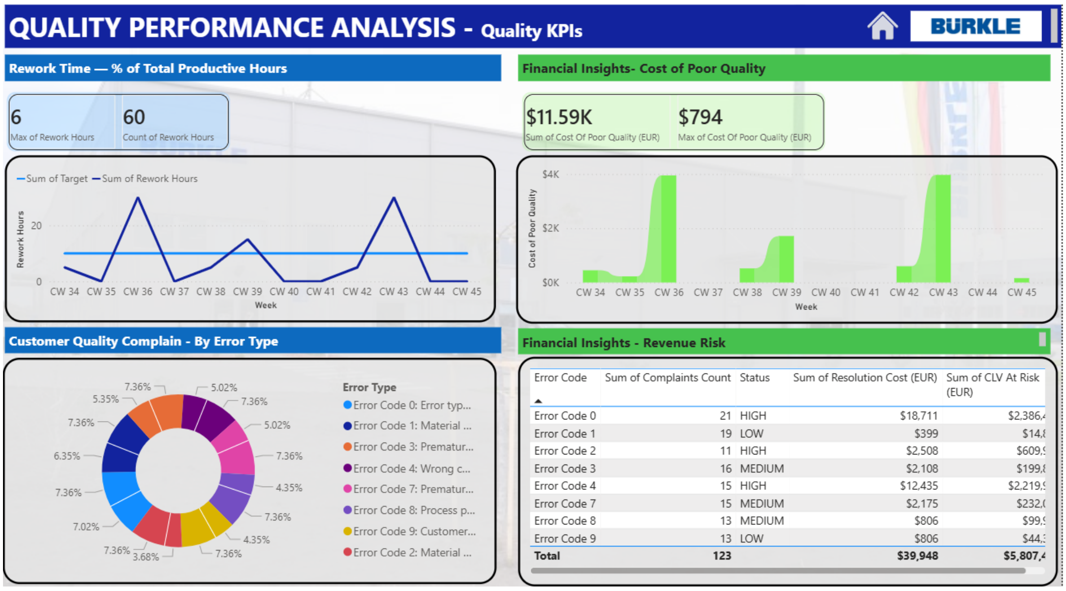
The Financial Insights panel, which is Located in the bottom right corner of this delivery performance module, is an important measure. When determining revenue risk, penalties and customer lifetime value (CLV) are taken into consideration. These factors are defined in customer contracts. This is a particular observation that falls under the purview of the finance department. It is designed to be implemented in the production environment, and it has an effect on the cognitive processes of product managers. The area chart has been used in this case to visualize the CLV risk by Calendar week over the bar chart. Because the area fill conveys cumulative risk exposure more intuitively than discrete bars. The diminishing trend in CLV at risk during the observation period is easily visible in the area chart's slope, a characteristic that would be less noticeable in a bar chart format.

5.4 Design and Development of the Quality Performance Page

5.4.1 Conceptual Framing

The quality analytical page signifies the quality aspect of the QDCSM framework. Quality is fundamentally examined from two primary perspectives: internal quality, which pertains to reworks within the production facility, and external quality, which relates to consumer complaints about defective products.

This internal and external perspective has also influenced monetary values to ensure the dashboard encompasses several viewpoints for performance evaluation.



Error Code	Sum of Complaints Count	Status	Sum of Resolution Cost (EUR)	Sum of CLV At Risk (EUR)
Error Code 0	21	HIGH	$18,711	$2,386
Error Code 1	19	LOW	$399	$14
Error Code 2	11	HIGH	$2,508	$609
Error Code 3	16	MEDIUM	$2,108	$199
Error Code 4	15	HIGH	$12,435	$2,219
Error Code 7	15	MEDIUM	$2,175	$232
Error Code 8	13	MEDIUM	$806	$99
Error Code 9	13	LOW	$806	$44
Total	**123**		**$39,948**	**$5,807**

Figure 27: Quality Performance Page (Source: Developed by the author)

5.4.2 Panel 1 - Rework Time as a Percentage of Total Productive Hours

Quality Analytical page begins with the operational panel located in the upper left corner, according to the same structure as other analytical pages. This visualizes two KPI cards: maximum rework per hour and total number of reworks over a 12-week period. A line chart has been added to display rework hours against the organization's rework targets by calendar week. A vital design component is the target line, represented as a horizontal line produced from a DAX expression formula, reflecting the existing organizational targets and standards. In the absence of reference line data, it solely displays the actual performance, excluding periods of underperformance. The line chart has been used above the bar chart for rework hours, as the continuous lines illustrate temporal trends and the correlation between successful weeks.

