BUILDING AN EFFECTIVE WAREHOUSE DASHBOARD: IMPROVING OPERATIONAL INSIGHT THROUGH KPIS

Abstract

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Management Summary

Introduction

Bricklog Holding B.V., founded in 2015 and headquartered in Apeldoorn, specializes in optimizing data management for Small to Medium-sized Enterprises (SMEs) in the transport and logistics sector. The company has transitioned from consultancy to a data-driven approach, offering a comprehensive Business Intelligence (BI) product designed to enhance warehouse operations by interpreting data from Warehouse Management Systems (WMS).

SMEs often struggle with leveraging data from WMS to gain actionable insights, which impacts warehouse efficiency and strategic decision-making. The current WMSs lack advanced analytics and Key Performance Indicators (KPIs) essential for comprehensive operational insight.

Research Objective

The goal is to design and implement a dashboard that integrates with existing WMS infrastructure, highlighting critical KPIs and metrics to enable SMEs to make informed decisions and optimize warehouse operations.

Main Research Question

How can a dashboard be designed to effectively implement performance tracking and streamline data visualization to enhance warehouse performance?

Approach

A systematic approach was adopted to address the research objective. A thorough literature review identified the best practices for designing dashboards and relevant KPIs. The Analytic Hierarchy Process (AHP) was utilized to prioritize and select the most critical KPIs. Insights from stakeholders at Bricklog guided the dashboard's design, ensuring it meets the specific needs of SMEs.

The dashboard is segmented into three main sections: Static, Dynamic, and Revenue. Key features include interactive data filtering, drill-through capabilities, and visual alerts for quick performance assessment. PowerBI was chosen for the dashboard implementation due to its compatibility with Bricklog's existing systems.

Validation involved a survey with a Bricklog representative and students from the University of Twente. This process focused on assessing the dashboard's usability, perceived usefulness, and the semantic quality of the KPIs.

Main Findings

1. **Measuring and Monitoring Warehouse Performance**
   It is crucial to select relevant KPIs systematically to effectively measure and monitor warehouse performance. A literature review and informal interviews with company employees identified several overlapping KPIs. Using the AHP method, KPIs were rated against weighted SMART criteria, resulting in a selection aligned with the dashboard's goals and practical constraints of data availability.
2. **Data Visualization Techniques**
   Best practices in dashboard design were applied, including frame-based menus for efficient navigation, drill-down features for detailed data exploration, and contextual metrics to enhance the impact of visualizations. Common mistakes such as exceeding screen boundaries and cluttering displays were avoided, ensuring the dashboard remained clear and user-friendly.

3. **Validation and Effectiveness**
   Surveys with students and a company representative assessed the dashboard's impact on warehouse performance. Feedback indicated the dashboard's usefulness, particularly the Dynamic section's detailed customer insights and drill-through capabilities. Suggestions for improvement included enhanced navigation aids, expanded KPIs, and extended data comparison capabilities.

Conclusion

The creation of a warehouse dashboard significantly improves operational insights and decision-making capabilities for SMEs in the warehousing sector. The dashboard effectively addresses the complexities of warehouse performance tracking by implementing a systematic approach to KPI selection and applying best practices in data visualization. Feedback from validation surveys highlighted its usefulness and suggested further enhancements to maximize its potential. This advancement demonstrates the potential for significant improvements in warehouse management practices through enhanced data visualization and KPI tracking, making it easier for end-users to gain valuable insights into their operations and improve overall efficiency.

Recommendations

- Address current shortcomings in the data model.
- Integrate validation feedback.
- Merge Revenue, Dynamic, and Static sections into a unified dashboard.
- Validate the dashboard with actual customers.
- Establish continuous feedback cycles.
- Develop training and support materials for users.

Contents

Table of Abbreviations

SME	Small to Medium-sized Enterprise
WMS	Warehouse Management System
BI	Business Intelligence
KPI	Key Performance Indicator
DSRM	Design Science Research Methodology
SLR	Systematic Literature Review
BPMN	Business Process Model and Notation
AHP	Analytic Hierarchy Process
BPM	Business Performance Management
BSC	Balanced Scorecard
GQM	Goal-Question-Measurement
SMART	Specific, Measurable, Achievable, Relevant, and Timebound
CI	Consistency Index
CR	Consistency Ratio

1. Introduction

1.1. Background of the company

This thesis focuses on Bricklog Holding B.V., hereafter referred to as Bricklog. Founded in 2015, Bricklog is headquartered in Apeldoorn, with an additional branch in Enschede. Initially, Bricklog primarily offered consultancy services. However, they observed that their customers were not fully utilizing business intelligence reports. This realization prompted Bricklog to transform, becoming a data club dedicated to assisting clients with data architecture and helping companies embrace a more data-driven approach.

The company's objective is to advise and optimize Small to Medium-sized Enterprises (SMEs) in the transport and logistics sector. SMEs often lag behind larger companies in terms of efficient data management. With Bricklog's expertise, these SMEs gain access to a range of products and services that enable effective data management. These offerings are bundled within their comprehensive Business Intelligence (BI) product, which forms the core of their business model.

To further expand its business, Bricklog has dedicated its efforts to developing a specialized BI product specifically designed to optimize warehouse operations. Small to medium-sized warehouses often face challenges in effectively interpreting the substantial volume of data collected through Warehouse Management Systems (WMS). Recognizing this gap, Bricklog aims to provide a solution. The premise of this thesis will be focused on the creation of a BI product that empowers deeper insights into warehouse operations, effectively addressing this critical need.

1.1.1. Understanding Bricklog's Operational Mechanics

Understanding Bricklog's operations involves delving deep into their unique data transformation procedure. This process can be broken down into three main stages: the data source, the Bricklog Data Factory, and the end product.

The first stage, the data source, signifies the raw, unprocessed data usually drawn from the WMSs utilized by the warehousing company. This data is the core foundation, fueling the entire operation.

The real transformation takes place in the second stage of the Bricklog Data Factory. Bricklog develops complex pipelines to rework raw data into a more usable, standardized format. This standardization enables the creation of a generic report that offers a solid foundation for data-related needs.

The final stage is the end product, which is the dashboards and reports. These are not just custom-made ones built from scratch for each client. Instead, they are primarily built upon the generic data model created in the data standardization phase. Using this model, Bricklog develops a set of relevant, generic reports.

A vital feature of this process is the customization level at this stage. Although the foundational reports are generic, they are also adaptable. Bricklog can modify these reports to meet the customer’s specific requirements. This flexibility streamlines the creation process and simplifies creating what each client needs.

1.2. Problem Identification

The capability gap in the existing WMSs utilized by SMEs presents a significant challenge. While these systems effectively track inventory and manage workflow, they lack the advanced analytics required to extract actionable insights from warehouse data, a crucial component in strategic decision-making. This deficiency leads to an underutilization of data, leaving businesses without the necessary metrics to enhance warehouse efficiency. Bricklog's solution is a dashboard that layers over the current WMS infrastructure, highlighting KPIs and metrics. This dashboard aims to deliver insight that enables SMEs to make informed decisions to optimize various warehouse operations previously unattainable with their existing systems.

Core problem: The absence of advanced analytics and KPIs in current WMS offerings hinders businesses from fully leveraging operational data to improve warehouse efficiency and make strategic decisions.

1.2.1. Significance and Project Scope

The lack of Key Performance Indicators (KPIs) and dashboards that provide insights into warehouse performance is a significant problem for transport companies with warehouses. Without a dashboard, it is difficult for managers to monitor inventory levels, keep track of performance indicators, and identify potential issues that could impact their warehouse's overall cost and efficiency. The creation of such a tool will allow managers to do this. The dashboard will also be relevant for other workers in the warehouse since it can provide specific insights into the stored products.

The scope of this research will be to develop a conceptual design for a dashboard that provides real-time visibility into warehouse performance. The dashboard will be designed to display key performance metrics based on the different parts of the warehouse. In addition, a prototype solution that demonstrates the functionality and potential of the dashboard will be created. The conceptual design will include a detailed description of the dashboard's user interface, the key performance metrics that will be displayed, and data visualization tools that will be used to help managers make informed decisions about their warehouse operations.

1.3. Research Questions

The main problem is that there is no way for warehouse managers to monitor what is happening in the warehouse efficiently. Recognizing the need for a dashboard as an initial step toward solving this issue, the following problem statement and action plan are formulated:

How can a dashboard be designed to effectively implement performance tracking and streamline data visualization to enhance warehouse performance?

To be able to answer this, it is necessary to answer sub-questions and knowledge questions based on this question.

1. **How can warehouse performance be effectively measured and monitored?**
    a. What KPIs are relevant for measuring warehouse performance?
    b. What method is most relevant for selecting the right KPIs for the dashboard?
    c. What KPIs are most relevant as determined through the selected method?
2. **What are the best data visualization techniques for designing an effective dashboard?**
    a. What are the best practices for designing dashboards that effectively communicate KPIs?
    b. What common mistakes should be avoided in dashboard design?

3. **Does the designed dashboard meet its intended goals for improving warehouse performance?**
    a. What are the best methods to validate the usability and effectiveness of dashboards?
    b. What metrics can be used to measure the impact of dashboards on warehouse performance?
    c. What improvements can be made to the dashboard based on assessment results?

1.4. Problem-Solving Approach

The main deliverable of this bachelor assignment will be a dashboard that gives insight into warehouse performance. Since the creation of a dashboard is the design of an artifact, the most suitable problem-solving approach is the Design Science Research Methodology (DSRM) (vom Brocke et al., 2020). The methodology consists of the following steps:

1. **Problem identification and motivation.** This phase defines the research problem, and the solution's value is justified.
2. **Define the objectives for a solution.** In this phase, the objectives of the solution can be inferred from the problem definition and knowledge of what is possible and feasible.
3. **Design and development.** In this phase, the artifact - in this instance, the dashboard - is created.
4. **Demonstration.** In this phase, a demonstration of the artifact is performed to show that it can solve the problem
5. **Evaluation.** In this phase, the artifact is evaluated. At the end of this activity, it will be decided whether it is necessary to iterate back to step three of the methodology.
6. **Communication.** In this phase, all aspects of the problem and the designed artifact are communicated to the relevant stakeholders.

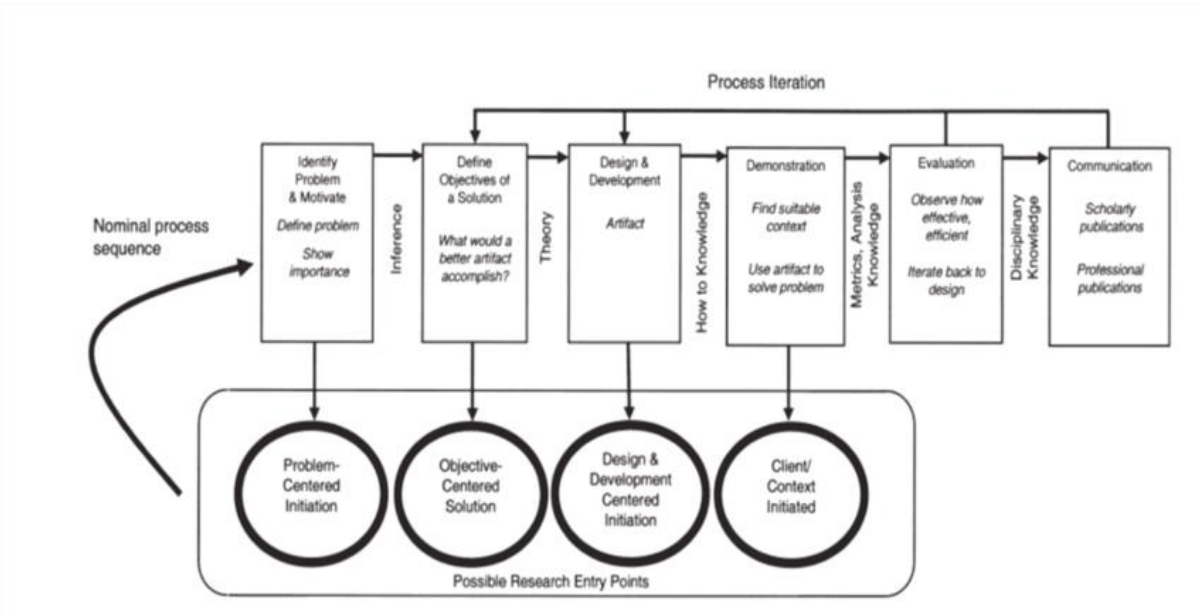


Figure 1: Design Science Research Methodology

In the following part, each of the six steps of the DSRM will be explained and how they are relevant to this bachelor's assignment.

1.4.1. Problem Identification and Motivation

This phase of the methodology was already performed in the previous section. The action problem identified is the absence of a dashboard that can provide a cohesive narrative on the various warehouse performance metrics. With the creation of the dashboard, Bricklog customers can use their data to gather actionable insights based on their warehouse performance.

1.4.2. Define the objectives for a solution

This research aims to develop a dashboard for Bricklog that is designed to enable performance measurement and provide customers with insights into the operational efficiency of their warehouses. The development of this artifact must be substantiated through the research of sub-questions that can be derived from the main research question, as seen in section 1.4. Answering these knowledge questions will aid in creating the artifact. For the question "What are the KPIs that are relevant for measuring warehouse performance?" a Systematic Literature Review (SLR) is performed (Xiao & Watson, 2019).

1.4.3. Design and Development

Integrating the research conducted with the SLR is essential for developing and designing the artifact. Engaging with stakeholders about their design preferences is important to ensure these are considered during this phase.

1.4.4. Demonstration

In the demonstration phase, it is important to tailor the presentation to the specific audience. Bricklog employees will likely prefer a technical demonstration covering all aspects of the artifact, while the end-users will probably want a demonstration focused on its practical application. Adapting the prototype demonstration to each audience group's unique needs and preferences is therefore important. A clear and concise explanation of how the artifact works and how it addresses the problem will help the audience better understand its potential impact and benefits.

1.4.5. Evaluation

In the evaluation phase of DSRM, it is important to assess whether the artifact effectively solves the problem. This is typically done through a naturalistic evaluation instead of an artificial one, which may involve unrealistic scenarios. The evaluation process should consider the artifact's typical user and usage context. By analyzing the results obtained in the field, it can be determined if the artifact has been successful in addressing the problem. Depending on the outcome, it may be necessary to iterate back to the third step of the DSRM.

1.4.6. Communication

The last phase of the DSRM is communication, which consists of two parts. The first part is the thesis, in which the artifact is explained and evaluated. Other researchers can build upon this knowledge. The second part will be a colloquium where others can witness the research.

1.5. Navigational Guide

This guide offers a quick overview of the thesis structure, helping you navigate the chapters and understand how the project unfolds.

- **Chapter 2: Context of the Research: Warehousing**

Delves into warehouse operations' essentials, including key functions and business process visualization through Business Process Model and Notation (BPMN), laying the foundational understanding necessary for dashboard design.

- **Chapter 3: Methodology**

Outlines the research design, covering KPI selection and dashboard design. This chapter is enriched by integrating validation methods, notably the Technology Acceptance Model (TAM), to thoroughly assess the dashboard's effectiveness and usability.

- **Chapter 4: Dashboard Design & KPI Selection**

Shifts focus on the practical aspects of creating a warehouse dashboard. It explores the rationale behind choosing specific KPIs, guided by literature and best practices, and details the dashboard design process.

- **Chapter 5: Implementation of Design and KPIs**

Provides an in-depth look at the dashboard's conceptual design, featuring mockups and user experience flows. This chapter elaborates on the finalized set of KPIs, detailing their importance and how they are integrated into the dashboard.

- **Chapter 6: Validation of Dashboard Design**

This chapter presents the validation process undertaken to evaluate the effectiveness and usability of the developed warehouse dashboard. It describes the methodology used for the validation and discusses the findings and their implications.

- **Chapter 7:**

This chapter summarizes the main findings, discusses the project's limitations, and provides actionable recommendations for future research and practical deployment of the developed dashboard.

2. Context of the Research: Warehousing

Warehouse operations are fundamental to the supply chain. This chapter delves into the essential elements and employs the BPMN to visualize and effectively map out the process flow. Mapping with BPMN helps see the steps in the warehouse more clearly, allowing for the identification of key processes that impact performance. The inclusion of BPMN is crucial as it provides a standardized method to visualize warehouse processes, which directly aids in identifying and linking relevant KPIs to these processes for better performance measurement.

2.1. The Essence of Warehouse Operations

The many activities that constitute warehouse operations are crucial for effectively storing and transferring goods within a facility. These tasks are pivotal in ensuring timely deliveries and cost-efficient distribution, enhancing customer experience and business revenue. Central to warehouse operations are aspects like managing inventory, processing orders, optimizing labor, making the most of available space, and adequately managing equipment.

What distinguishes these operations is their interconnected nature. For instance, shortcomings in inventory management could result in bottlenecks in the order picking process, affecting the speed of deliveries. Therefore, it is vital to consider warehouse operations as an interconnected system rather than isolated tasks (Grosse et al., 2017).

2.2. Key Functions in Warehouse Operations

The framework of warehouse operations consists of several critical functions that collectively contribute to the effective handling and flow of products (de Koster et al., 2007):

1. **Receiving:** The receiving function involves unloading goods from inbound shipments, inspecting them for accuracy and quality, and then recording their arrival. Effective receiving is critical for accurate inventory management.
2. **Putting Away:** Once goods are received, they are moved to their specified storage areas in the subsequent "Putting Away" step. This phase might also entail repackaging activities, such as converting full pallets into smaller cases or standardized bins. Additionally, it may involve relocating products within different sections of the warehouse or directly to the shipping areas. Effective strategies in this phase are vital for maximizing storage space and future retrieval efficiency.
3. **Storage:** This function focuses on securely holding goods until they are required, maximizing space and minimizing cost, thereby positively impacting the efficacy of other warehouse operations.
4. **Order Picking:** Items are fetched from their storage spots to fulfill incoming customer orders. It is often the most resource-intensive and expensive activity in the warehouse.
5. **Packing:** After picking, items are packaged for shipment. This includes quality inspections, labeling, and the addition of any necessary paperwork, such as packing slips.
6. **Shipping:** The concluding function is shipping, where the packaged goods are loaded onto transport vehicles for delivery. Efficient shipping methods can minimize delivery times and elevate customer satisfaction.

Each function plays a crucial role in running a smooth and effective warehouse. These tasks are often interdependent, requiring a cohesive approach for optimal performance.

2.3. Business Process Visualization

Frameworks like the BPMN can be used to understand the dynamics of warehouse operations. BPMN provides a standardized method for documenting and designing business processes in a graphical format, making it accessible to various stakeholders. It makes complex processes clearer and highlights critical areas for performance measurement in warehouse operations, directly informing the design and development of universally applicable KPIs and metrics for the dashboard.

This utility extends to illustrating interactions between different organizational departments, roles, and systems, making BPMN a popular choice for visualizing procedures across service development stages, including business analysis and systems development (Kazemzadeh et al., 2015).

2.3.1. Key Concepts in BPMN:

To understand how a BPMN diagram operates, it is important to understand the fundamental elements of this graphical model. Below are some of the most important concepts:

Pools and Lanes:

- Pools represent broader operational areas or departments.
- Lanes within pools signify specific roles or participants

Events:

- Represented by circles.
- Green circles indicate the start, and red circles indicate the end of a process.

Activities:

- Depicted as horizontal rectangles.
- Each activity describes a single task within the process.

Gateways:

- Shown as diamond shapes.
- Can be exclusive or parallel, dictating the flow of the process.

Arrows:

- Used to indicate the flow between events, activities, and gateways.

After explaining these key concepts, the next section will use BPMN to map out a general structure for warehouse operations.

2.3.2. BPMN

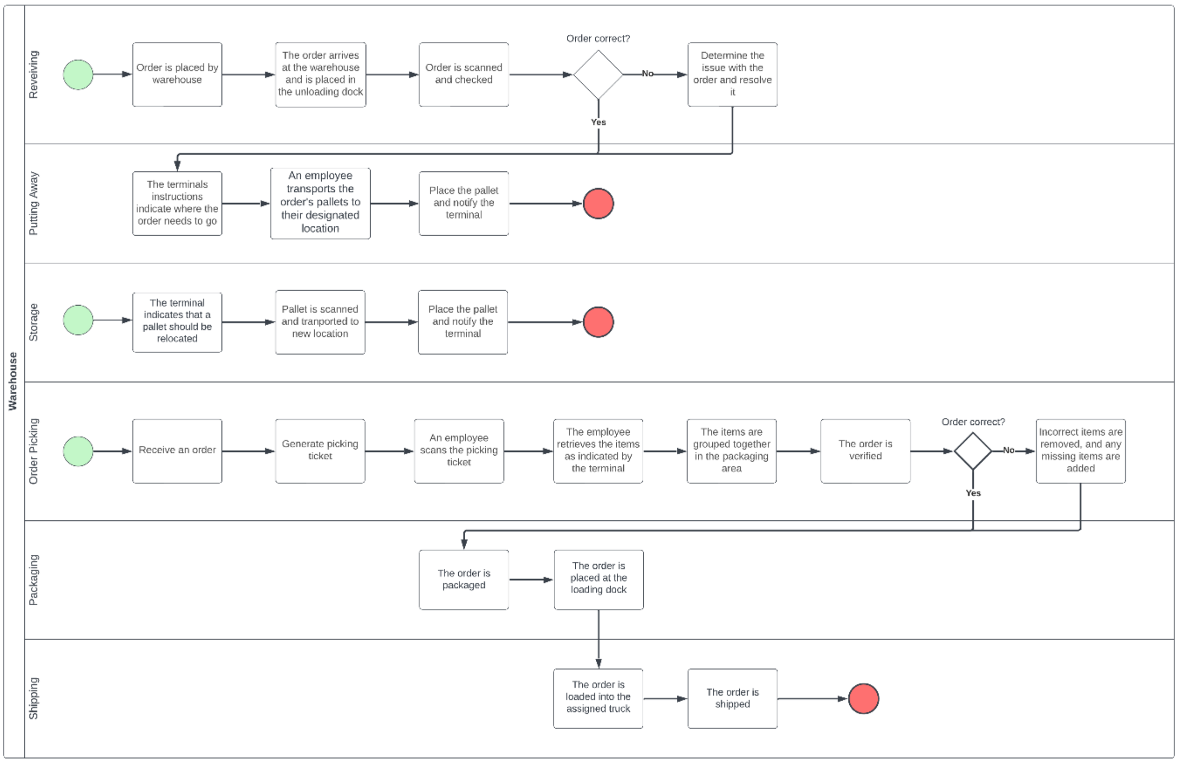


Figure 2: BPMN Model

The BPMN outlined above provides a general overview of standard warehouse operations essential for designing a flexible, generic dashboard for Bricklog. However, it is crucial to understand that warehouse practices can differ from the abovementioned process, leading to operational procedure variations. To provide a complete view, the next section will cover some standard processes and alternative ways a warehouse can operate.

In the standard model, goods arriving at the unloading dock are stored before processing. This typical flow supports straightforward tracking and reporting in a generic dashboard, focusing on storage duration and throughput metrics. However, alternative practices such as cross-docking, where goods move directly from the unloading area to the loading zone without intermediate storage, necessitate a different data modeling and dashboard design approach. Described by Van Belle et al. (2012) as particularly advantageous for items that are either perishable or time-critical, cross-docking minimizes both the duration and manpower needed to relocate goods. Cross-docked items must be categorized separately within the dashboard to reflect their impact on time-sensitive KPIs accurately. This ensures metrics like average handling time remain meaningful and do not skew results by mixing data from different operational methods.

Looking at the storage lane, it can be seen that movements are happening within the storage space. The movement of pallets within the warehouse occurs for various reasons, such as the strategic placement of goods in forward or reserve areas, replenishment needs, seasonal demand shifts, or warehouse layout optimizations (Rouwenhorst et al., 2000). These movements necessitate the dashboard to accurately track and reflect changes in inventory levels. By updating these levels, the dashboard provides real-time insights into storage efficiency and inventory management, supporting decision-making. This capability ensures that the dashboard remains a valuable tool for analyzing warehouse activities and optimizing storage and handling processes.

Moving on to the order-picking process, this general model assumes that items can only be ordered if they are in stock. For warehouses where this would not be the case, an extra activity would be added where inventory levels would be checked. If the item is not in stock, it must be ordered. The order-picking process could also differ due to the sorting policy used. There are generally two approaches: the pick and sort and the sort while pick method. In the pick and sort method, the items are first picked and then transported to a designated area for sorting and/or consolidation. Here, items are grouped by order. The sort while pick method involves sorting items simultaneously as they are being picked, which would eliminate the need for a separate sorting area (Rouwenhorst et al., 2000). Different sorting policies can lead to variations in how KPIs are calculated, necessitating adjustments in the dashboard to reflect operational performance accurately. This consideration ensures that KPI tracking is precise and aligned with the specific order-picking strategy.

3. Methodology

In order to address our research questions, we will utilize the research cycle from the book "Solving Managerial Problems Systematically" (Heerkens et al., 2017). The research design serves as a strategy to tackle the research problem effectively. The steps of this research cycle are as follows:

1. Research goal
2. Problem statement
3. Research questions
4. Research Design
5. Operationalization of variables
6. Data gathering methods
7. Data processing methods
8. Conclusion

As we have already gone through steps 1-3 in Chapter 1, the focus will now be on elaborating on steps 4-7.

3.1. Research Design

This research design encompasses several key theoretical and practical components critical to the development of an effective warehouse dashboard. This includes selecting KPIs, designing and implementing these KPIs within the dashboard, and validating the dashboard's design to ensure it meets the needs and usability requirements of its users.

A literature review can be conducted using various methods such as Systematic Literature Review (SLR), semi-systematic review, and integrative review to select appropriate KPIs for a warehouse dashboard. Among these, the SLR method is the most accurate and rigorous approach to collecting articles (Snyder, 2019). This literature review aims to identify a list of potential KPIs relevant to the warehouse domain and determine the best practices for dashboard design. In addition to the literature review, a small interview was conducted with company representatives to gather additional KPIs relevant to the specific company context.

The inclusion and exclusion criteria for the literature review were carefully defined to ensure the relevance and quality of the selected articles. These criteria included:

- **Inclusion Criteria:** Studies that focus on best practices for designing dashboards, studies that provide guidelines, frameworks, or principles for dashboard design, studies that focus on the communication of KPIs through dashboards, studies that discuss KPIs relevant to warehouse performance, studies that offer frameworks for selecting and implementing KPIs in warehouse management, and studies that are published in peer-reviewed journals, conference proceedings, or books.

- **Exclusion Criteria:** Articles not available in full text, publications older than twenty years, studies not written in English, English, and sources not specifically addressing KPIs or dashboard design.

After compiling a list of potential KPIs, the Analytic Hierarchy Process (AHP) method will be employed to identify the most crucial KPIs. The relevance of the AHP method in this context lies in its systematic approach to decision-making, allowing for the comparison and prioritization of KPIs based on a structured set of criteria. This selection is based on their alignment with SMART criteria and their relative importance, as outlined by Podgórski (2015). In the AHP method, KPIs are scored against SMART criteria and weighted according to the significance of each criterion relative to others. To perform the AHP method, further interviews were conducted with a company representative to ensure the criteria weights accurately reflect the company's priorities. Utilizing AHP helps pinpoint the most vital KPIs for monitoring and measuring warehouse performance.

When designing the dashboard, a Business Performance Management (BPM) methodology can be used to ensure that the selected KPIs are effectively represented on the dashboard. One such methodology is the Balanced Scorecard (BSC), which is widely used to align business activities with the vision and strategy of an organization (Kaplan & Norton, 1992). The BSC methodology provides a framework for designing a dashboard that effectively communicates the organization's performance by breaking down the organization's performance into four perspectives: financial, customer, internal processes, and innovation and learning. This strategy offers a broad view of the business by guiding the identification of critical questions:

- How do customers see the organization? (Customer Perspective)
- What must the organization excel at? (Internal Perspective)
- Can the organization continue to improve and create value? (Innovation and Learning Perspective)
- How does the organization appear to shareholders? (Financial Perspective)

Considering these questions when creating the dashboard and during informal interviews is important for a balanced approach. These perspectives offer insights into the organization from the viewpoints of different stakeholders, which guide the choice of relevant KPIs. This method helps monitor current operations and financial health, assess customer satisfaction, and gauge future growth and innovation potential. By including different viewpoints, the dashboard becomes a flexible tool for making decisions, helping with both immediate changes and future planning.

To ensure the effective communication of KPIs on the dashboard, it is also important to consider the principles of visual analytics. Visual analytics is an approach to data analysis that combines automated analysis techniques with interactive visualizations to support human analytical reasoning (Keim et al., n.d.). By incorporating visual analytics principles, the dashboard can be designed to effectively communicate the warehouse's performance, making it easier for stakeholders to interpret the KPIs and make informed decisions.

For the validation of the dashboard, there are several methods available: heuristic evaluations, expert reviews, cognitive walkthroughs, and surveys (Munzner, 2009). Each method offers distinct advantages and suits different project constraints and objectives.

Heuristic evaluations are known for their speed and efficiency, requiring fewer evaluators and providing a quick turnaround on usability feedback (Nielsen et al., 1990). This makes them ideal for projects with tight time constraints. Expert reviews involve a thorough analysis by domain experts who evaluate various elements such as information architecture, visual design, and interaction flow. While comprehensive, this method demands a substantial commitment of time and expertise. Cognitive walkthroughs simulate a user’s problem-solving process at each stage of interaction, requiring detailed analysis of decision points and user actions, which can be time-consuming (Nielsen, 1994).

Initially, combining heuristic evaluation and survey feedback was considered to leverage the advantages of both methods. Heuristic evaluations were deemed advantageous due to their efficiency and ability to quickly identify usability issues with fewer evaluators. Although typically requiring a larger sample size to ensure statistical validity, surveys were added to complement heuristic evaluations by capturing a wider range of user feedback.

However, due to practical challenges, a heuristic evaluation was not feasible. For this reason, the sole focus of the validation method shifted to a survey. This method allows for a flexible and inclusive approach, capturing essential user experiences for the validation process.

The research will involve students from the University of Twente and a company representative. The survey aims to understand how the dashboard can improve its utility and value for Bricklog's customers, who will indirectly benefit from the research through improved service offerings. The study will employ a mix of quantitative and qualitative research methods. It aims to solve the core problem by utilizing surveys with a Likert scale and open-ended questions to gather measurable insights and in-depth qualitative feedback on the dashboard's acceptance and intended use. This approach provides a well-rounded view of the dashboard's impact, with a more detailed methodology outlined in Section 3.3.

3.2. Operationalization of Variables

To ensure the effectiveness of the dashboard design can be measured, operationalization of variables is necessary. For this process, the dashboard will be evaluated in terms of its intended use, specifically its completeness and accuracy in tracking performance. It will also be assessed with the use of the Technology Acceptance Model (TAM), which was introduced by Fred Davis in 1985 and is used to model users' acceptance of information systems and technologies (Marangunić & Granić, 2015).

Firstly, to address the dashboard's intended use and effectiveness, we introduce semantic quality as the variable to assess the included KPIs. Semantic quality measures how accurately and completely the KPIs represent the reality of warehouse operations and their alignment with specified goals. According to Nelson et al. (2012) semantic quality is defined by two main constructs: validity, which ensures that all statements in the model are correct and relevant, and completeness, which ensures that the model includes all essential information needed to fully represent the domain. This variable directly addresses the dashboard's ability to fulfill its intended use.

Following the assessment of semantic quality, the integration of TAM into the methodology provides a structured approach for evaluating user acceptance. By focusing on TAM's core constructs, the aim is to understand the relationship between user interaction with the technology and its acceptance:

1. **The Perceived Usefulness (PU):** Evaluates whether users believe the dashboard enhances their job performance by providing relevant, actionable data, and delivering clear insights. (Davis et al., 1989)
2. **The Perceived Ease Of Use (PEOU)**: Assesses the dashboard's user-friendliness, including navigational ease, the intuitiveness of its layout, and the simplicity of interpreting and utilizing the data presented. (Davis et al., 1989)

Integrating TAM's constructs and assessing semantic quality into the survey creates a framework for measuring user acceptance and the dashboard's effectiveness in accurately representing warehouse operations.

3.3. Data Gathering Methods

Several data-gathering methods were employed to assess the dashboard's usability and effectiveness, primarily through a survey. This survey, featuring rating scales and open-ended questions, was initially planned to be distributed among stakeholders from Bricklog but was mainly completed by students from the University of Twente and a company representative. Students from the University of Twente primarily complemented the detailed feedback provided by a company representative, who individually evaluated the three parts of the dashboard.

In addition to the survey, informal observations were made when participants interacted with the dashboard. These observations were not the primary focus but offered supplemental insights into the dashboard's immediate usability and effectiveness. This approach allows for capturing natural user interactions without requiring extensive preparatory work or altering the research's scope to include a detailed observational study.

Focusing on the survey responses and informal observations, the study aims to provide a comprehensive understanding of the dashboard's usability, user experience, and practical value. This method helps identify key areas for improvement and ensures the dashboard effectively meets its operational goals.

3.4. Survey Questions and Explanation

The questionnaire for this research is designed to assess the dashboard's acceptance via the TAM constructs and its effectiveness through the semantic quality of KPIs. While TAM constructs assess user acceptance, semantic quality evaluates the completeness and accuracy of KPIs reflecting operational realities, essentially measuring if the dashboard fulfills its intended use. These concepts form the survey's structural foundation.

Below this text, the questions that the evaluators received can be found. These questions will be presented in a Likert scale format, where evaluators can express their level of agreement from 'Strongly disagree' to 'Strongly agree' or as open-ended questions. The methodology behind choosing between these formats leans on striking a balance. Open questions offer a wide array of responses, while close questions simplify analysis and enhance survey comparability (Janes et al., 2013; Martin, 2006). The complete survey form, including the layout and the response format, is available in Appendix A for reference.

Survey questions:

1. **Likert Scale Questions:**
   - The dashboard's design appears user-friendly for people with different levels of technical expertise.
   - The dashboard offers functionalities that are crucial for efficient warehouse management.
   - The layout and data presentation of the KPIs effectively communicate the critical metrics of warehouse operations.
   - The KPIs displayed on the dashboard accurately reflect key aspects of warehouse operations.
   - The information provided by the dashboard is likely to be useful to decision-making processes.
   - The instructions and help features provided within the dashboard make it easy to understand how to use all of its functionalities.
2. **Open-Ended Questions:**
   - In your view, what features of the dashboard are most beneficial for warehouse management?
   - Are there areas where you think the dashboard's representation of KPIs could be improved? Please elaborate.
   - Do you have any suggestions for additional data or features that could enhance the ease of use of the dashboard?

3.5. Data Processing Methods

Descriptive analysis and data visualization techniques will be used to process the data gathered from the questionnaire. However, it is important to also evaluate the validity and reliability of the measurement results. Reliability is concerned with the stability of research results over time, and similar research conducted using the same method at a later date should yield the same results. On the other hand, validity is concerned with whether the research measures what it intended to measure. There are three potential threats to validity: internal validity, external validity, and construct validity. These refer to whether research designs and measuring instruments are properly formulated and constructed, whether research can be applied to other groups, and whether abstract concepts are properly operationalized. Thus, when processing data from a questionnaire, it is crucial to consider both reliability and validity to ensure the accuracy and usefulness of the results. (Heerkens et al., 2017)

To ensure internal validity, a pilot study will be conducted on a small sample of participants to identify potential issues and adjust the questionnaire accordingly. To ensure internal validity, a pilot study will be conducted on a small sample of participants to identify potential issues and adapt the questionnaire accordingly. Simultaneously, this pilot study will also evaluate construct validity, with subject matter experts reviewing the questionnaire to ensure that the items accurately reflect the constructs they are intended to measure. The external validity will be ensured by researching which dashboard design practices and KPIs are relevant for gaining insight into warehouse performance in a general context beyond Bricklog. The research can guide the best practices in similar situations by identifying this.

4. Dashboard Design & KPI Selection

To address the research questions, a literature review is done to gather the information needed to create a dashboard. This review will help provide a theoretical framework summarizing the best practices for designing dashboards and selecting relevant KPIs. This will enable us to identify the most effective design strategies and help us develop the dashboard.

4.1. Dashboard Design

4.1.1. Key Theories and Constructs Related to Dashboard Design

To better understand what type of dashboard will be built there, first needs to understand what type of dashboards there are. For this research, there will be considered three main types of dashboards: strategic, operational, and analytical (Few, 2006).

A strategic dashboard is a digital dashboard widely recognized for its use in communicating an organization's performance relative to corporate objectives. Its purpose is to provide a quick overview of an organization's health and assist with executive decision-making for long-term goals. Unlike operational dashboards, strategic dashboards do not require real-time data and may include both quantitative and qualitative data. The dashboard should have an uncluttered interface to guide consumers quickly to the answers they seek, primarily targeting senior management, but can be shared with a wider audience to promote alignment across the enterprise toward corporate goals (Pappas & Whitman, 2011).

An operational dashboard focuses on constantly changing activities that require immediate attention. It requires an uncomplicated view to enable rapid visual parsing to identify off-target measures that require intervention. Unlike strategic dashboards, effective operational dashboards require real-time data to see if a measure is off-target. In addition to a high-level view, it must enable a deep dive to examine why a measure is off-target and take appropriate action. The display media on operational dashboards must be straightforward to enable a quick response in the stressful event of an emergency that requires immediate attention (Pappas & Whitman, 2011).

Analytical dashboards combine features of both strategic and operational dashboards. They have a broader timeframe, like strategic dashboards, support drill-downs, and visual exploration, like operational dashboards. Analytical dashboards must support interactions with data, such as drilling down into the underlying details, to enable exploration to make sense of the data. They exist at the intersection of strategic and operational data and can be used to examine the root causes of anomalies and forecast outcomes (Pappas & Whitman, 2011).

Based on the information provided earlier, it becomes clear that the dashboard that will be developed can be defined as an analytical dashboard. While it uses real-time data to monitor constantly changing activities within the warehouse, such as product movements and space utilization, it also incorporates features allowing in-depth data analysis. The dashboard will provide a user-friendly and straightforward view that allows for rapid identification of off-target measures that require immediate intervention. This aligns with the characteristics of operational and analytical dashboards described in the literature. Additionally, the dashboard will enable a deep dive into the data to examine why a measure is off-target and take appropriate action. Overall, the analytical dashboard will provide valuable insights and support timely decision-making for the warehouse management team by combining real-time monitoring with detailed data exploration capabilities.

There are two important steps to follow when creating an effective dashboard. The first step is to collect the correct data, and the second is to choose the proper visualization. The Goal-Question-Measurement (GQM) model can be used for collecting the correct data, which is a hierarchical approach to goal setting (Janes et al., 2013). At the conceptual level, the goal defines what you want to study and why. At the operational level, questions help you identify the important parts and aspects of the object being studied and how they can be used to assess the achievement of the goal. At the quantitative level, measures define what data needs to be collected objectively to answer the questions. This approach can be extended into the GQM+Strategies approach, which adds a goal hierarchy to provide context for why measurements must be collected (Janes et al., 2013). This model will help guide the collection of the correct data.

For choosing the proper visualization, we will consider two usage scenarios for a dashboard: push and pull (Janes et al., 2013). In the push scenario, the dashboard needs to be designed to deliver important information to the user without them having to seek it out actively. For the pull scenario, the user must seek a particular information and utilize the dashboard to retrieve it. The dashboard created for this research will be a hybrid of both push and pull scenarios. It will be designed to deliver all the important information to the user while also allowing them to delve deeper into the data if they wish to do so. Visualization techniques regarding these two usage scenarios will be incorporated into the dashboard.

4.1.2. Best Practices for Designing Dashboards

Through a review of the available literature, several aspects were identified that must be considered when developing a dashboard. According to Read et al. (2009), one of these aspects is the user preference for frame-based menu design over expandable index menu design. Frame-based menus display all options within a fixed visual layout, improving navigation efficiency and user familiarity by keeping menu items in constant positions. On the other hand, expandable index menus conceal options in collapsible lists, needing more clicks to explore and potentially raising cognitive load by not showing the entire menu structure right away. The study recommends using frame-based menus over expandable index menus based on these observations.

Another important aspect that needs to be considered is implementing a drill-down feature so that different granularities of data can be shown to various types of users. This will help users work interactively with the dashboard (Cahyadi & Prananto, 2015). This is also stated in Sarikaya et al, (2019), where numerous articles mention a desire for greater flexibility in dashboards, including drill-down options and adaptability to different users.

In visualization practices, it is evident that information can be presented in a table or a graphic visualization format. The decision on which format to use depends on the complexity of the information presented. As tasks become more complex, studies in cognitive fit theory have demonstrated that limitations in table information representation can lead to a switch toward the use of perceptual processes (Luo, 2019). This transition underscores that complex data is often better represented through visualizations. Building on this, Sedrakyan et al. (2019) highlights an essential consideration: the design of visualizations greatly influences users' ability to understand and retain information. By aligning visualizations with specific objectives and feedback mechanisms, we can significantly enhance memory retention, ensuring that visualizations effectively serve as tools for both comprehension and long-term recall.

However, the dashboard should not have too many visualizations and other indicators since quantity is not quality, and too many can detract from the goal of the dashboard, which is to provide a clear overview of information and insights. Additionally, the metrics used should give context to enhance their impact. For instance, a bar chart displaying monthly sales alongside the target and last year's sales provides more information than just the monthly sales (Allio, 2012). This blend of appropriate visualizations and contextual metrics is key to developing an effective dashboard that provides a clear overview of information and insights while avoiding overwhelming users with too much data.