5.4.3 Panel 2 - Financial Insights: Cost of Poor Quality

The upper left panel indicates the Cost of Poor Quality (COPQ). COPQ is a typical quality economic indicator that calculates the labor cost rate associated with rework hours and additional raw material costs. This direct operating loss has been turned into monetary terms through the application of this translation. The line chart that depicts rework hours was purposefully chosen to contrast with the bar chart that depicts COPQ by calendar week. It places emphasis on the particular monetary repercussions that are associated with weekly quality failures, whereas the line chart illustrates operational patterns and highlights the distinction between financial results and operational efficiency.

5.4.4 Panel 3 - Customer Quality Complaints by Error Type

The lower left portion is dedicated to client complaints, sorted by defect type. A Donut chart has been used for visualization due to its efficacy in identifying the predominant sources of total complaints arising from distinct types of problems. category of flaws is represented by a specific color, with each color corresponding to a caption that includes ten documented defect codes derived from the case study data. Label density must be considered when developing this panel due to the presence of ten error categories. chosen solution involved displaying percentage values within each segment and offering comprehensive error definitions in the accompanying legend, which Power BI presents as an interactive filter; selecting a legend item highlights the relevant segment and cross-filters other visualizations on the page.

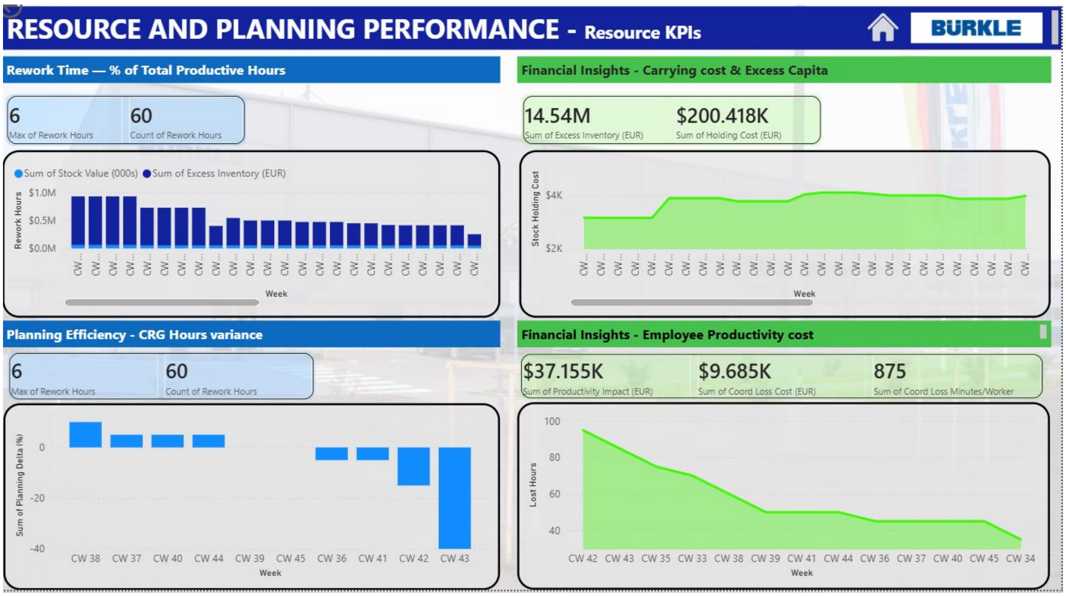
5.4.5 Panel 4 - Financial Insights: Revenue Risk from Quality Failures

Financial panels on the left and right employ chart-based approaches, whilst the one on the bottom right is organized as a matrix table. Matrix displays each error code with its corresponding complaint count, risk status categorization (HIGH, MEDIUM, or LOW), resolution cost, and customer lifetime value at risk. The risk level feature was established as a DAX-generated column that used threshold logic to categorize each error code according toto a composite score based on complaint frequency and resolution cost. This classification incorporates a priority layer into the quality management data, converting the table from a mere data display into a decision-support tool: a quality manager can promptly discern which error codes require immediate attention (High-status, high-resolution cost) and which can be managed through standard quality improvement procedures.