4.1.3. Common Dashboard Mistakes and How to Avoid Them

Effective dashboard design requires careful consideration of numerous factors. While there are many best practices to follow, it is also important to be aware of common mistakes that can undermine the usefulness of a dashboard. To this end, Few (2006) identified thirteen common dashboard design mistakes and explained why they should be avoided. By understanding these mistakes and taking steps to avoid them, designers can create dashboards that are more effective at communicating data and insights. The following points detail the common mistakes highlighted by Few, serving as a guide to enhance dashboard design:

1. **Exceeding the boundaries of a single-screen**
   Dashboards should avoid exceeding the boundaries of a single screen. This is because our short-term memory can only hold a few chunks of information at a time. Displaying all relevant information simultaneously allows for comparisons and insights that would otherwise be missed. Therefore, fragmenting the data should be limited as much as possible
2. **Supplying inadequate context for the data**
   As mentioned before, by Allio (2012), context must be provided for data. Providing the appropriate context for key metrics can be the difference between numbers that remain stagnant on the screen and those that enlighten and motivate action.
3. **Displaying excessive detail precision**
   Displaying excessive details that are not relevant can slow down users without providing any significant benefit. When there is too much information, it becomes harder for users to filter out what is important, wasting time and hampering their ability to gain insights and take action quickly.
4. **Choosing a deficient measure**
   Choosing a deficient measure can hinder the effective communication of the intended message to the dashboard users. A measure may be accurate but not the best choice for the message that needs to be conveyed, resulting in confusion and inefficiencies in understanding and taking action based on the data.
5. **Choosing inappropriate display media**
   Inappropriate display media is one of the most common design mistakes in quantitative data presentation. When choosing the display media, consider that another form might be more effective or clearer than the current one.
6. **Introducing meaningless variety**
   Introducing meaningless variety in dashboard design can lead to user frustration and wasted time. It is important to prioritize selecting the display method that works best for the presented information, even if that means using the same type of display multiple times. Display consistency allows users to interpret the data efficiently and saves time and energy.
7. **Using poorly designed display media**
   Poorly designed display media can hinder effective data communication. For example, if a pie chart uses colors that are too similar, it may be challenging to distinguish the different slices, which can hinder the user's understanding of the dashboard. To ensure clear data communication, it is important to consider the design of the medium and its components carefully.
8. **Encoding quantitative data inaccurately**
   Quantitative data can be inaccurately displayed in graphical representations due to poor design choices. For example, imagine a bar chart where the scale along the vertical axis begins

at a too high number. When comparing the bars, it may appear that there are significant differences between them. Still, in reality, the differences may be insignificant if the vertical axis had started at a lower number.

9. **Arranging the data poorly**
   Poorly arranged data in a dashboard can lead to a cluttered and confusing presentation of information, which in turn can make it difficult for users to find and understand the most important data. For a dashboard to effectively communicate information, it is necessary to prioritize the most important data, arrange it meaningfully, and use appropriate visual design to guide the user's attention.
10. **Highlighting important data ineffectively or not at all**
    Ineffectively highlighting important data can lead to confusion and an inability to perceive the most crucial information. This can result in missed opportunities or poor decision-making based on incorrect or incomplete information. It is important to use visual techniques that direct the user's attention to the most important data first.
11. **Cluttering the display with useless decoration**
    Excessive and unnecessary decoration on a dashboard can distract viewers and even cause them to lose interest in the data. Meaningless decoration can also take up valuable space on the dashboard that could be used to display important information. Blank space can often be better than unnecessary decoration.
12. **Misusing or overusing color**
    The misusage or overuse of color in dashboard design can be detrimental as it can lead to confusion and distract from important data. Color choices should be made thoughtfully, with an understanding of how we perceive color and the significance of color differences. Additionally, using colors such as red, yellow, and green to assign important meanings to data can exclude color-blind individuals.
13. **Designing an unattractive visual display**
    An unattractive visual display can be unpleasant and may deter viewers from using the dashboard effectively. It is important to prioritize displaying the data clearly and effectively without adding unnecessary distractions or obstructions to the viewer's understanding. Aesthetic design principles, such as simplicity, can be applied to create an attractive and user-friendly dashboard.

4.2. KPI Review

4.2.1. KPI Selection: Literature and Company Insight

A literature review is conducted to ensure the selection of relevant KPIs for the dashboard. This review aims to provide insights into KPIs that measure warehouse performance. Additionally, suggestions from Bricklog will be incorporated into the list of KPIs. The selection process for choosing the KPIs to be included in the dashboard will be explained in Chapter 5.

In the research conducted by Karim et al. (2021), experts were consulted to perform a comprehensive analysis of warehouse productivity indicators. This analysis created a revised list containing the most crucial productivity measurement indicators. The indicators were categorized based on four warehouse resources: labor, equipment, space, and information systems, as seen below.

Category	**Indicator**	**Definition**
Labor	Receiving productivity	Number of vehicles unloaded per labor hour
	Putaway productivity	Putaway per man hour
	Picking productivity	Total number of products picked per labor hour in picking activity

	Manpower productivity	The ratio of the total number of items managed to the amount of item-handling working hours
	Shipping productivity	Total number of products shipped per labor hour
Equipment	Receiving productivity	Total number of products picked per equipment in picking activity
	Putaway productivity	Putaway per equipment
	Picking productivity	Total number of products picked per equipment in picking activity
	Shipping productivity	Total number of products shipped per equipment
Space	Building utilization	The ratio of the number of square feet used per total square feet capacity of the building
	Storage space utilization	The rate of space occupied by the storage
	Staging area utilization	The ratio of items per square foot over the amount of time
	Turnover	The ratio between the number of outgoing items and average items in stock
	Throughput	Items per hour leaving the warehouse
	Transport utilization	The ratio between weight/volume loaded over the total amount of weight/volume of container capacity
Information system	Warehouse management system	Measurement of the assigned task per hour

Table 1: KPI List Karim et al.

Further research on warehouse performance indicators was done by Staudt et al. (2015). In their research, a literature review was conducted, in which the warehouse activities of receiving, storage, picking, shipping, and delivery were studied. The most relevant indicators from these activities were selected and classified according to four dimensions: time, quality, cost, and productivity, as seen below.

Category	**Indicator**	**Definition**
Time	Order lead time	Lead time from order placement to shipment
	Receiving time	The average time taken to process received stock, which includes accounting for it, sorting it according to category, and then storing it.
	Putaway time	Lead time since a product(s) has been unloaded to when it is stored in its designated place
	Order picking time	Lead time to pick an order line
	Queuing time	The time that products wait on hold to be handled
	Delivery lead time	Lead times from the warehouse to customers
	Shipping time	Lead time to load a truck per total orders loaded
	Equipment downtime	Periods in which equipment is not functional, downtime incurred for repairs
	Dock to stock time	The amount of time it takes to get shipments from the dock to the inventory floor without inspection
Quality	On-time delivery	Number of orders received by the customer on or before the committed date

	Orders shipped on time	Number of orders shipped on time per total orders shipped
	Order fill rate	Orders are filled on the first shipment
	Physical inventory accuracy	Measures the accuracy (by location and units) of the physical inventory compared to the reported inventory
	Picking accuracy	Accuracy of the orders picking process where errors may be caught before shipment, such as during packaging
	Storage accuracy	Storing products in proper locations
	Shipping accuracy	Number of errors orders shipped
	Delivery accuracy	Number of orders distributed without incidents
	Stock-out rate	Number of stock products out of order
	Scrap rate	Rate of product loss and damage
	Cargo damage rate	Number of orders damaged during delivery activity
	Perfect orders	Orders delivered on time, without damage, and with accurate documentation
	Customer satisfaction	Number of customer complaints/number of orders delivered
Cost	Inventory cost	Total storage costs/unit
	Order processing cost	The total processing cost of all orders per number of orders
	Labor cost	Cost of personnel involved in warehouse operations
	Distribution cost	The mean number of vehicles and total travel distance per day provide measures of distribution costs.
	Maintenance cost	Costs of building maintenance
	Distribution cost	The mean number of vehicles and total travel distance per day provide measures of distribution costs.
	Cost as a % of sales	Total warehousing cost as a percent of total company sales
Productivity	Labor productivity	The ratio of the total number of items managed to the amount of item-handling working hours
	Throughput	Items/hour leaving the warehouse
	Shipping productivity	Total number of products shipped per period
	Transport utilization	Vehicle fill rate
	Warehouse utilization	The average amount of warehouse capacity used over a specific amount of time
	Inventory space utilization	Rate of space occupied by storage
	Outbound space utilization	utilization of the area inside the warehouse used for retrieving, order picking, packing, and shipping
	Picking productivity	Total number of products picked per labor hours in picking activity OR order lines per hour
	Receiving Labor productivity	Number of vehicles unloaded per labor hour

	Receiving Efficiency	Inventory received per hour
	Turnover	The ratio between the cost of goods sold and the average inventory

Table 2: KPI List Staudt et al.

Beyond the academic literature, selecting KPIs with Bricklog's specific needs is also important. Recognizing that many of their customers might already be acquainted with other dashboards, such as the transport dashboard, Bricklog emphasized the importance of a familiar user experience. This led to the incorporation of several revenue-related KPIs. Furthermore, valuable insights from discussions with Bricklog employees highlighted additional KPIs that were deemed relevant. The list of these KPIs can be seen below.

Category	**Indicator**	**Definition**
Revenue	Revenue	The total amount of money generated.
	% Difference	The percentage change in revenue from the previous year to the current year.
	% Total	The proportion of a particular customer's revenue about the total revenue of all customers.
	Cumulative Revenue	The accumulated revenue when adding up revenues of customers in a sequence
	% Cumulative	The accumulated percentage of total revenue
	Revenue Per Order	This is the average amount of revenue generated for each order.
	Revenue Per Pallet	This is the average amount of revenue generated for each pallet.
	Average Order Size	This metric measures the average number of distinct products (or sales order lines) included in a single sales order.
Dynamic	Top Product Category	This KPI indicates the most frequently dealt-with or highest-volume product category for a particular customer about specific warehouse operations.
	Movements Per Pallet	This metric measures the average number of times a pallet associated with a specific customer is moved or handled within a designated period.
	Average Pallet Movement Time	This KPI calculates the average time duration between successive movements of pallets in the warehouse for a specific customer.
Static	Inventory Volume per Week/Day	This metric measures the total number of individual inventory items in a warehouse within a specified week or day.

Table 3: KPI List Bricklog

These two studies and Bricklog's suggestions will form the basis for selecting KPIs for the dashboard. Chapter 5 will select the most relevant indicators from this list.

4.2.2. Practical KPI Considerations

While the academic literature provides a foundation for selecting KPIs, it is important to note that such a list does not always consider the real-world context. To create a warehouse dashboard, it is necessary to take a realistic approach, especially when considering the data that will underpin the KPIs.

The availability of data is key to the selection and implementation of KPIs for the warehouse dashboard. To accurately reflect the warehouse operations with KPIs, the data needs to be reliable, timely, and relevant; otherwise, the KPIs lose substantial efficacy. Academic literature often suggests KPIs that require extensive and detailed data, which may not align with the realities of actual warehouse operations. For instance, ideally, pallets would be scanned at every stage of the order-picking or storage process, but some warehouses might lack such a policy, leading to gaps in data.

It is also important to note that the dashboard in this project is built on dummy data provided by Bricklog. While this data serves as a great foundation for the development of the dashboard, it may not be as complex or have the variance that real-world data has. This also means that it is possible that specific data points for KPIs could be missing as they were not taken into consideration when creating the dummy data or were too complex for the time scope in which Bricklog needed to create this dummy data. As a result, the dummy data has an inherent limitation in its ability to emulate the warehouse environment fully.

Given the constraints and considerations discussed, it becomes clear that a preliminary list of KPIs needs to be established, filtering out those that are impractical due to data limitations. The following section, 4.2.3, presents this preliminary list, detailing the rationale behind the inclusion or exclusion of certain KPIs.

4.2.3. Preliminary KPI List

Based on the practical considerations from the previous section, a preliminary list of KPIs was developed. This list is a refined selection considering the available data and the warehouse dashboard's specific needs.

Several exclusion criteria shaped the preliminary list of KPIs:

- **Data Availability:** Indicators from the categories "information systems," "quality," and “costs” were removed due to the lack of data within these categories.
- **Relevance to Product:** Some indicators were identified as more appropriate for Bricklog's transport dashboard. Given its distinction as a separate product, they were considered outside this project's scope.
- **Redundancy:** To prevent redundancy, KPIs with overlapping meanings were eliminated.

Following these criteria, the refined selection resulted in a preliminary list of KPIs, detailed below:

Indicators	Definition
Putaway productivity	Putaway per man hour/ equipment
Picking productivity	Total number of products picked per labor hour/equipment in picking activity
Labor productivity	The ratio of the total number of items managed to the amount of item-handling working hours
Receiving productivity	Total number of products picked per equipment in picking activity
Shipping productivity	Total number of products shipped per period/ equipment

Building utilization	The ratio of the number of square feet used per total square feet capacity of the building
Storage space utilization	The rate of space occupied by the storage
Staging area utilization	The ratio of items per square foot over the amount of time
Turnover	The ratio between the number of outgoing items and average items in stock
Order lead time	Lead time from order placement to shipment
Receiving time	The average time taken to process received stock, which includes accounting for it, sorting it according to category, and then storing it.
Putaway time	Lead time since a product(s) has been unloaded to when it is stored in its designated place
Order picking time	Lead time to pick an order line
Queuing time	The time that products wait on hold to be handled
Shipping time	Lead time to load a truck per total orders loaded
Equipment downtime	Periods in which equipment is not functional, downtime incurred for repairs
Warehouse utilization	The average amount of warehouse capacity used over a specific amount of time
Outbound space utilization	utilization of the area inside the warehouse used for retrieving, order picking, packing, and shipping
Receiving Labor productivity	Number of vehicles unloaded per labor hour
Receiving Efficiency	Inventory received per hour
Revenue	The total amount of money generated
% Difference	The percentage change in revenue from the previous year to the current year.
% Total	The proportion of a particular customer's revenue about the total revenue of all customers.
Cumulative Revenue	The accumulated revenue when adding up revenues of customers in a sequence
% Cumulative	The accumulated percentage of total revenue
Revenue Per Order	This is the average amount of revenue generated for each order.
Revenue Per Pallet	This is the average amount of revenue generated for each pallet.
Average Order Size	This metric measures the average number of distinct products (or sales order lines) included in a single sales order.
Top Product Category	This KPI indicates the most frequently dealt-with or highest-volume product category for a particular customer about specific warehouse operations
Movements Per Pallet	This metric measures the average number of times a pallet associated with a specific customer is moved or handled within a designated period
Average Pallet Movement Time	This KPI calculates the average time duration between successive movements of pallets in the warehouse for a specific customer.
Inventory Volume per Week/Day	This metric measures the total number of individual inventory items in a warehouse within a specified week or day

Table 4: Preliminary KPI List

With the preliminary list established, the foundation is set for a more rigorous selection process. Chapter 5 will delve deeper into the final selection of KPIs, employing the AHP method to refine and finalize the indicators for the dashboard.

5. Implementation of Design and KPIs

This chapter elaborates on the dashboard's design. We then explore the KPI selection process, providing insights into how the final KPIs were chosen and their significance. Finally, the design of the PowerBI dashboard is presented.

5.1. Conceptual Design Overview

The conceptual design will provide a framework for the actual design of the artifact, which is the PowerBI dashboard. A mockup provides a general idea of what the dashboard will look like. Furthermore, a user experience flow will be elaborated, and the features will be explained.

5.1.1. Mockup

The mockup are available in Appendix B. The dashboard will be divided into three main sections, as previously discussed with the company stakeholders. These sections are:

- **Static Part:** This section is the inventory part of the dashboard. It provides a daily snapshot of the warehouse, offering a quick overview of its status at a specific time.
- **Dynamic Part:** This section focuses on warehouse movements and consists of three categories: incoming items, outgoing items, and internal movements.
- **Revenue Part:** This section tracks the amount of money generated.

The decision to divide the dashboard into Static, Dynamic, and Revenue parts was primarily influenced by the company's desire to cater to diverse user needs and simplify the presentation of complex data. Users can focus on specific warehouse operations aspects most relevant to their immediate tasks or strategic goals by segmenting the dashboard. This segmentation also lays the groundwork for a future, more integrated dashboard that would bring the different parts together to provide a view of the warehouse's overall efficiency.

These three sections will be selectable from an overview that includes other Bricklog products the customer may own, all grouped under warehousing. The first thing users will see in each section is an overview page. This page provides general information, such as the movement volume or revenue within a given time frame. Specific details about each pallet will be displayed on the right side of this overview page. This could include information like the customer it belongs to or its current location, among other details relevant to that dashboard section.

Users can navigate to the report page from the overview page for a more in-depth analysis. This page will include graphs and a drill-through option for the Dynamic and Revenue sections. The drill-through will be customer-based for both of these sections. Once in the drill-through view, users can see specific KPIs and other information based on their selection.

An information button will be located in the upper left corner to guide users through using the dashboard effectively.

5.1.2. Feature List

The inclusion of specific features in the dashboard comes from discussions with company stakeholders and reviewing relevant literature. This approach highlighted key elements that needed to be integrated into the dashboard design, forming the basis for a tool that enhances user interaction and provides critical, up-to-date information for effective warehouse management. These features aim to make the dashboard a practical resource that meets current operational needs:

- **Year Selection:** Users can choose the specific year they want to view.

- **Updates daily:** The dashboard will update daily, ensuring users have the most current overview of warehouse activities.
- **Information feature:** Clicking in the top left corner will provide additional information about everything displayed on the screen at that moment, assisting users in navigating the dashboard.
- **Interactive Data Filtering:** Interacting with particular data on the dashboard will filter the current page to display related information. For example, selecting a week on the overview page will filter the overview table to display data for that week. The user can have several filters working simultaneously, and the active ones can be seen in the top right corner.
- **Drill-Through Capability:** Users can access a drill-through view to explore more detailed information. Within this view, users can search for specific orders on the Revenue page and specific pallets on the Dynamic page to track their activities.
- **Data comparison:** Within the report page of the dashboard, users can view KPIs from the current year and the previous year for comparison purposes.
- **Visual Alerts:** The compared data will feature percentage-based numbers representing the changes, with color-coding to facilitate quick performance assessment.

These features aim to provide users with a thorough and up-to-date understanding of what is happening within the warehouse.

5.1.3. User Experience Flow

Creating a user experience flow before designing a system, such as a dashboard, helps match the design with user needs and behaviors. This step ensures the design follows the user's thought processes and tasks and guides how the system should interact with users. This approach streamlines the development process and ensures the final product meets user expectations.

The outline below describes each step, followed by an accompanying picture to provide a clear view of the user's process flow. Each step explains the possible user interactions, the view at that moment, and the objective of the interaction. It is also important to note that some steps are optional, and others are non-sequential. The non-sequential steps can occur after any step from one point forward, ensuring users are not confined to a single pathway and can interact with and explore data as needed.

Step 1: Selecting the Warehouse Section

- **Interaction:** The user begins by navigating through various product icons representing different Bricklog products.
- **View:** Upon selecting the warehousing icon, the user is presented with warehouse-related products, including the three sections (Static, Dynamic, and Revenue) developed for this thesis, among others.
- **Objectives:** To let the user navigate to the preferred warehousing section.

Step 2: Decision to Access Information

- **Interaction:** The user can click on the information guide based on familiarity with the dashboard.
- **View:** A visible icon in the top left corner of the page to access additional information about using the dashboard.
- **Objective:** To provide optional support and guidance for users who need it.

Step 3: Accessing Information (optional)

- **Interaction:** If the user wants additional information, they can click on the information button at the top left corner of the page.
- **View:** Guidance and additional information on how to use the dashboard effectively are provided.
- **Objective:** To support the user in navigating and utilizing the dashboard effectively.

Step 4: Engaging with the Overview Page

- **Interaction:** The user explores the overview page of the selected warehousing section.
- **View:** General information and specific details are displayed depending on the selected warehousing section.
- **Objective:** To give the user a general understanding of the key metrics and activities within the selected section.

Step 5: Navigating to Report Page

- **Interaction:** From the overview page, users can navigate to the report page for more in-depth analysis.
- **View:** The report page includes graphs based on time and products. Information per customer is shown, and a drill-through option is included for the Dynamic and Revenue sections.
- **Objective:** Let the user delve deeper into the data and analyze specific trends and metrics.

Step 6: Utilizing the Drill-Through Option

- **Interaction:** After choosing a customer in the Dynamic and Revenue sections, the user can select the drill-through button.
- **View:** Once in the drill-through view, the user can see specific KPIs and other information based on their selection.
- **Objective:** To provide the user with customer-specific insights.

Step 7: Interacting with Data (non-sequential)

- **Interaction:** When the user interacts with the graphs or data displayed, filters are applied on the current page they are on.
- **View:** The dashboard adjusts to the selected filters.
- **Objective:** To allow the user to tailor the view to get specific insights and information.

Step 8: Navigation to Another Warehouse section (optional)

- **Interaction:** The user can navigate back to the initial selection of warehousing sections.
- **View:** The user returns to the warehousing product selection screen.
- **Objective:** To allow the user to explore different sections without starting over or exiting the dashboard.

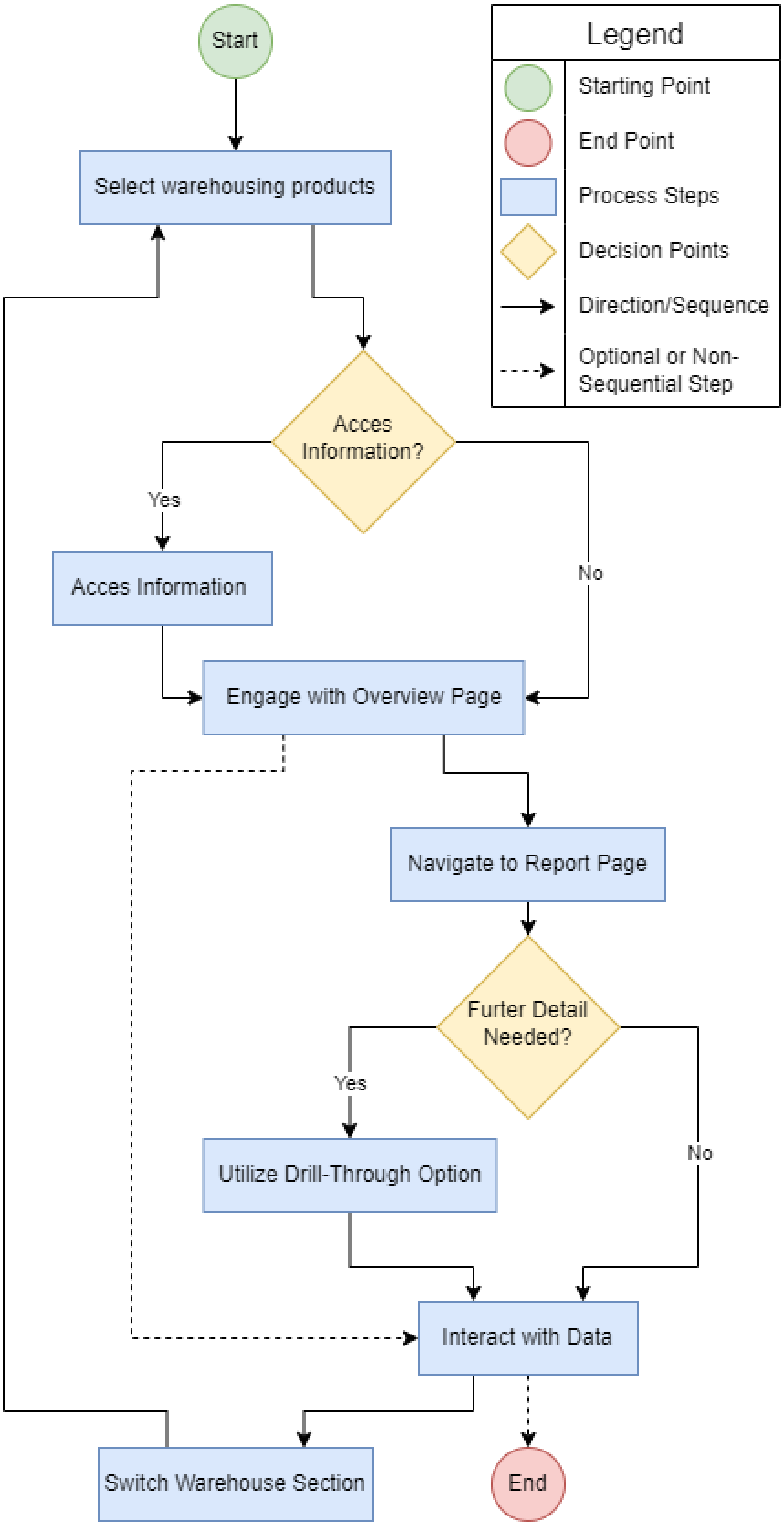


Figure 3: User Experience Flow Chart

5.2. KPI Selection and Overview

Before selecting the ideal KPIs for the warehouse dashboard, it is crucial to understand the scientific method that will direct the decision-making process. This section effectively outlines the methodology, providing a solid basis for a strategic and systematic approach to KPI selection. With this framework in place, the discussion will shift to introducing and exploring the chosen KPIs, highlighting their significance and how they will seamlessly integrate into the dashboard design.

5.2.1. Scientific Method for KPI Selection

The scientific method chosen for KPI selection is the AHP developed by Saaty (1987). This method provides a structured approach to decision-making, particularly when dealing with multiple criteria. Within this method, KPIs are assessed using the SMART criteria: Specific, Measurable, Achievable, Relevant, and Timebound (Podgórski, 2015). These SMART criteria are weighted, ensuring that more crucial criteria do not hold the same value as less important ones. To better understand the AHP method in the context of KPI selection, it will be broken down into its fundamental steps:

1. **Setting the Criteria:** The SMART criteria are established as the primary decision criteria.
2. **Pairwise Comparisons:** In a matrix format, each SMART criterion is compared against every other, scored on a scale from 1 to 9.
3. **Determining Weights:** Weights are derived from the pairwise comparison matrix for each criterion, indicating their importance.
4. **Consistency Check:** Calculate the Consistency Index (CI) and Consistency Ratio (CR) for each comparison matrix to ensure the evaluations are internally coherent. If the CR exceeds 0.1, re-evaluate the pairwise comparisons.
5. **Scoring the Alternatives:** Each potential KPI is scored against each SMART criteria on a scale of 1 to 5.
6. **Calculating KPI Scores:** The score for each KPI against a criterion is multiplied by the weight of that criterion. The weighted scores are then aggregated to get a total score for each KPI.
7. **Selection Based on Cut-off:** A cut-off score is determined, and KPIs above this cut-off are selected for inclusion.

Following the outlined steps, it becomes clear that the foundational criteria used in this method require a closer examination to prevent any misunderstandings regarding their meanings. Below the meaning of each criterion can be found:

- **Specific:** This criterion emphasizes that the KPI should clearly define what it measures, ensuring that all users easily understand it.
- **Measurable:** The KPI must be quantifiable with an appropriate unit of measurement. The data for this should be identifiable and consistently accessible.
- **Achievable:** The necessary resources, whether human, technical, or informational, should be available for data gathering and measurement.
- **Relevant:** The KPI should align with the primary objectives, resonate with the organization's operations, and meet the needs of its users.
- **Time-bound:** The timeframe in which a specific KPI value could be attained should be definable.

The next step in the AHP method involves determining the weights for each SMART criterion and performing a consistency check. To determine the weights of the criteria, a five-by-five matrix is created in the following form:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}$$

The values of elements a_{ij} indicate to what extent object X_i is preferred over object X_j when compared. The rating scale used for this can be seen in the table below.

Number	Definition
1	Equal
2	Between equal and moderate
3	Moderate
4	Between moderate and strong
5	Strong
6	Between strong and very strong
7	Very strong
8	Between very strong and extreme
9	Extreme

Table 5: Rating Scale

The matrix showcasing the comparisons is presented below:

$$\begin{bmatrix} 1 & 1/6 & 1/5 & 1/7 & 2 \\ 6 & 1 & 2 & 1/2 & 4 \\ 5 & 1/2 & 1 & 1/3 & 3 \\ 7 & 2 & 3 & 1 & 5 \\ 1/2 & 1/4 & 1/3 & 1/5 & 1 \end{bmatrix}$$

Using this matrix, the normalized matrix can be calculated by dividing each cell by the sum of its column.

$$\begin{bmatrix} 0{,}057 & 0{,}043 & 0{,}03 & 0{,}066 & 0{,}143 \\ 0{,}343 & 0{,}255 & 0{,}299 & 0{,}23 & 0{,}286 \\ 0{,}171 & 0{,}128 & 0{,}149 & 0{,}153 & 0{,}143 \\ 0{,}4 & 0{,}511 & 0{,}448 & 0{,}460 & 0{,}357 \\ 0.029 & 0{,}064 & 0{,}075 & 0{,}092 & 0{,}071 \end{bmatrix}$$

Finally, to determine the weights, the values of each row are summed and then divided by the number of elements in that row, yielding the following result:

$$\begin{bmatrix} 6{,}76\% \\ 28{,}24\% \\ 14{,}89\% \\ 43{,}5\% \\ 6{,}61\% \end{bmatrix}$$

A consistency check has to be performed to determine if the pairwise comparison matrix is consistent. For this, the following formulas are used:

- $CI = \frac{\lambda_{max} - n}{n - 1}$
- $CR = \frac{CI}{RI}$

In the first formula, the Consistency Index (CI) is calculated, for which you first need λ_{max}, the highest matrix eigenvalue. This is done by multiplying each element of the original pairwise comparison matrix by the corresponding weight from the weight vector, which gives the following matrix:

$$\begin{bmatrix} 0{,}068 & 0{,}047 & 0{,}030 & 0{,}030 & 0{,}132 \\ 0{,}406 & 0{,}282 & 0{,}298 & 0{,}218 & 0{,}264 \\ 0{,}203 & 0{,}141 & 0{,}149 & 0{,}145 & 0{,}132 \\ 0{,}473 & 0{,}565 & 0{,}447 & 0{,}435 & 0{,}330 \\ 0{,}034 & 0{,}071 & 0{,}074 & 0{,}087 & 0{,}066 \end{bmatrix}$$

The final step to calculate λ_{max} is to take the average of the sum of each row divided by its corresponding weight. Which yields the following result:

$$\lambda_{max} = \frac{1}{5} * \left(\frac{0{,}339}{0{,}0676} + \frac{1{,}468}{0{,}2824} + \frac{0{,}77}{0{,}1489} + \frac{2{,}25}{0{,}435} + \frac{0{,}332}{0{,}0661}\right) = 5{,}115$$

This value can then be used in the CI formula:

$$CI = \frac{5{,}12 - 5}{4} = 0{,}0288$$

As a final step, it needs to be checked for CR to see if it is less or equal to 0,1. For n = 5, the Random Index (RI) is 1,12, so:

$$CR = \frac{0{,}0288}{1{,}12} = 0{,}0257 \leq 0{,}1$$

The pairwise comparison matrix is considered consistent since the CR value is less than or equal to 0.1. This validation allows us to confidently use the derived weights for each criterion, as shown in the table below:

Criterion	**Weight**
Specific	6,76%
Measurable	28,24%
Achievable	14,89%
Relevant	43,50%
Time-Bound	6,61%

Table 6: AHP Criteria Weights

Having established the weights for the criteria, we can now rate each KPI on a scale from one to five. The score for each criterion is multiplied by its corresponding weight and then summed. The final score for each KPI will determine whether it is selected for inclusion. The scores for each KPI are in the table below.

KPIs	Specific	Measur-able	Achieva-ble	Relevant	Time-bound	Total
Putaway productivity	5	3	2	5	4	3,92
Picking productivity	5	3	2	5	4	3,92
Labour productivity	4	3	2	5	3	3,79
Receiving productivity	5	4	5	5	5	4,72
Shipping productivity	5	4	5	5	5	4,72
Building utilization	4	4	3	4	3	3,79
Storage space utilization	5	5	5	5	5	5,00
Staging area utilization	5	3	3	3	3	3,14
Turnover	4	3	1	5	5	3,77
Order lead time	5	3	2	5	4	3,92
Receiving time	5	3	5	5	5	4,44
Putaway time	5	3	5	5	5	4,44
Order picking time	5	2	2	5	2	3,51
Queuing time	5	3	2	5	4	3,92
Shipping time	4	1	1	5	1	2,94
Equipment downtime	5	1	1	5	1	3,01
Warehouse utilization	5	5	4	5	5	4,85
Outbound space utilization	5	4	3	4	4	3,92
Receiving Labour productivity	5	2	4	5	4	3,94
Receiving Efficiency	5	2	2	5	5	3,71
Revenue	5	5	5	5	5	5,00
% Difference	5	5	5	5	5	5,00
% Total	5	5	4	5	5	4,85
Cumulative Revenue	5	5	5	5	5	5,00
% Cumulative	5	5	5	5	5	5,00
Revenue Per Order	5	5	4	5	4	4,79
Revenue Per Pallet	5	4	3	5	4	4,35
Average Order Size	5	5	4	5	4	4,79
Top Product Category	5	5	5	3	5	4,13
Movements Per Pallet	5	3	3	5	4	4,07
Average Pallet Movement Time	4	4	4	5	4	4,44
Inventory Volume per Week/Day	5	5	4	5	5	4,85

Table 7: KPI Scores

The KPIs scoring four or higher are selected for inclusion in the dashboard. This threshold was determined through internal company consultation. The following section will explain each selected KPI and its calculation methods.

5.2.2. Overview of Selected KPIs

Now that the KPIs meeting the established threshold have been selected, the following section will explain how each is calculated and how they will be implemented in the dashboard.

Shipping Productivity

The KPI "Shipping Productivity" measures the efficiency of the shipping process by quantifying the total number of products shipped within a specified period. In the dataset, each movement activity is categorized with an ActivityID, classifying the movement as inbound, outbound, or internal. For this KPI, calculations will be filtered based on outbound activity. It will be featured in the Dynamic section of the dashboard, specifically under the Outbound category. The KPI will be visualized for comparative analysis as an annual figure and a monthly bar chart, including the previous month's data. A table format will also be available, allowing selection by weeks or days to show the shipping volume.

Receiving Productivity

“Receiving Productivity" is a KPI similar to "Shipping Productivity," but it focuses on inbound logistics by measuring the inventory received within a specified period. Like the Shipping Productivity KPI, it utilizes the ActivityID to identify inbound activities for its calculations. In terms of visualization on the dashboard, it follows the same format as Shipping Productivity but is tailored for the Inbound category within the Dynamic section.

Receiving Time & Putaway Time

The KPIs "Receiving Time" and "Putaway Time" are crucial for evaluating the efficiency of inbound warehouse operations. "Receiving Time" measures the average duration needed to process incoming stock, including accounting, sorting, and storing. "Putaway Time" tracks the time from unloading a product to its storage placement. However, due to the limitations of using a dummy dataset, which only records the start and end times of the entire inbound process, these KPIs will reflect the combined duration of both Receiving and Putaway activities. This is calculated by averaging the time between the TimeStart and TimeEnd of each inbound movement. The combined KPI will be displayed in the Dynamic section of the dashboard under the 'Inbound' category, presented in a table format with customers listed on the left and their average times on the right, alongside other relevant customer data.

Revenue

The 'Revenue' KPI, calculated using the SalesOrderLineID, tracks the total sales generated. It is presented in the Revenue section of the dashboard. While its visualization approach is similar to 'Shipping Productivity,' with an annual overview, a monthly bar chart for comparison, and a table displaying weekly or daily figures, it uniquely includes a stacked bar chart highlighting top-performing products. Additionally, there is a customer-based table ranking revenue contributions.

% Difference

This KPI shows the percentage change in revenue from the previous year to the current year, calculated by comparing the two figures. It is placed in the same customer-based table as the revenue KPI. The percentage values are color-coded: green for positive change and red for negative change.

% Total

This KPI represents each customer's revenue as a proportion of the total revenue. It is calculated by dividing the individual customer's revenue by the total revenue and displayed alongside the other customer data in the Revenue section.

Cumulative Revenue & % Cumulative

The "Cumulative Revenue" KPI provides a running total of the revenues by adding each customer's revenue in sequence. This provides a clear view of the revenue accumulation per customer. Alongside this, the "% Cumulative" KPI shows this in a percentage-based number. Both KPIs are visualized in the Revenue section of the dashboard in the customer-based table.

Revenue per Order/Pallet

The "Revenue Per Order/Pallet" KPI combines two closely related metrics: the average revenue generated for each order and each pallet. Both of these metrics are placed within the revenue part of the dashboard. The revenue per order is featured in the customer section, which can be viewed as an average of the total or per customer. The metric will also be shown in the customer drill-through section. The Revenue Per Pallet is only placed in the customer drill-through section. These KPIs are calculated by dividing the total revenue by the number of orders or pallets.

Average Order Size

The 'Average Order Size' KPI provides insights into the scale of customer orders by measuring the average number of distinct SalesOrderLineIDs. These IDs represent unique products or pallets within each SalesOrderID, with each ID corresponding to an individual order. This KPI is positioned within the customer-based table in the Revenue section of the dashboard. Its placement enables analysis of order sizes across different customers, highlighting variations from larger to smaller orders.

Top Product Category

The "Top Product Category" KPI in the Dynamic part of the dashboard identifies the most frequently handled or highest-volume product category for each customer across different warehouse operations, such as inbound, outbound, and internal movements. The KPI is calculated by summarizing product occurrences by group for each movement type and then identifying the most prevalent group. Multiple groups are combined into a single list if they share the highest count. The KPI will be shown in a customer-based table, offering insight into which product categories are dominant for each customer.

Movements per Pallet

The “Movement per Pallet” KPI measures the average number of internal movements of a pallet associated with a specific customer over a given period. This KPI focuses exclusively on internal movements, as every pallet undergoes inbound and outbound movements. The key interest here is in tracking the frequency of internal movements, as more movements can imply increased handling costs. The KPI will be placed in the Dynamic part of the dashboard, specifically within the drill-through section on movements. It will be calculated by dividing the total number of internal movements by the distinct count of pallets.

Average Pallet Movement Time

The "Average Pallet Movement Time" KPI, placed in the customer table for each movement type in the Dynamic part of the dashboard, calculates the average time duration between movements of a customer's pallets in the warehouse. It is calculated by filtering the dataset for specific movement activities and then calculating the time difference between the start and end of each movement in minutes. The average is obtained by dividing the total time by the number of movements and then formatted to display in minutes and seconds.

Inventory Volume per Week

The "Inventory Volume per Week" measures the average inventory turnover during specific periods, providing insights into the rate at which stock is moved into the warehouse. It is placed in the Static part of the dashboard, where it is visualized in a table where dates are shown on the left and turnover amounts on the right. It is calculated by dividing the total inventory by the distinct count of days or weeks.

Warehouse Utilization & Storage Space Utilization

In the Static part of the dashboard, we encounter a limitation with the "Warehouse Utilization" KPI, which was intended to measure the average capacity used over time. Due to data constraints, accurately assessing Warehouse Utilization is not feasible, as the available data primarily captures storage space. Consequently, the focus has shifted solely to "Storage Space Utilization," assessing the rate of occupied storage space. This KPI calculates the ratio of occupied storage spaces to the available locations, providing insights into how effectively storage space is used. However, it does not encompass other critical warehouse areas like packaging, shipping, and receiving, which are essential for a complete understanding of warehouse utilization. The KPI is visually represented as an average number over a year and in a clustered column chart for trend analysis. However, a significant challenge arises in the customer table representation due to the lack of detailed customer linkage in the data, limiting the ability to show individual customer space usage and thus hindering comprehensive warehouse utilization analysis on a customer-by-customer basis.

5.3. Dashboard Overview

The dashboard's creation tool is PowerBI. This tool was chosen due to its established use within Bricklog for all its data visualization needs. Utilizing PowerBI ensures the dashboard integrates well with existing systems.

The PowerBI dashboard is structured into three key sections: Revenue (Omzet EN), Dynamic (Mutaties EN), and Static (Voorraad EN), each accessible through the selection of one of the icons in Figure 4. These icons serve as direct entry points to the respective areas, simplifying navigation and focusing the user's experience on areas of interest within the warehouse data. This section will go into the functionalities of each part with accompanying screenshots.

Figure 4: Dashboard Selection Icons

It is also important to note two consistent features across the sections: the information icon ('i') at the top left corner, shown in Figure 5, provides users with guidance on dashboard functionalities. Furthermore, the filter indication area at the top right corner of each page, demonstrated in Figure 7 in Section 5.3.1., shows which filters are currently applied to the data being viewed. These dashboard features facilitate ease of use and intuitive interaction with the displayed information. Specifically, the information icon aligns with the 'pull' scenario of data presentation, requiring user engagement to access additional insights, thereby maintaining an uncluttered interface while offering in-depth understanding upon request. This design strategy ensures efficient interface use, allowing users to pull information as needed without overwhelming the primary view.