5.5 Design and Development of the Resource and Planning Performance Page

5.5.1 Conceptual Framing

The Resource and Planning performance page comprises a combination of many performance metrics in accordance with the present organizational structure. The specific structures, 'C', 'S', and 'M' (Cost, Safety, and Morale) have been regarded as a singular analysis page. This analysis page is the most complex module from a technological perspective. This represents an expansion beyond the conventional boundaries of QDCSM approach.



RESOURCE AND PLANNING PERFORMANCE - Resource KPIs

Rework Time — % of Total Productive Hours

6 Max of Rework Hours
60 Count of Rework Hours

Financial Insights - Carrying cost & Excess Capita

14.54M Sum of Excess Inventory (EUR)
$200.418K Sum of Holding Cost (EUR)

Planning Efficiency - CRG Hours variance

6 Max of Rework Hours
60 Count of Rework Hours

Financial Insights - Employee Productivity cost

$37.155K Sum of Productivity Impact (EUR)
$9.685K Sum of Coord Loss Cost (EUR)
875 Sum of Coord Loss Minutes/Worker

Figure 28: Resource Planning Page (Source: Developed by the author)

5.5.2 Panel 1 - Inventory Management: Stock Value and Excess Inventory

The upper left corner of the final analytical structure is designated for the operational panels. The focus has been placed on inventory from two perspectives. The first perspective represents the overall stock count, while the second denotes the excess inventory count. Clustered chart has been used here to illustrate the disparity in comparison to its target level. The organization can determine excess inventory levels depending on its requirements and production schedules. This design concept is deliberate, enabling users to assess the surplus inventory in relation to the entire inventory. An extensive surplus inventory figure is less concerning if it is a minor percentage of total stock; conversely, a modest excess inventory figure may be quite substantial if total stock levels are already minimal. The clustered bar format conveys this proportional context more effectively than two distinct charts would.

5.5.3 Panel 2 - Financial Insights: Carrying Cost and Excess Capital

The panel in the upper right corner of the screen, situated opposite the operational performance measures for inventory and excess inventory, presents two key performance indicators (KPIs) for inventory and excess inventory. The key performance indicators are the total excess inventory value and the inventory holding cost. The DAX formula was employed to determine the expense of maintaining inventory. This computation is carried out differently by different organizations; some express it as a percentage of the weekly stock value in relation to the overall inventory, while others take floor area into account. ratio was acquired straight from the company's financial division, indicating the prompt use of the new conceptual framework. The variations in inventory holding costs by calendar week are shown by the area chart. Distribution Module's CLV Risk chart reflects the reasoning behind the area chart's selection since it more clearly depicts the continuous and cumulative characteristics of holding costs than other chart types.

5.5.4 Panel 3 - Planning Efficiency: CRG Hours Variance

In the lower left corner of the page, there is a diverging bar chart that analyzes efficient entities. In this context, CRG (Capacity, Resource, Grouping) hours are used to assess the planning delta (%) for the upcoming calendar week, while addressing is applied for planning purposes. The diverging bar displays a positive value when it rises and a negative value when it falls. But it's the possible veering off course from the planned efficiency path. The DAX expression is used to display the variance between projected and actual CRG hours per calendar week. Positive numbers on the zero streamline indicate excess planning, potentially due to under planning or a surge in demand, whereas negative values signify overplanning or a shortage in demand. This measure was established by incorporating various insights obtained from the case study.

5.5.5 Panel 4 - Financial Insights: Employee Productivity and Coordination Loss Cost

The lower right finance panel is designated for the conceptualization of monitoring coordination losses and enhancing organizational productivity. the central concept of incorporating real-time data into the proposed framework. It introduces several aspects to the traditional QDCSM framework. time lost due to coordination issues translates into financial information. impact on productivity, the cost of coordination loss, and the minutes of coordination loss per worker collectively operationalized the concealed productivity deficit. The financial translation may be accomplished through the use of DAX expression, and the calculation of average financial values can be readily incorporated. The panel comes to a close with an area chart that illustrates Lost Hours per calendar week. This graphic provides a temporal perspective on the progression of productivity loss.

5.6 Summary of Dashboard KPIs and Their Framework Mapping

Table 14 offers a comprehensive reference of all key performance indicators used in the dashboard, their alignment with QDCSM dimensions, their financial equivalents, and the DAX measure types employed in their implementation.