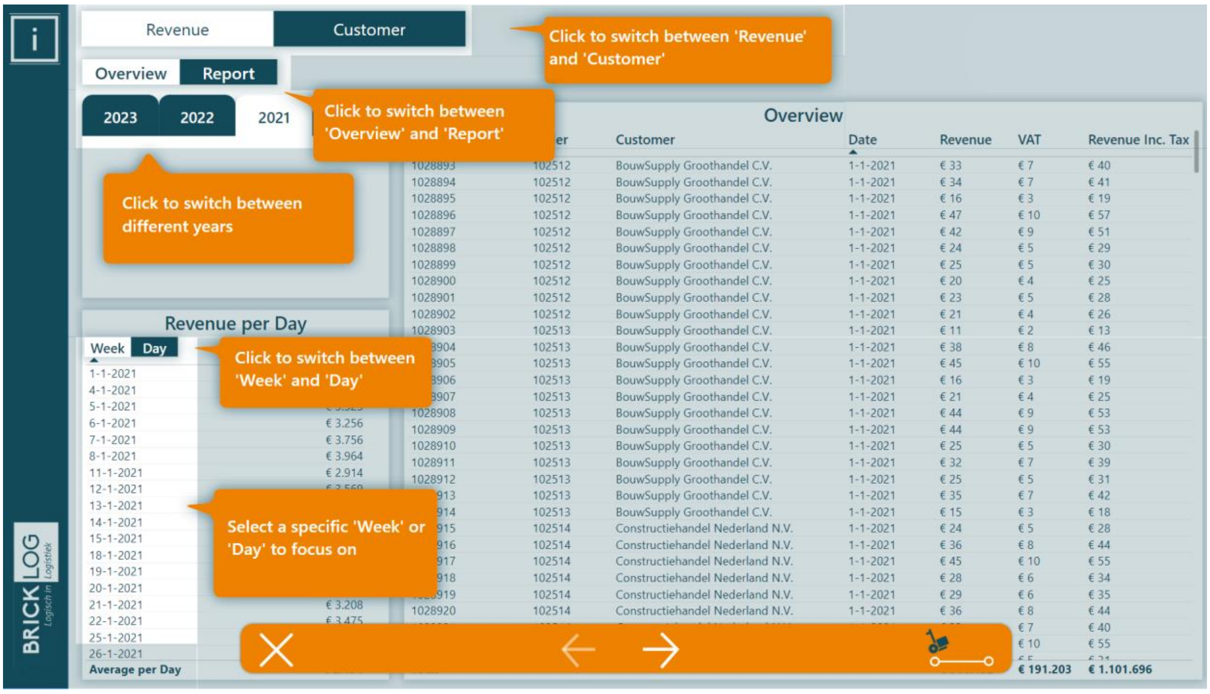


Figure 5: Information Feature

5.3.1. Revenue Section

The Revenue section is designed to provide an overview of the warehouse's revenue streams. Upon selecting the revenue icon, users are presented with the revenue overview page (Figure 6). This page displays the yearly revenue with a frame-based design, facilitating quick comprehension and efficient navigation. The overview table on the right side offers a detailed breakdown of each order, while an interactive table in the bottom left corner showcases the weekly and daily revenue. The interactivity embedded within this table allows users to click on a specific week or day to update the rest of the page with corresponding data.

The chosen frame-based menu design ensures that users can easily navigate between different data points without overwhelming them with information, effectively avoiding the mistake of cluttering the display with too much detail. Moreover, this approach aligns with the 'push' scenario, where the most pertinent information is immediately visible to the users, thus facilitating proactive data delivery.

These design principles and the layout choices adopted for the Revenue section set a standard for the entire dashboard. Each section is designed with the same attention to clarity, navigational efficiency, and thoughtful information presentation to ensure a coherent and user-friendly experience.

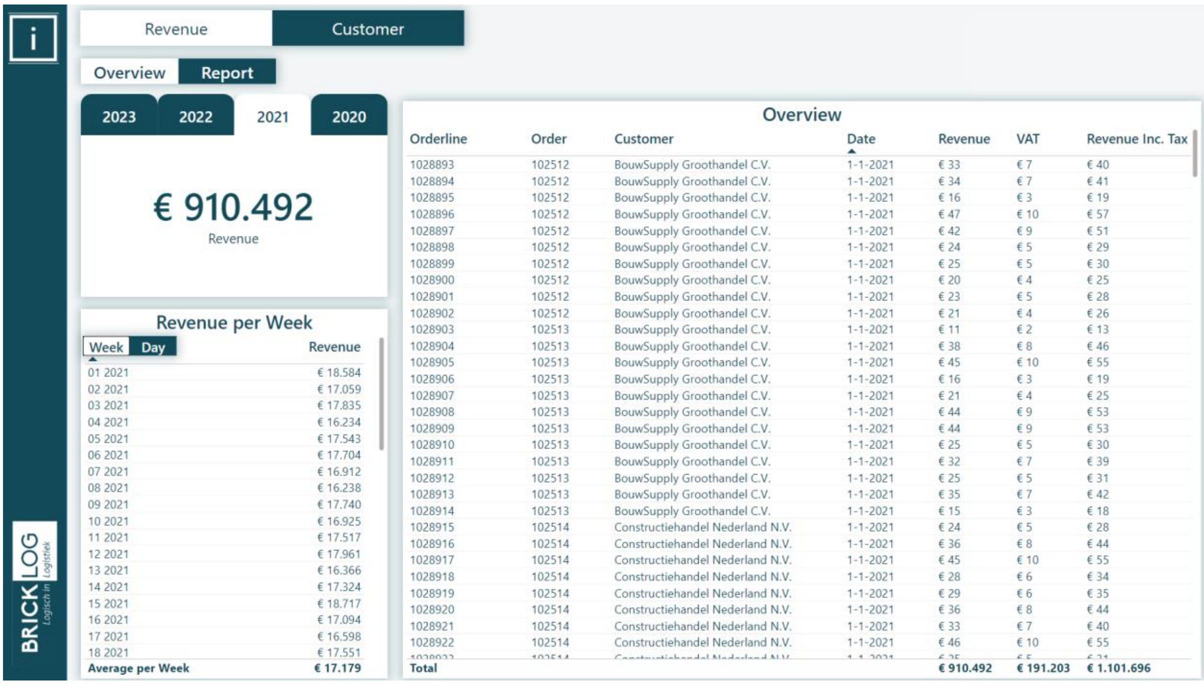


Figure 6: Revenue Overview

For a deeper dive into the warehouse's financial metrics, users can click the report button, which re-directs to the new page depicted in Figure 7, featuring a customer-based revenue ranking. This table integrates essential KPIs such as Revenue, % Difference, % Total, Cumulative Revenue, and % Cumulative. These KPIs, consistent with those used in other revenue-related dashboards from Bricklog, enhance the understanding of customer contributions to overall revenue and ensure a uniform presentation for customers across different platforms. In addition, a chart comparing monthly revenue with the previous year provides essential context, enabling users to discern trends and shifts over time. Another chart showcases the top-performing products. This interactive experience is highlighted in the second picture, where selecting an element in one chart will correspondingly adjust the other sections of the page to reflect that selection, demonstrating the dashboard's dynamic filtering capability.

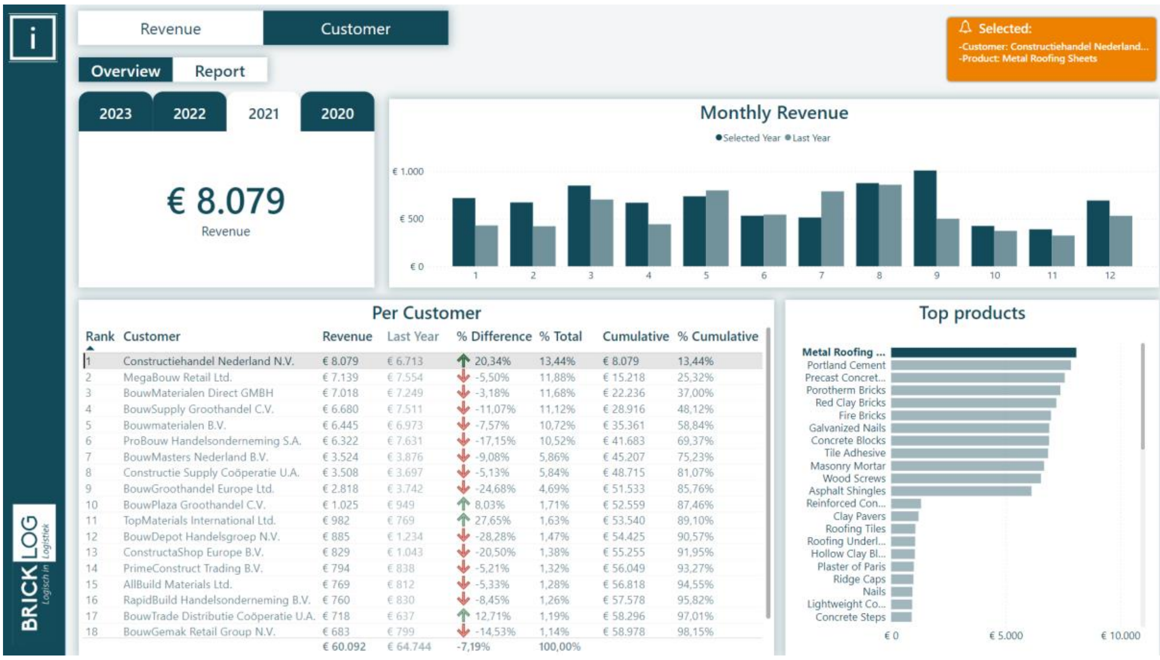


Figure 7: Revenue Report (filtered)

In the Revenue section of the dashboard, a specialized page presents a customer-centric view, integrating revenue and orders (Figure 8). This page features a table that displays each customer with corresponding revenue figures alongside their total number of orders, facilitating a quick assessment of customer value and transaction volume. This design choice supports the operational dashboard's focus on monitoring key performance indicators and the immediate assessment of critical metrics, as outlined in Section 4.1. Including KPIs such as 'Revenue per Order' and 'Average Order Size' on this page provides direct insights into transactional efficiency and customer purchasing behavior, which is important for strategic business analysis. The 'Monthly Revenue & Orders' chart visually represents the relationship between revenue and the number of orders. From here, selecting a customer enables a drill-through to a more detailed page, illustrating the dashboard’s functionality for in-depth data exploration and interaction, essential for informed decision-making and strategic planning.

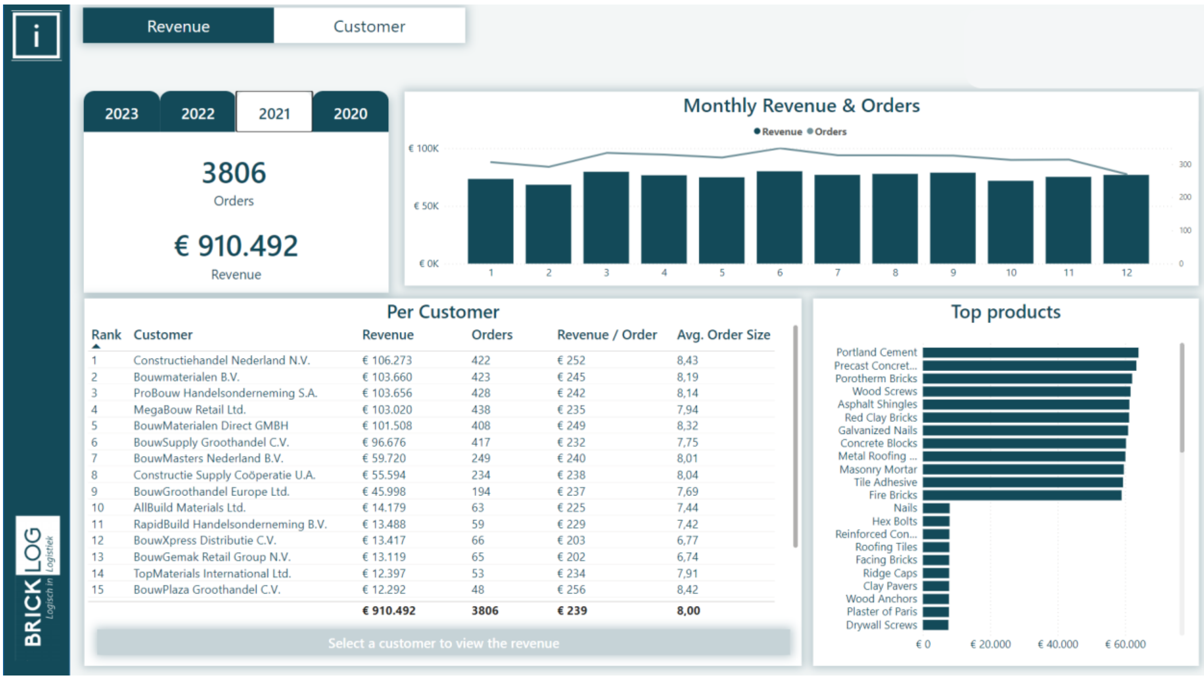


Figure 8: Revenue Customer Page

Executing a drill-through on a selected customer leads to a detailed page that displays the customer's transactional data (Figure 9). This page provides the total revenue for the customer and the number of orders placed, and it breaks down revenue by week, by order, and by pallet. It includes a table listing individual orders, order lines, and products, enabling a detailed analysis of the customer's transactions. The 'Revenue & Orders' chart presents these metrics over time, reflecting the customer's transaction trends. The selection of KPIs such as 'Total Revenue,' 'Number of Orders,' 'Revenue per Order,' and 'Revenue per Pallet' on this page specifically aims to offer insights into the efficiency and scale of customer engagements. These metrics provide an understanding of the economic interactions with each customer, illustrating the volume of transactions and the value derived from each. This is important in tailoring business strategies and optimizing customer relations.

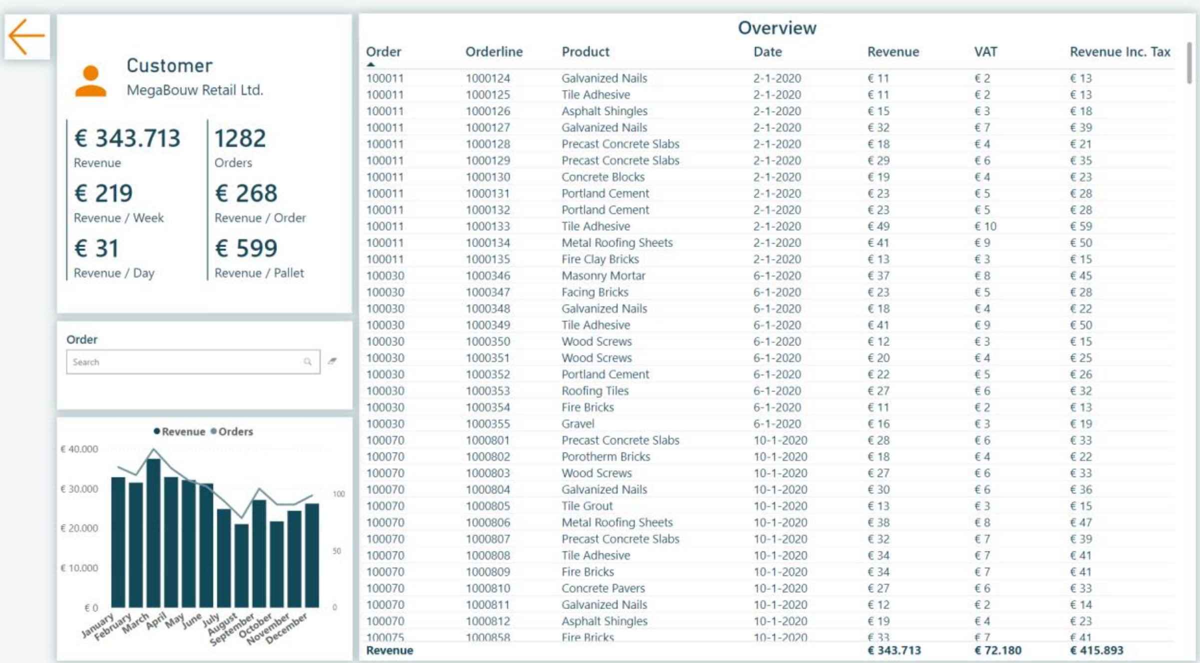


Figure 9: Revenue Drill-through

5.3.2. Dynamic Section

The Dynamic section of the dashboard is organized into three sub-sections to track different types of inventory movements: Inbound, Outbound, and Internal Movements. Each sub-section is tailored to monitor and analyze specific activities within the warehouse operation. The Inbound Overview page is the first page you land on after selecting the Dynamic icon (Figure 10). This page presents the cumulative total of all incoming items and their detailed data, providing a clear view of inventory as it enters the warehouse. The design of this page is consistent with the Revenue section's design to maintain a familiar interface across the dashboard.

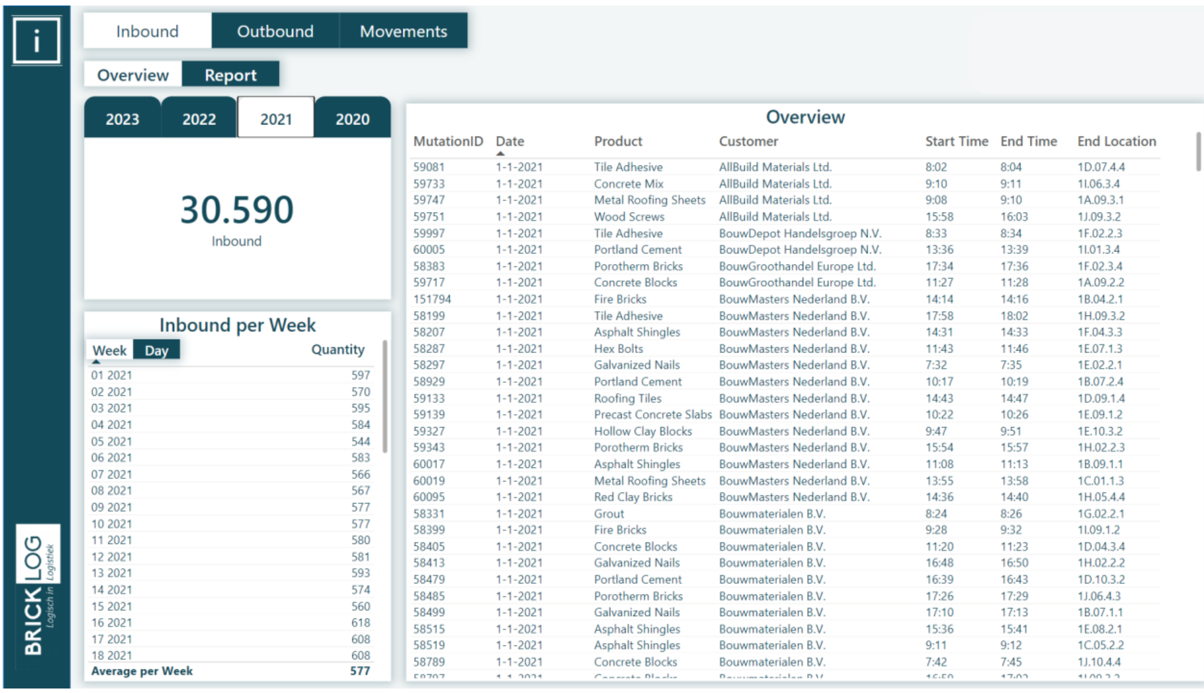


Figure 10: Dynamic Inbound

Advancing from the overview, the Inbound report, as shown in Figure 11, provides an expanded analysis with a per-customer breakdown, offering insights into yearly comparisons of volumes handled, average inbound times, and top product categories. The 'Average Inbound Time' KPI in the customer table measures the efficiency of processing inventory from receipt to readiness for storage, helping to pinpoint operational bottlenecks and improve workflows. The 'Top Product Categories' KPI highlights the types of products most frequently managed per customer, aiding dashboard users in tailoring inventory strategies to meet specific customer demands. Like the Revenue section, this page includes interactive monthly inbound and top product graphs, filtering the information displayed during user interaction. The layout and features of the Inbound and Outbound sections mirror each other, focusing respectively on incoming and outgoing inventory to simplify user adaptation and enhance overall dashboard usability.