Table 14: Summery

Dashboard Page	Operational KPI	Financial Counterpart	QDCSM Dimension

Delivery	On-Time Delivery % (Supplier → Co.)	Production Stoppage Cost (€)	Delivery
Delivery	Late Order Count (Supplier → Co.)	Avg Cost per Late Order (€)	Delivery / Cost
Delivery	On-Time Delivery %(Co. → Customer)	CLV at Risk (€)	Delivery
Delivery	On-Time Order Volume	Contract Penalty Exposure (€)	Delivery / Cost
Quality	Rework Hours (vs Target)	Cost of Poor Quality — COPQ (€)	Quality
Quality	Rework Instance Count	Max COPQ per Week (€)	Quality / Cost
Quality	Complaint Count by Error Type	Resolution Cost by Error Code (€)	Quality
Quality	Error Type Distribution (%)	CLV at Risk by Error Code (€)	Quality / Cost
Resource & Planning	Stock Value (€000s)	Stock Holding Cost (€)	Cost
Resource & Planning	Excess Inventory (€)	Excess Capital Tied Up (€)	Cost
Resource & Planning	Planning Delta — CRG Hours (%)	Productivity Impact (€)	Cost / Morale
Resource & Planning	Coordination Loss Minutes/Worker	Coordination Loss Cost (€)	Cost / Morale

5.7 Chapter Conclusion

This chapter provides a record of the design and development of the operational and financial performance dashboard. This dashboard is an embodiment of the digital application of the QDCSM-P&L integrated performance measurement framework that was built after this research was conducted. Power BI was selected as the implementation platform following a comprehensive assessment of functional and organizational parameters. The platform's three-tier architecture data, logic, and representation perfectly align with the conceptual structure of the framework, as elucidated in this chapter. The four pages of the dashboard, which include the main page, delivery performance, quality performance, and resource and planning performance, were planned and designed in response to particular aspects of the QDCSM framework. Financial impact panels were methodically linked to each and every operational key performance indicator panel.

The technical and intellectual contributions of the development work documented here are embodied in the dual-column design principle, the consistent color-coding system, and the introduction of innovative metrics such as the COPQ measure and Coordination Loss Cost. The dashboard is showcased not as a completed product but as a validated proof-of-concept, an artefact that illustrates the viability of consolidating operational and financial performance visibility within a singular, interactive, real-time monitoring environment.

6 Discussion

This research project examined the performance management problems faced by a low-volume high-mix (LVHM) factory by conducting practical case study of Bürkle Hungary Kft, integrating qualitative analysis with framework formation and digital deployment. The results fulfill all four research objectives and contribute significantly to the wider literature on factory performance management.

6.1 Q1 - KPI Discovery & Tracking Methods

The case analysis indicated that the organization employs a systematic array of KPIs, encompassing OTD outbound, OTD inbound, supplier quality, planning hour efficiency, rework rate, and employee productivity, which are tracked via an ERP system with bi-daily manual updates and weekly consolidated reporting. These Measurements regularly give some operational insight, but they aren't generated with enough temporally depth for proactive decision making, and they're separate from monetary outcomes. These sections underscore the need for production managers and senior management linked to the production department to obtain financial data in real time. Furthermore, as indicated in prior study, it was feasible to ascertain the potential reasons for the failure of this organizational structure to achieve a significant number of KPIs. variability in products, unstable processes, low repeatability, and complexity in cost tracking was noted.

6.2 Q2 - QDCSM-Based Performance Framework

The formation of the QDCSM-P&L interconnected framework revealed a disparity between the measures of operational success on the shop floor and the reporting of financial performance. This vacuum has been recognized repeatedly in both the case organization and the literature. SMART, BSC, and OKR are examples of existing frameworks that function primarily at the strategic or managerial level. These frameworks do not provide mechanisms that directly translate operational aberrations at the product level into implications for profit and loss. Address this issue, the proposed framework incorporates all five elements of QDCSM quality, delivery, cost, safety, and morale into a system aligned with profit and loss. This enables product managers to evaluate operational decisions from both technical and financial viewpoints concurrently. The proposed paradigm necessitates reduced organizational maturity, diminished talent investment, and cheaper implementation costs compared to existing established frameworks. provides extensive real-time monitoring, which is particularly advantageous for LVHMs with limited resources.

6.3 Q3 - Sensor-Based System for Labor Productivity

The Coordination Loss KPI represents a groundbreaking outcome of this research, tackling a phenomenon recognized by those who have operated on a production floor: the continual, understated depletion of time caused by avoidable issues, including delayed materials, unclear or recently modified instructions, and teams waiting for one another due to insufficient information. This time dissipates without a trace in most KPI systems, it is neither rework nor absence, but rather lost.

Formalizing coordination loss as a measurable KPI required working through what actually causes it and how it might be tracked reliably. The design process evaluated several possible solutions and converged on CCTV-and-computer-vision architecture as the strongest option across accuracy, cost, maintenance, and data reliability. The economic case is modest at small scale but strengthens considerably as the number of operators grows, a pattern well documented in the industrial IoT literature, where shop-floor monitoring technologies tend to justify themselves through volume rather than single-unit deployment. What this also demonstrates is a broader point about the framework itself, it is not limited to conventional, long-established KPIs. Even a newly conceptualized indicator like Coordination Loss, one that didn't exist in formal measurement systems before and relies on emerging computer vision technology for detection, can be absorbed into the QDCSM-P&L structure and monitored alongside traditional metrics. The framework is designed to accommodate that kind of evolution, which matters in manufacturing environments where the nature of operational disruption keeps changing.

6.4 Q4 - Real-Time Decision Support Visualization

The Power BI dashboard represents the digital realization of the conceptualized QDCSM-P&L framework translating what was designed as a theoretical construct into a functional, deployable management instrument. This distinction matters, the framework on its own establishes the logic of integration between operational and financial performance domains, but it is the dashboard that gives that logic a tangible, interactive form accessible to practitioners within their day-to-day organizational context.

The dual-column layout positioning each operational KPI panel in direct visual correspondence with its financial consequence was not an incidental design decision. It was a deliberate structural choice to preserve the conceptual integrity of the framework in its digital form. Conventional business intelligence dashboards tend to compartmentalize operational and financial data across separate reporting pages, which places the interpretive burden on the user. The architecture adopted here removes that burden by making the cross-domain relationship immediately apparent, regardless of the viewer's functional background or technical literacy.

The DAX-computed metrics introduced within the dashboard Cost of Poor Quality, Production Stoppage Cost, Customer Lifetime Value at Risk, Coordination Loss Cost, and Planning Delta extend beyond what conventional QDCSM reporting typically captures. Their inclusion elevates the dashboard from a descriptive monitoring tool to an instrument that actively supports managerial judgement. Reporting at weekly calendar granularity, rather than the monthly cycle prevalent in most financial reporting practices, further strengthens the responsiveness of the system compressing the feedback loop between operational events and informed managerial response.

7 Conclusion

LVHM manufacturing has long occupied an uncomfortable position within the performance measurement literature, too complex for the metrics inherited from mass production, yet too resource-constrained for the sophisticated measurement architectures developed for large enterprises. This research engaged directly with that tension, taking as its starting point a practical and theoretically underexplored problem, the structural disconnect between what production teams measure and what organizational decision-makers need to know, financially and in real time. Through empirical investigation at Bürkle Hungary Kft., combined with conceptual framework development and applied dashboard design, the study demonstrated that this disconnection is neither inevitable nor difficult to address it is primarily architectural. The existing KPI landscape revealed meaningful performance gaps, most notably a supplier on-time delivery rate of 40% and over 6,200 lost labor hours across a 13-week window, but the more significant finding was the absence of any mechanism for translating those operational realities into financial terms at the production department level. The QDCSM-P&L integrated framework was developed to provide exactly that mechanism, and the Power BI dashboard was designed as its digital realization making the operational-financial relationship visible, timely, and interpretable without requiring specialist knowledge from those using it.

The Coordination Loss KPI stands as the most theoretically distinctive contribution of this work. Unproductive labor time arising from workflow disruption material shortages, instruction delays, inter-departmental synchronization failures has been a routine feature of LVHM production environments for as long as they have existed. Its consistent absence from formal KPI architecture is not a minor oversight; it represents a structural blind spot that quietly erodes productivity while remaining invisible to management reporting systems. Formalizing it as a measurable, financially accountable indicator, and demonstrating a technically viable path to its detection, is a meaningful step toward closing that gap. What this research ultimately argues is that the performance management problem in LVHM SMEs is not one of data scarcity, it is one of integration. What has been missing is the conceptual and technical architecture to make it coherent. The framework KPI, and dashboard developed here offer a low-cost, scalable, and practically deployable response to that absence one that does not require organizational transformation as a precondition for implementation. In that sense, the contribution is not only to the academic literature on manufacturing performance measurement, but to the broader question of even how smaller manufacturers can build management capability proportionate to the complexity of what they produce.