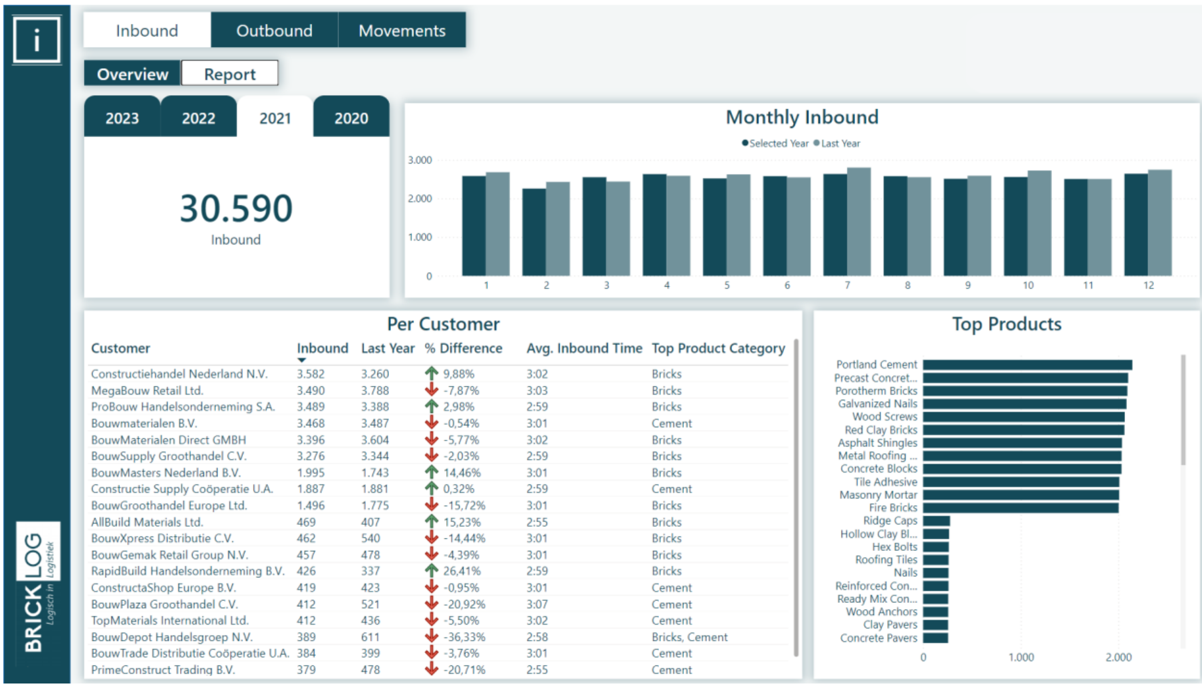


Figure 11: Inbound Report

For the Internal Movements section, the dashboard utilizes a structure similar to the Inbound and Outbound sections, as shown in Figure 12. This segment provides an overview of the warehouse's internal movements, highlighting the volume of movements by month and identifying the most frequently moved products. A 'Per Customer' table also allows for a quick reference of movement quantities, paralleling the functionality seen in other sections. By selecting a customer, users can execute a drill-through action, which directs them to a more detailed page for an in-depth analysis of the internal movements associated with that customer.

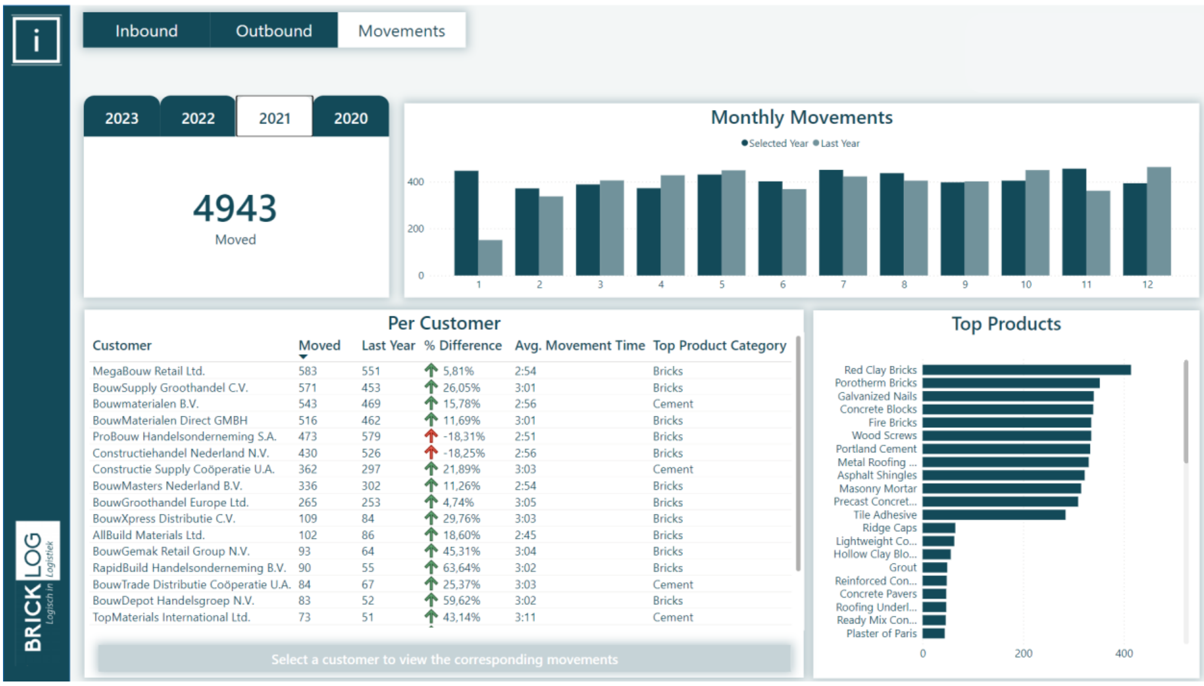
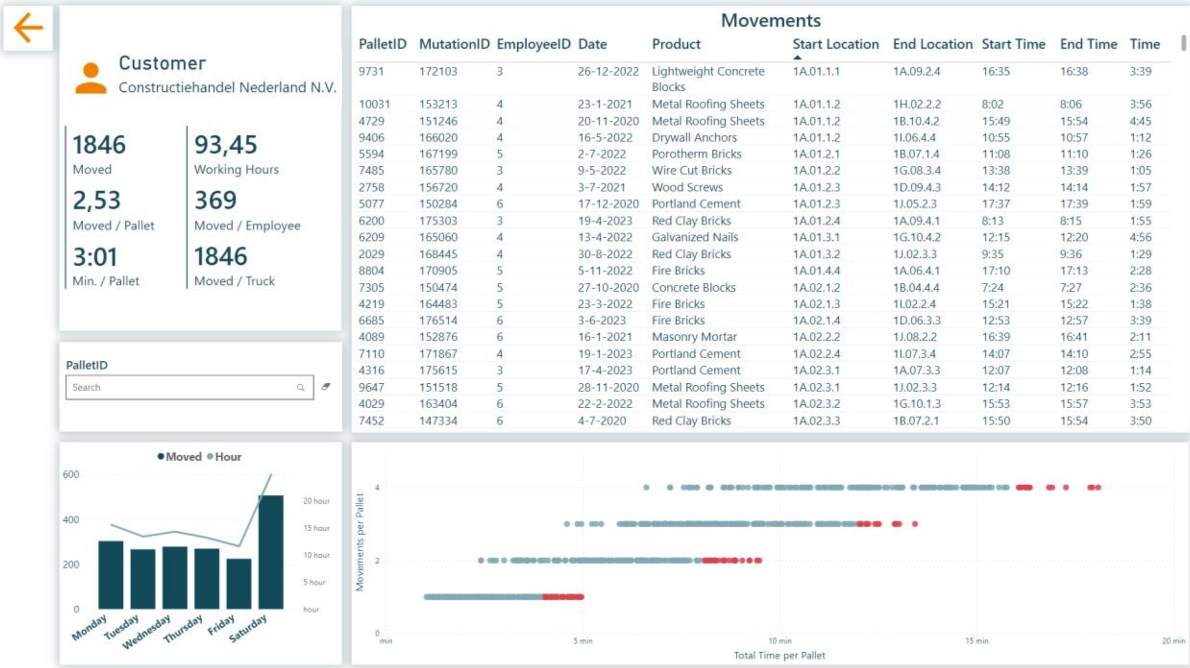


Figure 12: Dynamic Movements

The drill-through page for the Internal Movements section, depicted in Figure 13, provides a detailed analysis for a specific customer. This page divides the movements into precise metrics, such as the total number of items moved and the associated working hours. At the top, summary metrics offer a quick overview of activities, quantifying items moved, hours spent, and efficiency indicators like time spent per pallet. Newly added KPIs such as 'Movements per Employee,' 'Movements per Truck,' and 'Working Hours' were integrated following feedback from Bricklog.

The overview table presents each movement, including columns for pallet ID, mutation ID, responsible employee, activity date, product details, and the start and end locations with their corresponding times. This table allows users to see the detailed data for each movement, facilitating the analysis of specific movements within the warehouse.

The chart on the bottom left of this page visually represents the relationship between the number of items moved and the hours worked, simplifying the visualization of how effort translates into operational results. Additionally, the scatter plot on the bottom right visualizes each pallet as a point, plotting the number of movements against the time taken. Red points highlight pallets that exceed predefined thresholds in either movements or time, effectively identifying outliers. This visual tool quickly pinpoints inefficiencies, assisting users in identifying which pallets require attention to optimize operational efficiency.



PalletID	MutationID	EmployeeID	Date	Product	Start Location	End Location	Start Time	End Time	Time
9731	172103	3	26-12-2022	Lightweight Concrete Blocks	1A.01.1.1	1A.09.2.4	16:35	16:38	3:39
10031	153213	4	23-1-2021	Metal Roofing Sheets	1A.01.1.2	1H.02.2.2	8:02	8:06	3:56
4729	151246	4	20-11-2020	Metal Roofing Sheets	1A.01.1.2	1B.10.4.2	15:49	15:54	4:45
9406	166020	4	16-5-2022	Drywall Anchors	1A.01.1.2	1I.06.4.4	10:55	10:57	1:12
5594	167199	5	2-7-2022	Porotherm Bricks	1A.01.2.1	1B.07.1.4	11:08	11:10	1:26
7485	165780	3	9-5-2022	Wire Cut Bricks	1A.01.2.2	1G.08.3.4	13:38	13:39	1:05
2758	156720	4	3-7-2021	Wood Screws	1A.01.2.3	1D.09.4.3	14:12	14:14	1:57
5077	150284	6	17-12-2020	Portland Cement	1A.01.2.3	1J.05.2.3	17:37	17:39	1:59
6200	175303	3	19-4-2023	Red Clay Bricks	1A.01.2.4	1A.09.4.1	8:13	8:15	1:55
6209	165060	4	13-4-2022	Galvanized Nails	1A.01.3.1	1G.10.4.2	12:15	12:20	4:56
2029	168445	4	30-8-2022	Red Clay Bricks	1A.01.3.2	1J.02.3.3	9:35	9:36	1:29
8804	170905	5	5-11-2022	Fire Bricks	1A.01.4.4	1A.06.4.1	17:10	17:13	2:28
7305	150474	5	27-10-2020	Concrete Blocks	1A.02.1.2	1B.04.4.4	7:24	7:27	2:36
4219	164483	5	23-3-2022	Fire Bricks	1A.02.1.3	1I.02.2.4	15:21	15:22	1:38
6685	176514	6	3-6-2023	Fire Bricks	1A.02.1.4	1D.06.3.3	12:53	12:57	3:39
4089	152876	6	16-1-2021	Masonry Mortar	1A.02.2.2	1J.08.2.2	16:39	16:41	2:11
7110	171867	4	19-1-2023	Portland Cement	1A.02.2.4	1I.07.3.4	14:07	14:10	2:55
4316	175615	3	17-4-2023	Portland Cement	1A.02.3.1	1A.07.3.3	12:07	12:08	1:14
9647	151518	5	28-11-2020	Metal Roofing Sheets	1A.02.3.1	1J.02.3.3	12:14	12:16	1:52
4029	163404	6	22-2-2022	Metal Roofing Sheets	1A.02.3.2	1G.10.1.3	15:53	15:57	3:53
7452	147334	6	4-7-2020	Red Clay Bricks	1A.02.3.3	1B.07.2.1	15:50	15:54	3:50

Figure 13: Movements Drill-through

5.3.3. Static Section

The Static section, represented in Figure 14, focuses on inventory levels and storage within the warehouse, providing a snapshot of average storage space utilization and inventory volume changes over time. Including the average storage space utilization percentage at the top of the page quickly informs users how much of the warehouse's capacity is being used, which is critical for optimizing space management and planning future inventory needs. The inventory overview offers a weekly view of inventory volumes, allowing users to track stock levels across different periods. However, it should be noted that there is an anomaly in the presented data: the customer information, which should be associated with the stock, is missing due to a data generation error. This absence means that the stock items are not linked to specific customers in the current dataset, a point of consideration when interpreting the information.

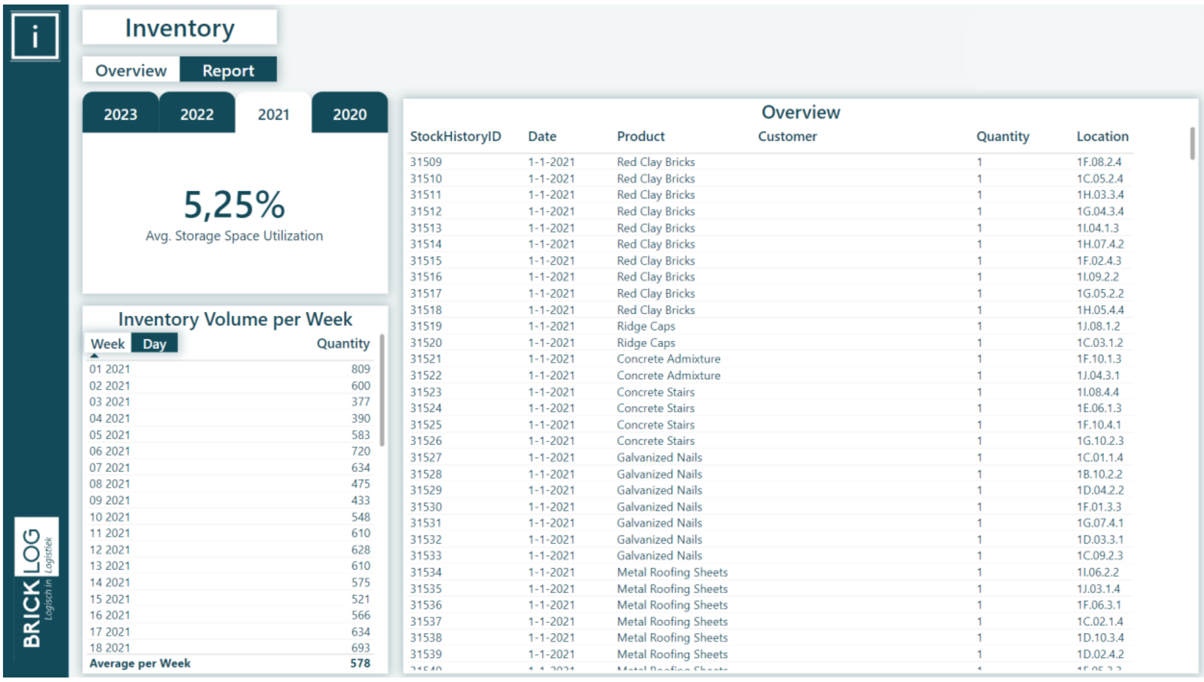


Figure 14: Static Overview

In the report view of the Static section, displayed in Figure 15, the dashboard quantifies inventory storage space utilization and lists the top products by volume. The graph delineates the monthly average space, while the product chart shows inventory preferences. Notably, since the customer is not linked to the products, it affects the customer-specific metrics, as seen in the figure. This is only a problem in this dataset; otherwise, the table should function correctly.

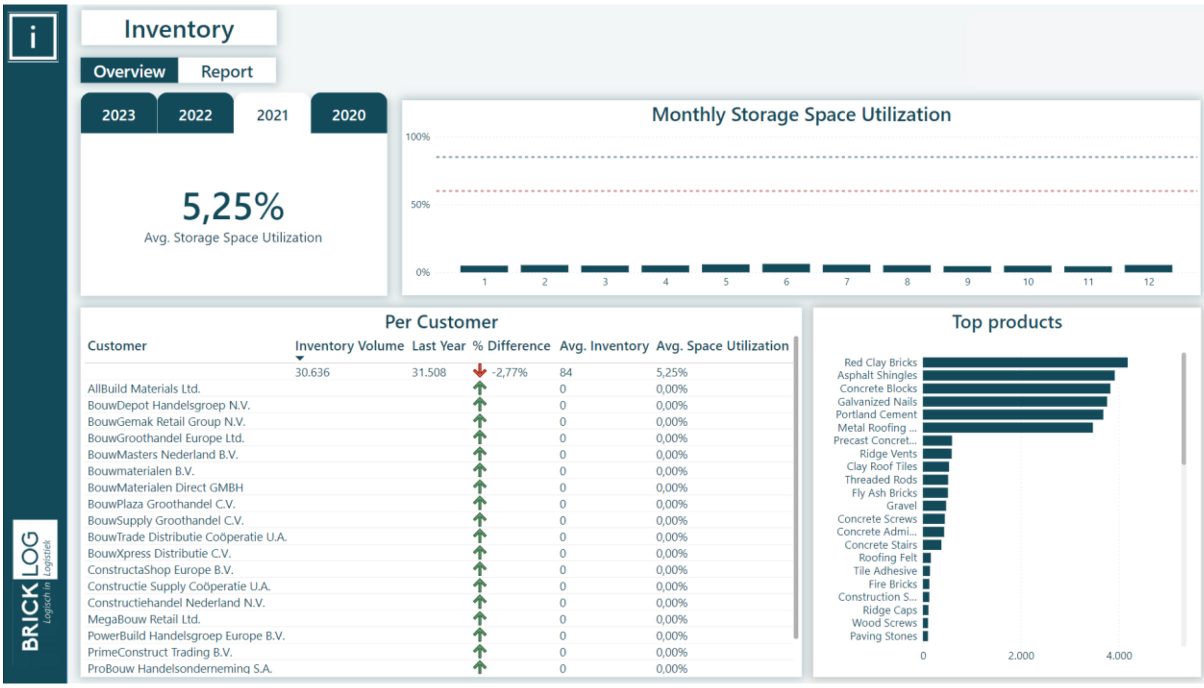


Figure 15: Static Report

6. Validation of Dashboard Design

This chapter presents the validation process undertaken to evaluate the effectiveness and usability of the developed warehouse dashboard. Validation is crucial for ensuring the dashboard meets the practical requirements and usability standards for real-world applications. It involves a detailed examination of the dashboard's functionality and user interaction, assessed through its operational effectiveness and the usability dimensions defined by TAM. This chapter describes the methodology used for the validation and discusses the findings and their implications.

6.1. Validation Methodology

As detailed in Chapter 3, the validation of the dashboard initially considered multiple methods, including heuristic evaluations and surveys, to ensure a comprehensive evaluation of its usability and effectiveness. Due to practical constraints, the methodology was streamlined to focus exclusively on survey-based feedback. This method was implemented to gather extensive user experiences from students at the University of Twente and a company representative, effectively capturing quantitative and qualitative insights into the dashboard's performance. The company representative provided additional insights by evaluating the dashboard thrice, each focusing on Revenue, Dynamic, and Static aspects.

6.2. Data Collection

The data collection phase began with an initial briefing to familiarize the participants, consisting of a company representative and 15 students, with the purpose and structure of the dashboard. This orientation ensured that users understood the dashboard before interacting, setting the stage for an informed evaluation.

During their interaction with the dashboard, participants explored its features independently. Interventions were made as necessary to guide them towards specific features to ensure all functionalities were assessed and facilitate navigation. These interventions, noted as observational data, provided live insights into user experience challenges.

After exploring the dashboard, participants completed an electronic survey. They marked an "X" in the appropriate boxes for the Likert scale questions and typed their answers for the open-ended questions. The responses from the Likert scale questions were later entered into Excel, and numerical values were assigned ranging from 1 (strongly disagree) to 5 (strongly agree). The responses were categorized by question for the open-ended questions to identify common themes and insights. Each set of open-ended responses was analyzed, and similar answers were grouped and quantified to reflect the frequency of similar comments. This categorization and quantification method will help analyze the collective feedback on various aspects of the dashboard.

6.3. Company Validation Results

A company representative participated in the evaluation process to provide a more comprehensive validation of the dashboard. The representative's in-depth knowledge of the subject matter added significant value to the assessment. In contrast to the student group, which evaluated the dashboard as a whole, the representative individually assessed each of the three distinct parts of the dashboard during the survey process. This section presents the results from the company representative's responses, organized into categories related to PU, PEOU, and the semantic quality of the KPIs.

6.3.1. Perceived Usefulness

6.3.1.1. Likert Scale Results for Q2 and Q5:

In evaluating the Perceived Usefulness of the dashboard, the company representative provided ratings for the same Likert scale questions as the students, specifically:

- **Q2:** "The dashboard offers functionalities that are crucial for efficient warehouse management."
- **Q5:** "The information provided by the dashboard is likely to be useful to decision-making processes."

Figure 19 visualizes the responses for each part of the dashboard. This visualization illustrates the representative's ratings for each question across the different dashboard sections, offering insights into how each specific part of the dashboard was perceived in terms of usefulness.

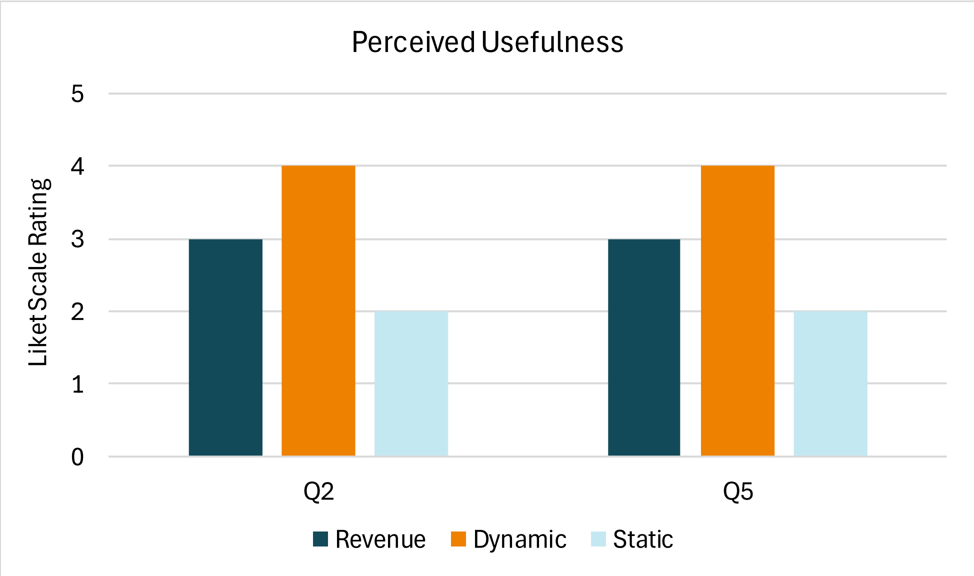


Figure 16: PU Company Validation

As shown, the ratings vary between the different sections of the dashboard, with the Dynamic part receiving notably higher scores, which suggests it is perceived as more useful. In contrast, the Static part receives lower ratings, indicating less satisfaction with its usability. When averaging the scores for Q2 and Q5 across the different parts, the result would point to a neutral perception of overall usefulness for the entire dashboard. This indicates considerable room for improvement, particularly in enhancing the Static part's perceived usefulness to elevate the dashboard's overall utility.

6.3.1.2. Open Question Q7 Results:

After evaluating the PU of the dashboard through the Likert scale questions, the company representative provided specific feedback on features they found most beneficial for warehouse management for each of the different parts:

- **Revenue:** The representative appreciated "the table to view the revenue and cumulative revenue per customer," which shows its usefulness in providing clear and actionable financial data.
- **Dynamic:** The feature allowing "the possibility to drill through on a customer and see statistics about the mutations of that specific customer" was noted as beneficial since it allows the dashboard to provide detailed customer insights.

- **Static:** The "average storage space utilization" feature was recognized for aiding in the efficient management of warehouse space.

6.3.2. Perceived Ease of Use

6.3.2.1. Likert Scale Question Q1 and Q6:

To assess the PEOU of the dashboard, the company representative evaluated the following Likert scale questions:

- **Q1:** "The dashboard's design appears user-friendly for people with different levels of technical expertise."
- **Q6:** "The instructions and help features provided within the dashboard make it easy to understand how to use all of its functionalities."

Figure 20 visualizes the representative's responses and reflects the ease of use ratings across the different sections of the dashboard.

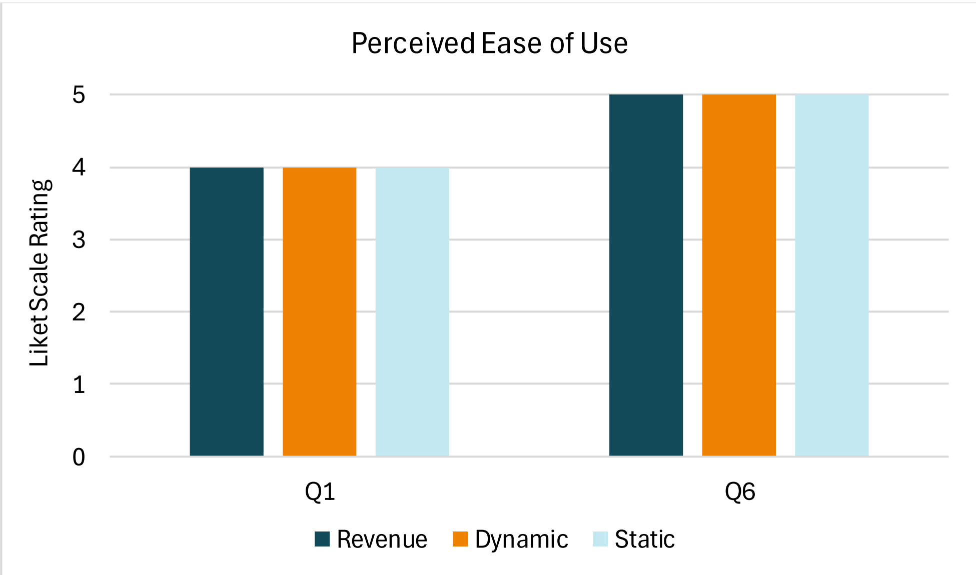


Figure 17: PEOU Company Validation

The chart illustrates that the representative found all dashboard sections equally user-friendly, with Q1 and Q6 receiving high ratings across the different parts. This uniform high scoring suggests that regardless of the dashboard's section, the ease of use was consistently perceived as high. This indicates that the dashboard's design successfully made the interface user-friendly and intuitive. The high PEOU ratings can also be attributed to the representative's familiarity with similar systems, which likely influenced their positive perception of the dashboard's usability.

6.3.2.2. Open Question Q9 Results:

The company representative provided specific suggestions for additional data or features that could enhance the ease of use of the dashboard:

- **Revenue:** It was suggested that integrating the capability to view the total orders over time would be beneficial. This would allow for a broader analytical perspective, as the dashboard only allows viewing the data within a year. Adding this feature would allow users to access historical data quickly without manually compiling annual data, simplifying trend analysis and saving time.

- **Dynamic:** The representative recommended tracking mutations for specific employees to better understand individual performance within the warehouse. Doing so would enable warehouse managers to access detailed performance data directly, making it more straightforward to assess and respond to operational needs.
- **Static:** For the Static section, the representative pointed out a need for its extension, which includes daily stock metrics or location-based inventory metrics. These enhancements simplify inventory management by providing immediate visibility into stock levels at various locations, thereby helping users make quicker decisions based on real-time data availability.

6.3.3. Semantic Quality

6.3.3.1. Likert Scale Results for Q3 and Q4

The company representative evaluated the semantic quality of the dashboard through the following Likert scale questions:

- **Q3:** "The layout and data presentation of the KPIs effectively communicate the critical metrics of warehouse operations."
- **Q4:** "The KPIs displayed on the dashboard accurately reflect key aspects of warehouse operations."

The representative's responses are visualized in Figure 20, which reflects the semantic quality ratings across the different sections of the dashboard.

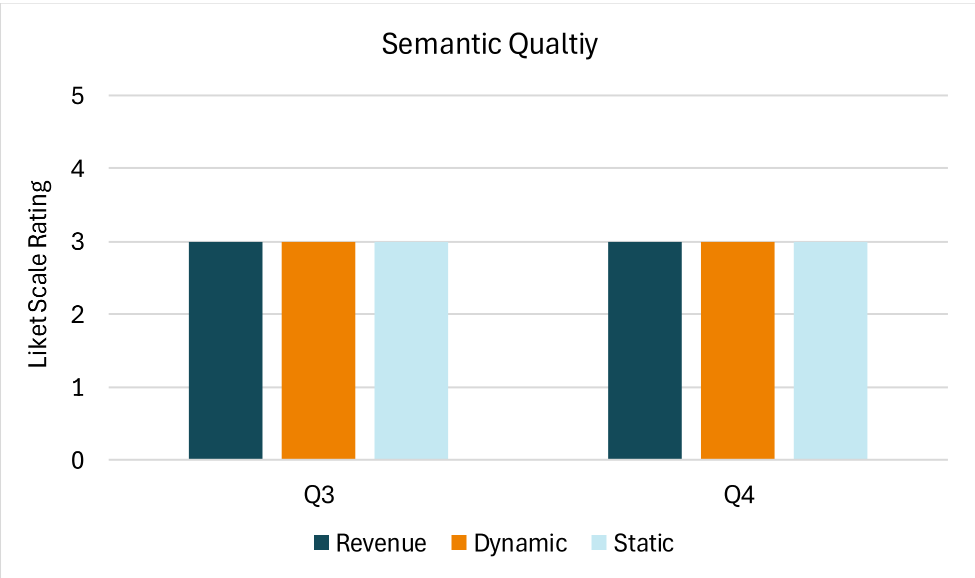


Figure 18: Semantic Quality Company Validation

This uniform neutral response indicates that while the KPIs meet the basic needs, there is still significant room for improvement in how they are presented and in ensuring that they accurately reflect the key parts of the warehouse operations.

6.3.3.2. Open Question Q8 Results:

In response to the question about improvements regarding the representation of the KPIs on the dashboard, the representative provided the following feedback:

- **Revenue:** Including tax per order in the revenue table was seen as less useful. This comment indicates a preference for focusing on more impactful financial metrics, which would add value to decision-making.

- **Dynamic:** The representative noted that while the dashboard contains a lot of information, the layout is too dense, making it challenging to determine which KPIs or statistics are most critical. This suggests that a more streamlined presentation is needed to enhance the visibility of key data points.
- **Static:** The feedback for the Static part of the dashboard pointed out a lack of diverse KPIs, with the exception of storage space utilization. Additional KPIs in this section would benefit it and provide a more complete view of the operational metrics for this part.

6.4. Student Validation Results

Due to the small sample size, students were included in the validation process to ensure a more comprehensive evaluation. While the company representative provided insights based on in-depth knowledge of the subject matter, the student participants, with varying levels of technical expertise, helped to assess the dashboard's ease of use and overall user experience. Emphasizing the PEOU was particularly important, as it provided a broader perspective on the user-friendliness of the dashboard. However, for completeness, all aspects, including PU and the semantic quality of the KPIs, were included in the evaluation.

6.4.1. Perceived Usefulness

In assessing the PU dashboard, questions Q2 and Q5 on the Likert scale were complemented by open-ended question Q7 to gain quantitative and qualitative insights.

6.4.1.1. Likert Scale Results for Q2 and Q5:

The specific questions on the Likert scale were:

- **Q2:** "The dashboard offers functionalities that are crucial for efficient warehouse management."
- **Q5:** "The information provided by the dashboard is likely to be useful to decision-making processes."

Participants' responses to these statements were predominantly positive, with the majority selecting the higher end of the scale, as visualized in the accompanying column chart (see Figure 16). The majority rating these aspects as a 4 or 5 indicates a high level of agreement on the dashboard's usefulness.

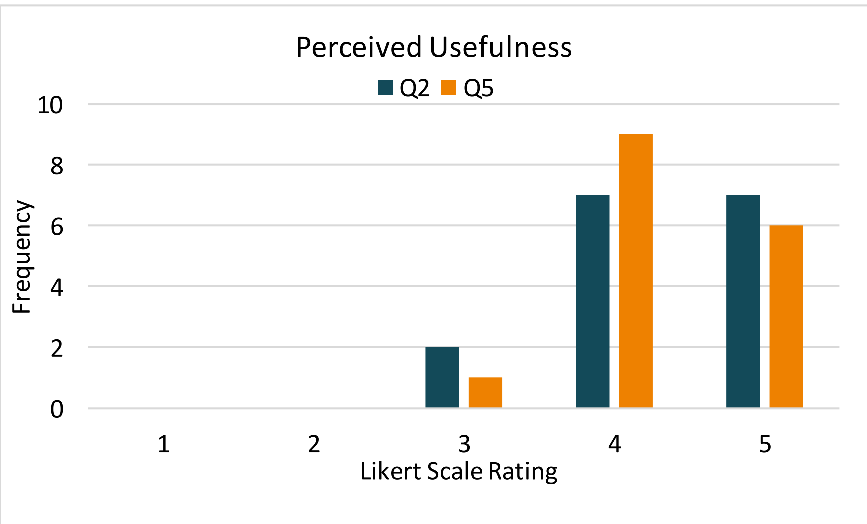


Figure 19: Perceived Usefulness Column Chart

Although most responses indicated high perceived usefulness, lower scores on Q2 and Q5 indicate opportunities to enhance the dashboard's features and information delivery to fully meet user expectations of usefulness.

6.4.1.2. *Open Question Q7 Results:*

Participants responded to the following open question, providing insights into the features they find most beneficial on the dashboard:

- **Q7:** "In your view, what features of the dashboard are most beneficial for warehouse management?"

The responses are organized into different categories, and similar answers are put together and quantified to reflect the frequency:

Tracking and Monitoring (11x)

- Tracking of pallet/product movements and times (5x)
- Highlighting pallet outliers (2x)
- Tracking of average space utilization (2x)
- Tracking worker efficiency
- Display of high turnover rates for specific products and associated suppliers or customers

Comparison and Data Analysis (8x)

- Monthly comparison of product movements (2x)
- Data-driven insights for future predictions and strategy adaptation (2x)
- Product-specific data analysis
- Comparison of different customers' impact
- Capabilities for warehouse efficiency comparison
- Current and previous year data comparison

Detailed Data Access (6x)

- Drill-through function for detailed viewing of pallet movements (2x)
- Capability to select and investigate specific data for issue identification (2x)
- Sorting functionality for quick data review
- Customizable selection filters for KPI values by specific months, customers, and other criteria

The significant mentions of real-time data capabilities, such as tracking movements and times, illustrate the perceived value of the dashboard for daily operations management. These responses highlight the operational benefits and support for the dashboard's efficient workflows, as noted by the users. Furthermore, the frequent references to analytical tools like comparison capabilities and product and customer-specific data analysis from the feedback illustrate its effectiveness in delivering actionable insights according to the participants. Lastly, the noted usefulness of detailed data access through drill-through functions reflects user appreciation for the dashboard’s capability to facilitate deep data exploration, enhancing its overall utility, as reported by the respondents.

6.4.2. Perceived Ease of Use

In assessing the dashboard's Perceived Ease of use, Likert scale questions Q1 and Q6 were used alongside responses to a relevant open-ended question to gather both quantitative and qualitative insights. Additionally, open-ended question Q9 provided further insights by inviting participants to suggest enhancements that could improve the dashboard’s ease of use.

6.4.2.1. *Likert Scale Results for Q1 and Q6:*

Participants evaluated the following aspects of the dashboard:

- **Q1:** "The dashboard's design appears user-friendly for people with different levels of technical expertise."
- **Q6:** "The instructions and help features provided within the dashboard make it easy to understand how to use all of its functionalities."

The accompanying column chart visualizes the distribution of ratings from these questions (see Figure 17). It shows a general consensus that the dashboard is user-friendly, with a majority of the responses skewing towards the higher end of the scale.

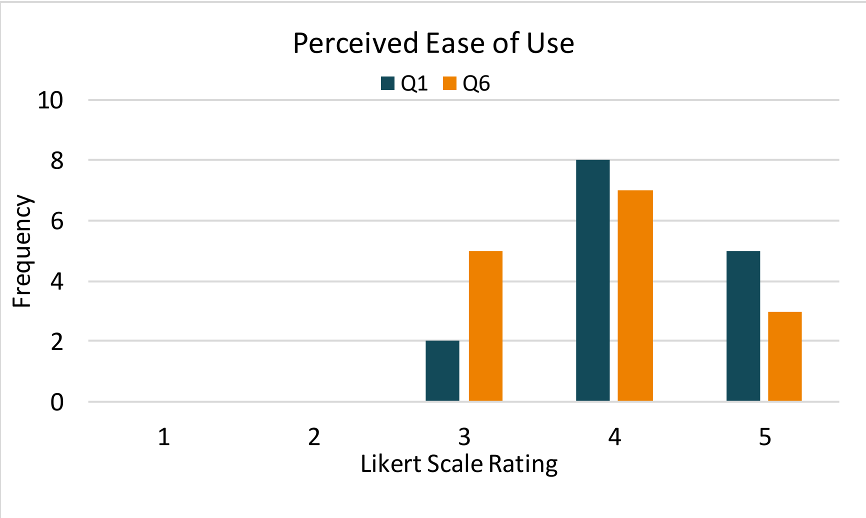


Figure 20: Perceived Ease of Use Column Chart

The graph indicates that while most participants find the dashboard's overall design user-friendly, the instructions and help features (Q6) did not meet the same level of approval. With a notable number of responses at a scale of 3 and fewer at the high end of 5, the current help features may not be as intuitive or straightforward as required. This feedback pinpoints a critical area for enhancement to ensure all functionalities are easily understandable and accessible to all users.

6.4.2.2. *Open Question Q9 Results:*

Participants also responded to open-ended question Q9, which sought suggestions for enhancing the dashboard's ease of use:

- **Q9:** "Do you have any suggestions for additional data or features that could enhance the ease of use of the dashboard?"

Responses:

Improved Navigation and Comprehensive Overview (8x)

- Improve the dashboard with unified navigation and an overview page that highlights key KPIs and alerts for potential issues (7x).
- Improve categorization and add more filters for a clearer dashboard overview.

Advanced Data Analysis and Visualization Features (7x)

- Enhance the dashboard by incorporating color highlights and trend lines in graphs to improve visual clarity and understanding of data trends (3x).
- Simplify performance tracking by integrating features to monitor and analyze employee productivity (3x).
- Provide data on movements per product rather than breaking it down by per customer.

Enhanced Information Accessibility and Visibility (4x)

- Information button enhancements to improve clarity and visibility (4x).

The improvements recommended by participants aim to enhance the dashboard's analytical capabilities and ease of use. Feedback strongly emphasizes the need for improved navigation and data visualization. By integrating a unified navigation system and an overview page, the dashboard could significantly enhance accessibility, reducing the time needed to locate crucial information and making the user experience more intuitive. Additionally, the request for advanced graphical tools, such as color highlights and trend lines, suggests a need for clearer data presentations to simplify the analysis of complex information. This aligns with suggestions for better tracking of employee productivity. Enhancing the clarity of the information button is also critical, as it provides users with the necessary guidance to utilize the dashboard's features effectively.

6.4.3. Semantic Quality

In assessing the dashboard's Semantic Quality, Likert scale questions Q3 and Q4 were utilized to evaluate how effectively the layout and presentation of KPIs communicate critical metrics and reflect the key aspects of warehouse operations. Open-ended question Q8 complemented these assessments by soliciting participant feedback on potential improvements.

6.4.3.1. Likert Scale Results for Q3 and Q4:

Participants evaluated the effectiveness of the KPI presentation in the dashboard through the following questions:

- **Q3:** "The layout and data presentation of the KPIs effectively communicate the critical metrics of warehouse operations."
- **Q4:** "The KPIs displayed on the dashboard accurately reflect key aspects of warehouse operations."

The upcoming figure visualizes the ratings distribution for these questions. It illustrates a generally favorable perception, with most ratings concentrated at the higher end of the scale, indicating a robust alignment of KPIs with operational realities.

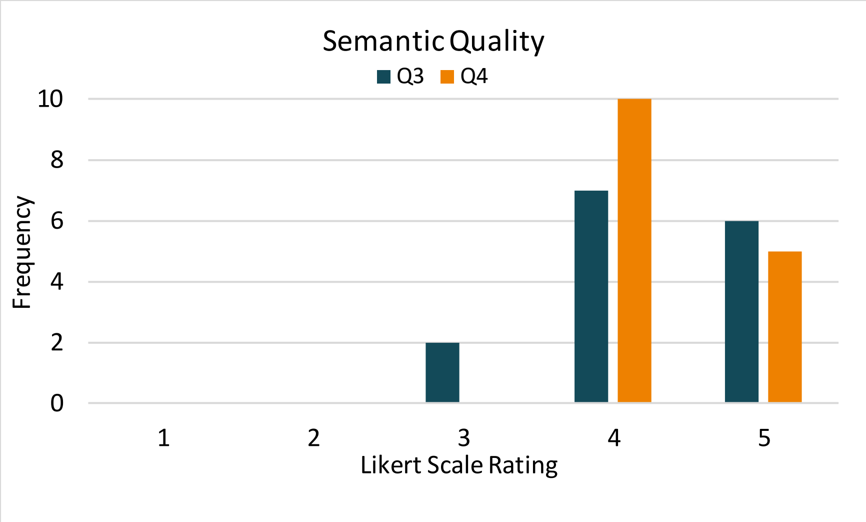


Figure 21: Semantic Quality Column Chart

The higher ratings for Q4, in particular, suggest that the KPIs displayed are well-received for accurately reflecting key operational metrics. However, the feedback on Q3 indicates room for improvement in how these KPIs are presented to enhance their communicative effectiveness.

6.4.3.2. Open Question Q8 Results:

Participants responded to open-ended question Q8, providing insights into how the representation of KPIs on the dashboard could be further refined:

- **Q8:** "Are there areas where you think the dashboard's representation of KPIs could be improved? Please elaborate."