7.1 Limitation of Study

7.1.1 Single-Site Case Study and Generalizability

The empirical foundation of this research rests on a single case organization, Bürkle Hungary Kft., a custom machine assembly operating within the Central European manufacturing context. While the depth of engagement with this organization spanning multiple interviews, direct observations, and document analysis provides rich qualitative insight, it inherently restricts the external validity of the findings. The proposed QDCSM-P&L framework, the Coordination Loss KPI, and the Power BI dashboard were all developed and calibrated against the specific product types, workflow structures, labor cost rates, and ERP configurations present at Bürkle. It cannot be assumed without further empirical testing that the framework performs with equal coherence in other LVHM environments, particularly those operating with different product complexity levels, multi-shift arrangements, unionized labor conditions, or non-European regulatory contexts. The research should therefore be understood as a proof-of-concept validated at a single site rather than a universally tested model.

7.1.2 Observation Period and Data Temporality

The operational KPI data analyzed in this study was collected over a period of approximately 12 to 13 weeks, covering calendar weeks 33 to 45 of 2025. While this window is sufficient to identify patterns and demonstrate framework applicability, it is not long enough to capture seasonal production variability, annual demand cycles, or the longitudinal effects of process changes. LVHM manufacturing environments are characteristically volatile, and performance trends observed during a single quarter may not represent the organization's typical operating condition. The OTD outbound rate of 40%, for instance, may reflect an atypical period of supplier disruption rather than a stable baseline, a distinction that has significant implications for how the derived financial impact figures should be interpreted.

7.1.3 Conceptual Status of the Coordination Loss Tracking System

The sensor-based coordination loss tracking system presented in Chapter 4 remains at the conceptual design stage. Although the Pahl methodology was rigorously applied to generate and evaluate solution variants, and solution C the CCTV and computer vision architecture was selected through a structured technical evaluation, the system has not been physically prototyped, deployed, or validated in a live production environment. Consequently, the accuracy of worker presence detection, the reliability of coordination loss classification, the practical implications of occlusion in complex workshop layouts, and the real-world system latency under concurrent multi-camera operation all remain untested. The economic feasibility analysis, which projects a cost-to-benefit ratio of 1.73:1 over five years based on a 5% improvement coefficient, is built on assumptions that have not been empirically confirmed and should be treated as indicative rather than predictive.

7.2 Future Recommendations

7.2.1 Systematic Multi-Site Validation Across Diverse LVHM Contexts

The theoretical coherence and internal consistency of the QDCSM-P&L framework having been established through the present case study, the logical next step in its scholarly development is cross-contextual empirical validation. Future research programs should engage a minimum of four to six LVHM manufacturing organizations, selected to represent meaningful variation along dimensions including workforce size, product technical complexity, national regulatory context, and degree of existing digital infrastructure. A comparative case study design, conducted over a full annual operating cycle at each site, would generate the evidence base needed to identify which structural elements of the framework are genuinely portable across contexts and which require site-specific calibration. This program of research would also produce the multi-organizational dataset necessary for establishing reference ranges for KPIs such as Coordination Loss Rate and Cost of Poor-Quality values that currently must be determined by each organization independently against its own internal benchmarks rather than against industry norms.

7.2.2 Extension of the Framework Toward Predictive and Prescriptive Analytic

The present research establishes a diagnostic performance architecture one that makes operational and financial conditions visible in near real time and supports retrospective causal analysis. A substantive research opportunity exists in extending this architecture toward predictive capability through the integration of supervised machine learning models trained on accumulated KPI time-series data. Candidate applications include the development of early warning classifiers that identify emerging coordination loss accumulation before it translates into delivery deviation, regression models predicting end-of-week OTD performance from mid-week operational signals, and anomaly detection algorithms that flag supplier quality trajectories before they breach the 1% defect rate target. Given the characteristically small batch sizes and high product variability of LVHM environments conditions that generate sparse, irregular time-series data poorly suited to standard machine learning approaches methodological investigation of transfer learning, few-shot learning, and Bayesian inference techniques appropriate to data-constrained manufacturing settings would constitute a genuinely original contribution to the manufacturing informatics literature.

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