Responses:

Enhanced Detail and Clarity in KPIs (12x)

- Implement storage duration KPIs per pallet and customer to highlight inventory turnover. (4x)
- Improve KPI representation by detailing inbound/outbound movement metrics and showing times for individual subprocesses separately (3x)
- Analysis of warehouse space utilization, identifying the most and least used locations. (3x)
- Enhance certain KPIs with additional graphs to improve data comprehension.
- Visibility of various costs associated with inventory and operations.

Comparative Analysis and Visibility (5x)

- Add the option to compare weekly or monthly data across multiple years, such as Week X of every year. (3x)
- Add features to compare performance across product categories and identify products that are generating losses.
- Shift some focus from customer-centric KPIs to product-centric KPIs to better understand warehouse inventory.

The participants' responses suggest the need to integrate additional and more specific KPIs to enhance the dashboard’s effectiveness. The dashboard could more accurately highlight inventory turnover by introducing storage duration KPIs for each pallet and customer, thereby enabling more strategic storage optimization and potential cost reductions. Participants noted that current KPIs focused solely on overall inbound and outbound movements lack depth; breaking down these processes into individual subprocesses could yield valuable insights and significantly enhance operational efficiency. Moreover, deepening the analysis of warehouse space utilization would allow managers to strategically use space, which could lead to reducing costs. Another important point suggested involves the dashboard's inability to compare data across multiple years. This capability would provide a more precise overview of long-term trends and facilitate more informed strategic planning. Together, these enhancements would improve the dashboard’s functionality, making it a more powerful tool for management decision-making.

6.5. Summary of Validation Results

This chapter evaluated the warehouse dashboard through surveys conducted with university students and a company representative. The evaluation assessed the dashboard's effectiveness and usability across three dimensions: PU, PEOU, and the Semantic Quality of KPIs. The general feedback from both of the parties can be seen below:

- **Company feedback:** Feedback from the company representative, who brought a more expert perspective to the validation, was notably more critical, pinpointing specific areas for improvement across the different sections of the dashboard. The Dynamic section of the dashboard was recognized for its effectiveness and usefulness, and its detailed customer insights and dynamic data exploration features were particularly praised. However, The Static section was identified as underperforming in terms of its perceived usefulness. Despite these variances regarding its usefulness across the different parts of the dashboard, the ease of use was consistently rated highly across all the sections. Suggestions for an even better ease of use included extending the range of data visualization over time and introducing a better way to track employee performance. The feedback on semantic quality indicated that while the current KPIs met basic operational needs, there is significant room to refine their presentation and broaden the scope of the metric, especially for the Static part of the dashboard.

- **Student feedback:** The general feedback from participants highlighted a positive perception of the dashboard, acknowledging its real-time data and analytical capabilities as particularly beneficial, contributing to its perceived usefulness. However, despite the overall positive reception, there were concerns about the intuitiveness and user-friendliness of the navigation. Suggestions were made to improve the clarity of instructions and help features to make the dashboard more accessible and easier to understand. Additionally, the semantic quality of the KPIs generally received positive feedback, but there were also recommendations for adding more specific and detailed KPIs, along with enhancements to its comparative capabilities.

7. Conclusion

This chapter concludes the research by addressing the main research question and sub-questions, summarizing the research problem and objectives, discussing the main findings, and providing limitations and recommendations.

7.1. Motivation

For this thesis, research was conducted to tackle the problem of inadequate data visualization and underutilization of operational data in SMEs within the warehousing sector. The core issue identified was the capability gap in existing WMSs, which lack the advanced analytics required to extract actionable insights from warehouse data, which is crucial for strategic decision-making.

Bricklog aims to address this gap by developing a specialized BI product to optimize warehouse operations. This solution involves creating a dashboard that overlays the current WMS infrastructure, highlighting KPIs and other metrics to enable SMEs to make informed decisions and optimize various warehouse operations.

To structure this research and provide a clear pathway to solving the problem, the following main research question was posed:

"How can a dashboard be designed to effectively implement performance tracking and streamline data visualization, measured by the decreased effort in gaining insights into warehouse performance?"

To answer this main research question, several sub-questions were formulated. The answers to these sub-questions will provide the necessary insights to address the main research question. In the following section, each sub-question will be answered.

7.2. Main Findings

Sub-question 1: How can warehouse performance be effectively measured and monitored?

To effectively measure and monitor warehouse performance, it is important to select the relevant KPIs related to this and employ a systematic method for their selection. This ensures that the dashboard will provide actionable insights and supports informed decision-making.

The KPIs relevant to measuring warehouse performance were selected through a literature review and informal interviews with company employees. During this process, several overlapping KPIs were identified, and along with other factors, such as the availability of data and their relevance to the dashboard, a preliminary list was made. This list which can be found in Section 4.2.3. table 4 highlights the KPIs that were considered for implementation in the dashboard. It should be noted that the excluded KPIs, while not included in this dashboard, remain important and should be considered in other contexts where data availability and relevance may differ.

Despite creating a preliminary list, each KPI still needed to be individually checked due to the factors mentioned before. Therefore, a thorough method was applied to evaluate each KPI. The method selected for this was the AHP method, in which each KPI was rated against the weighted SMART criteria (Specific, Measurable, Achievable, Relevant, and Time-bound) on a scale from 1 to 5. This method facilitated the identification of the most relevant KPIs aligned with the dashboard's goals and the practical constraints of data availability. The selected through this method can be found in Section 5.2.2.

The tool created will be useful for measuring and monitoring warehouse performance by focusing on the most relevant KPIs and implementing them into the dashboard. This will allow managers and other stakeholders to make informed decisions based on the information provided by the dashboard.

Sub-question 2: What are the best data visualization techniques for designing an effective dashboard?

Adhering to best practices in dashboard design and avoiding common mistakes is important for optimally presenting the KPIs on the dashboard. These principles, derived from the literature, have been applied to the dashboard to ensure that it is visually appealing but also functional and user-friendly.

A literature review revealed best practices for communicating the KPIs effectively. These include frame-based menus, which improve navigation efficiency by keeping menu items in constant positions, and drill-down features, which allow users to explore data at different granularities. Contextual metrics enhance the impact of visualizations by providing context, while appropriate visualization choices align visualizations with the complexity of the information. Additionally, avoiding clutter ensures that the dashboard remains clear and user-friendly.

These practices were implemented in the dashboard design, as detailed in Section 5.3. For example, frame-based menus facilitated quick navigation, and drill-down features allowed for deeper data exploration. Additionally, contextual metrics were included to easily interpret and act upon the information presented, and efforts were made to avoid clutter by using a simple and clear layout.

The literature also highlights several common mistakes that can undermine the effectiveness of the dashboard. These include exceeding the screen boundaries, providing inadequate context, including excessive detail, cluttering the display with useless decoration, and choosing inappropriate display media. A detailed discussion of these common mistakes is provided in Section 4.1.3. In designing the PowerBI dashboard, these mistakes were considered and avoided. The dashboard is structured into three key sections, Revenue, Dynamic, and Static, each divided into overview and report pages. This structure is there to make sure the user can access important information easily without being overwhelmed. Appropriate context was also provided for each data point to enhance the understanding, and visualization choices were made thoughtfully to ensure clarity and effectiveness, as detailed in Section 5.3.

By adhering to these best practices and avoiding common mistakes, the dashboard was designed to deliver actionable insights for the users and stakeholders. The design is intended to support decision-making processes within the warehouse by making critical data easily accessible and interpretable.

Sub-question 3: Does the designed dashboard meet its intended goals for improving warehouse performance?

For assessing a dashboard's impact on warehouse performance measurement, it was important to select and apply an effective validation method and identify relevant metrics that can be used to measure its usability and effectiveness. Additionally, the results from these assessments should be taken into account for guidance on improving the dashboard.

Different methods were found through the literature to validate the usability and effectiveness of the dashboard. These methods included heuristic evaluations, expert reviews, cognitive walkthroughs, and surveys. Each method has its strengths and should be considered based on the specific situation when validating. For this research, practical constraints led to the exclusive use of surveys. However, it should be noted that each method has its strengths and should be considered according to the specific situation when conducting a validation. The surveys used in this research included both Likert scale and open-ended questions and were conducted with students and a company representative. This approach provided quantitative and qualitative insights into the dashboard's usability and effectiveness.

A combination of metrics was used to measure the effectiveness of the dashboard. Firstly, semantic quality was assessed to evaluate how accurately and completely the KPIs represented warehouse operations. Semantic quality directly addresses the dashboard's ability to fulfill its intended use by ensuring the completeness and accuracy of the information presented. Additionally, the TAM was employed to evaluate user acceptance. TAM's core constructs, PU and PEOU, provided a structured approach to understanding how users interact with and accept the dashboard. PU evaluates whether users believe the dashboard enhances their job performance by providing relevant, actionable data, while PEOU assesses the user-friendliness of the dashboard, including ease of navigation and interpretation of data.

The survey feedback from the students and the company representative highlighted several areas for improvement. The feedback will be discussed through the lens of each measured variable, with detailed results in Section 6.3. and 6.4.

Company Feedback:

- **PU:** The Likert scale results from the company representative revealed a mixed perception of the dashboard's usefulness. The Dynamic section received high ratings, indicating that it was seen as useful, particularly for its detailed customer insights and drill-through capabilities. The Revenue section was rated as neutral, with feedback indicating that the revenue table for the customer was seen as beneficial. However, the Static section was rated low and seen as insufficient. This suggests that while certain aspects of the dashboard are valued, others need enhancement to meet user needs better.
- **PEOU:** The company representative rated the dashboard highly regarding ease of use across both Likert scale questions, indicating that it has a user-friendly design and an intuitive interface. The high PEOU ratings were likely influenced by the representative's familiarity with similar systems, which contributed to their positive assessment of the dashboard's usability. The open-ended feedback suggested extending specific dashboard parts to include capabilities for comparing data over longer periods. Additionally, enhancing employee tracking and expanding the functionalities of the Static section were recommended. These improvements would make the dashboard easier for its intended functions and increase its overall usefulness.
- **Semantic Quality:** The representative's feedback on the semantic quality through the Likert scale question was neutral, indicating that while the current KPIs met basic operational needs, there is significant room for improvement. The open-ended feedback highlighted the need for more impactful financial metrics in the Revenue section, a streamlined layout in the Dynamic section to highlight critical data points better, and additional diverse KPIs in the Static section to provide a more comprehensive view of warehouse operations.

Student Feedback:

- **PU:** The Likert scale results showed that most students rated the dashboard positively, indicating that they found the functionalities useful for warehouse management and decision-making. However, some lower scores suggested areas for improvement. The open-ended question responses highlighted the features they found beneficial, such as the drill-through function, real-time data tracking, and the ability to compare data over different periods.

- **PEOU:** The Likert scale response indicated that students generally found the dashboard user-friendly, although some aspects, like the instructions and help features, received lower ratings. The suggestions from the open-ended question include improvements in navigation, such as adding more visual aids like color highlights and trend lines and enhancing the clarity of the information button.
- **Semantic Quality:** Likert scale results for semantic quality showed that the students perceived the KPIs effectively communicating the critical metrics of warehouse operations. The open-ended question feedback suggested the need for more specific KPIs to enhance the dashboard's effectiveness. This includes implementing storage duration KPIs, detailed inbound/outbound movement metrics, and comparative analysis features across multiple years.

Based on the feedback, several improvements can be made to the dashboard:

1. **Enhanced Navigation and Visual Aids:** To enhance user-friendliness, add more visual aids like color highlights and trend lines and improve the clarity of the information button.
2. **Expanded KPI Set:** The dashboard's effectiveness can be significantly enhanced by including more specific KPIs across various sections. Incorporating storage duration metrics in the static section will provide a more comprehensive view of warehouse operations. In the Dynamic section, expanding the inbound/outbound movement metrics into more detailed stages will offer deeper insights into warehouse activities. Additionally, the Revenue section will benefit from more impactful financial metrics.
3. **Extended Data Comparison Capabilities:** Allow for comparison of data over longer periods and multiple years.
4. **Streamlined Layout:** Simplify the layout of the Dynamic section to highlight critical data points more effectively.
5. **Employee Tracking:** Enhance capabilities for tracking employee productivity and other related metrics.

Overall, the designed dashboard meets its intended goals for improving warehouse performance. The feedback from both students and the company representative indicates that, while areas need improvement, the dashboard is generally perceived as useful and effective. The positive ratings for PU and PEOU, along with the constructive suggestions, demonstrate that the dashboard is a valuable tool for warehouse management. The identified improvements will further enhance its functionality and user experience, ensuring it continues to meet its goals effectively.

This comparison highlights the importance of a balanced approach that addresses ease of use and comprehensive functionality. The company representative's feedback, focusing on operational effectiveness and strategic improvements, is valuable for aligning the dashboard with industry-specific requirements. At the same time, the students' feedback on usability ensures the dashboard remains accessible and user-friendly, supporting a broader range of users. This combined feedback provides a roadmap for refining the dashboard to enhance its overall effectiveness and utility.

Main research question: How can a dashboard be designed to effectively implement performance tracking and streamline data visualization to enhance warehouse performance?

Several key practices were followed to design an effective dashboard for performance tracking and data visualization. Relevant KPIs were selected using a systematic AHP method, ensuring they aligned with decision-making processes for warehouse performance. Best practices from the literature, such as frame-based menus for efficient navigation and drill-down features for detailed data access, were implemented to enhance the dashboard's visual appeal and functionality.

The impact of the dashboard was assessed through surveys with students and a company representative. Students appreciated features like drill-through functions and real-time data tracking but suggested improvements in navigation and visual aids. The company representative emphasized the need for enhanced functionality, particularly in the Static section, and more diverse KPIs. This feedback highlighted the importance of balancing usability and functionality to cater to novice and expert users.

By implementing this dashboard, a solution is offered that addresses the complexities of warehouse performance tracking, making it easier for end-users to gain insights into their operations and improve overall efficiency. This advancement highlights the potential for significant improvements in warehouse management practices through enhanced data visualization and KPI tracking.

7.3. Limitations

The development and implementation of the dashboard faced several limitations, primarily related to data quality and the validation process. These limitations are categorized as follows:

Data Limitations

- **Errors in Data Generation:** The dummy data used for the dashboard was generated in multiple sessions, leading to inconsistencies. Specifically, an error occurred during the generation of the PalletID for the Stock_Mutation data, where for a significant portion, the PalletID is not generated in this table. This has affected the pallet-specific KPIs in the Revenue section since it uses the PalletID to count the number of pallets. For example, the revenue per pallet does not accurately reflect the actual number in many cases. The Dynamic part was unaffected because every internal movement activity happens to have a PalletID coupled. The issue was left unaddressed in the calculations to ensure future data integrations by customers would not require additional adjustments.
- **Insufficient Customer Data in the Static Section:** The Static section relies on the Stock_History table, which lacks customer data. Consequently, tables requiring customer data in this section remain empty. This issue would be resolved if the customer data were generated and integrated into the model.
- **Limited Scope for Productivity KPIs:** The current data structure categorizes activities into inbound, outbound, or internal movements, limiting the ability to measure specific productivity metrics such as picking or put-away productivity. In an actual warehouse, these activities are broken down into more granular stages, such as receiving and putting away for inbound or picking and shipping for outbound. However, The current model couples these stages into single activities, preventing accurate measurement of individual productivity metrics like picking and receiving productivity.
- **Time-Related KPIs:** Due to the nature of the data, the same problem that affects the productivity KPIs also applies to the time-related KPIs. Since the data model categorizes activities into broad categories like inbound, outbound, or internal movements, it prevents the detailed breakdown of processes. Consequently, specific time-related KPIs such as order picking time or queuing time are aggregated into a single activity, making it impossible to measure them separately.
- **Utilization KPIs:** The lack of detailed data on storage areas and overall building size restricted the depth of utilization KPIs. Currently, only a generic storage space utilization KPI is

available based on whether storage locations are filled. The existing data includes tables with location type IDs and specific dimensions (height, length, etc.) for storage locations, but other types of locations lack these definitions. Moreover, these non-storage locations are not used in the Stock History table, limiting the scope of utilization metrics. Although specific product volume data is available, which could allow for a more detailed calculation of space utilization, this has not been implemented due to the limited data scope. Expanding these calculations would require more detailed information on all storage and non-storage areas within the warehouse.

- **Labour Productivity:** Accurately measuring labor productivity was challenging due to the absence of data on employee working hours.
- **Order Lead Time:** The data model's structure did not link sales order lines to stock mutations, making it impossible to measure order lead time without restructuring the data model.
- **Turnover Rate and Revenue Depth:** The data lacked information on the cost of goods sold and other cost factors, limiting the ability to calculate turnover rates and in-depth revenue-related KPIs. The Revenue section could be enhanced with data on storage time costs and location-specific expenses to assess profitability better.
- **Quality-Related KPIs:** The dummy data did not include error data for activities like picking or storing, preventing the implementation of quality-related KPIs in the Dynamic and Static sections.

Validation Limitations

- **Students' Limited Knowledge:** The validation process included students who, while strengthening the overall validation, lacked deep knowledge of warehousing and dashboard design. This limited their ability to provide detailed, expert feedback.
- **Single Company Representative:** Only one expert from the company participated in the validation. Although this individual provided valuable insights, having multiple experts would have reduced potential biases and offered a more comprehensive evaluation.

These limitations highlight the challenges encountered during the dashboard's development and validation. Addressing these issues in future iterations will enhance the dashboard's accuracy, functionality, and overall utility.

7.4. Discussion

The development of the warehouse performance dashboard revealed several areas for improvement. Data quality was a significant challenge, with inconsistencies in the generated dummy data affecting the accuracy of certain KPIs. Additionally, the data was fairly limited, with many empty columns intended for future use, thus limiting KPI implementation. The structure of the movement data did not accurately reflect actual warehouse operations, further restricting the KPIs. These limitations were somewhat expected given the nature of a data company without its own warehouse operations.

Feedback from both students and the company representative highlighted important points, some of which were not feasible within the scope of this dashboard. For instance, many students suggested a unified overview page, which, while beneficial, was not the focus of this research. The primary goal was to develop the individual sections of the dashboard first, as there was no existing framework upon which to build. Similarly, suggestions for additional KPIs were constrained by the limitations of the available data, making it challenging to implement all the recommendations.

The validation process also faced challenges. While students provided valuable insights from a novice user's perspective, their lack of expertise in warehousing limited the depth of their feedback. The company representative offered expert insights, but the reliance on a single expert left room for biases and potential oversights. Future dashboard development should address these limitations by incorporating a broader range of expert feedback and ensuring a more complete data set to enhance the dashboard's overall utility.

7.5. Recommendations

These recommendations aim to improve the functionality and applicability of the current BI product for warehouse operations:

- Address its current shortcomings to further develop the existing data model. This includes splitting activity data into more granular stages (e.g., separating receiving and put-away for inbound activities), incorporating non-storage locations into the data set, restoring error data, and filling in currently empty columns. These improvements will support a broader range of KPIs and prepare the infrastructure for future customers who might collect additional data.
- Integrate the feedback from the validation process after enhancing the data model. This step will ensure that the dashboard fills in the gaps of its current shortcomings identified by the students and the company representative.
- Merge the three different sections (Revenue, Dynamic, Static) into a unified dashboard that provides an overarching view of critical KPIs, with alerts for any metrics falling below threshold levels. A centralized dashboard will offer a holistic view, allowing for better decision-making.
- Conduct validation with actual customers who will use the dashboard. Feedback from real end-users will provide practical insights into the dashboard's effectiveness and usability in real-world scenarios, helping refine the tool to meet industry standards and customer expectations better.
- Establish a process for feedback implementation cycles so that the dashboard can be continually improved and adapted to varying customer needs.
- Develop training and support materials for users, ensuring that new users can quickly learn how to use the dashboard correctly and maximize its utility.

Bibliography

During the preparation of this work, I used Grammarly Pro to enhance sentence structure, check spelling, and reword phrases for clarity. Additionally, I used ChatGPT for sentence restructuring and improving coherence. After using these tools/services, I thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome.

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Appendix A: Validation Questions

Name					
Position					
Date					
Likert Scale	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The dashboard's design appears user-friendly for people with different levels of technical expertise.					
The dashboard offers functionalities that are crucial for efficient warehouse management.					
The layout and data presentation of the KPIs effectively communicate the critical metrics of warehouse operations.					
The KPIs displayed on the dashboard accurately reflect key aspects of warehouse operations.					
The information provided by the dashboard is likely to be useful to decision-making processes.					
The instructions and help features provided within the dashboard make it easy to understand how to use all of its functionalities.					
Open-Ended Questions					
In your view, what features of the dashboard are most beneficial for warehouse management?					
Are there areas where you think the dashboard's representation of KPIs could be improved? Please elaborate.					
Do you have any suggestions for additional data or features that could enhance the ease of use of the dashboard?					

Appendix B: Mockups