STREAMLINING MANUFACTURING PROCESS WITH TABLEAU: A DATA VISUALIZATION APPROACH

project for Robert Bosch Automotive Technologies Thailand Co., Ltd.

BY

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A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING IN ROBOTICS AND AI

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

ACADEMIC YEAR 2022

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ABSTRACT

This project undergoes the implementation of data visualization for the manufacturing operation through multiple tools such as Tableau, and Azure Databricks. The process consists of five main steps: gathering requirements, data preparation, design & iteration implementation, and monitoring and evaluating the result. Shopfloor management KPIs are calculated, and the traceability concept is also introduced. Key findings revolve around the impact of dashboard loading time, Clear requirements through workshops, simplified dashboard designs, enhanced user experience through training, and the importance of feedback. Cost savings are calculated to be 213k THB annually.

Keywords: manufacturing, data visualization, data streamlining, assembly, molding, traceability

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Poom Konghuayrob for guiding me and allowing me to continue my work here at Robert Bosch Automotive.

I would also like to give my deepest thanks to Mr. Bartosch Spitza, who has given me tremendous knowledge and experience.

Thanks to the engineering team who have always helped me with difficult tasks and made this project possible.

Finally, I would like to thank my mom, my dad, and Panadda Luckananukul for always being supportive no matter the circumstances. Thank you, truly.

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Chapter 1 : Introduction

1.1 Background and Context

1.1.1 Industrial 4.0

The 4^{th} Industrial revolution, a term used in every industry, mostly manufacturing. It is when a huge change in the system where technologies such as the Internet of things, along with big data, play a pivotal role in the manufacturing processes, forever changing the system to suit the new world. Many manufacturers are trying to implement technologies to increase their productivity, produced parts, and reduce the gap between the physical and digital world.

Data visualization played a main role in the revolution. By taking advantage of the big data concept and data analytics tools, highly impactful data can be critical to the any company nowadays. Thus, everyone is trying to implement data driven tools and solutions to build their competitive edge over the competition in the market.

1.1.2 Manufacturing KPI

Manufacturing Management usually has key performance indicators, to measure the score of their machine breakdowns, the operator's productivity, or find the improvement areas to increase yield and prevent possible damage to their line.

Some of the main manufacturing KPI are overall equipment efficiency (OEE), quality loss, and utilization. This data is extremely useful in the manufacturing process. To create these KPIs, one must have the connection to the source of the data. Machine data are usually sent to the database if one is able to bring those data to generate useful insights.

Cloud database in Robert Bosch Automotive Technologies provides raw data that came directly from the machine in real time. Data visualization process can bring that data to life.

1.1.3 Data Visualization

Data visualization is one of the crucial processes in data science. It is a practice of displaying or sharing useful data and insights in a manner that viewers can interpret it and make data driven decisions effectively.

Data visualization for manufacturing processes requires lot of lot resources to streamline data into dashboards for engineers and management. In Robert Bosch Hemaraj, many resources are ready at disposal, waiting for a data visualization expert to take a serious look at the data and make something great both for the people and for the future I4.0 role of the company.

1.1.4 Tableau

Tableau is a powerful data visualization program. It allows users to create dashboards easily with the easy-to-use design. It can connect to multiple data sources at the same time. It supports real time data connection. It allows data manipulation at a high level. While the software is intuitive for users, it is quite difficult to master.

Tableau software is the perfect solution for data visualization of structured big data such as Robert Bosch Hemaraj manufacturing process. Most machines data are stored in a cloud database, a connection between tableau and the cloud can be established, with some knowledge about SQL.

Tableau Server hosts all the dashboards published by the developers. Anyone inside the company can request access and view the dashboard's action anywhere in the world with secured connections.

1.1.5 SQL

Structured Query Language or SQL is a database language to allow requests to get database to get useful data. Tableau and Databricks allows for custom SQL creation to extract and transform the data.

1.1.6 Microsoft Azure Databricks

Cloud service provided by Microsoft Azure. Mainly used for machine learning and data science topics. Robert Bosch Hemaraj has recently moved from on premises database to Azure cloud recently.

1.1.7 Robert Bosch

Robert Bosch is a multi-national engineering company founded in Germany by Robert Bosch himself. The company business can be categorized into 4 main sectors.

1. Mobility Solutions
2. Industrial Technology
3. Consumer Goods
4. Energy and Building Technology

Robert Bosch Automotive Technologies Thailand Co., Ltd. is in the Mobility Solutions sector. The plant produced connectors and fuel ejector valves for tier one companies.

Robert Bosch connectors manufacturing line are separated into two operations: Molding and Assembly. The process starts by running the plastic granulate through the pipes into molding injectors, where high temperatures melt the granulate into liquid state and then shoot out into a mold. Thus, creating the main plastic part for the connector. Next, the part is stored inside the supermarket until it is taken out to the assembling machine, where both in-house parts and supplier parts are assembled to create a finished product.

Robert Bosch has a time plan to introduce i4.0 technologies to the plant. Data visualization in Tableau is one of the main topics.

This project this entirely develop under the direct resources of Robert Bosch Automotive Technologies Thailand Co., Ltd., specifically, for the Hemaraj plant. This Data visualization will take advantage of the manufacturing data from the connectors' manufacturing process. It lies on the implementation timeline of the company's Industrial 4.0 projects.

1.1.8 Traceability

Traceability is the ability to trace back to the origin of the object which in this case finished good. It is a very important and useful concept for the manufacturing industry. It helps maintain the quality of the product by focusing on what cause the defect in the parts and eliminate unrelated possible cause.

Data Visualization yet again, is an important subject for traceability. The ways to show traceability as an interactive view are based on the concept that has been set up. The traceability solutions are now being implemented inside Robert Bosch Hemaraj. The main database for collecting batch ID has not been set up yet. However, it is possible to develop traceability dashboards with mock data first, to ensure minimum challenges that might occur while implementing, the dashboards will be developed in this project as well.

1.2 Problem Statement

The problem statement for this research project is based around the limitations of existing data visualization solutions in the manufacturing industry. The main problem lies in the inability of traditional reports and spreadsheets to provide real-time and comprehensive insights into the manufacturing process. These traditional methods are often fragmented, lack interactivity, and fail to present the data in a visually intuitive manner.[1]

Construction industry research has identified that problems in various domains, including people, organization, and process, contribute to inefficiencies. Similar challenges can be observed in the manufacturing sector, where complexities and the unique nature of the manufacturing process give rise to a range of issues. Streamlining the manufacturing process requires addressing these problems and improving decision-making through better data visualization tools.[2]

In summary, the problem statement in this thesis revolves around the lack of effective data visualization solutions in the manufacturing sector. The goal is to develop a comprehensive data visualization system using Tableau, SQL, and Azure Databricks to provide real-time insights and improve decision-making in the manufacturing process.[4]

1.3 Objectives

The objective for this project is to find an effective way to implement data visualization for manufacturing operations. This project will result in key findings of data visualization process. The main benefits targeted are to improve the manufacturing process, reduce operators' manual tasks, and increase cost savings.

Chapter 2 : Literature Review

Data visualization, especially in the manufacturing sector, is a rapidly developing field, grounded by advancements in technology and the increasing availability of large datasets. Implementing data visualization effectively, however, requires careful planning, the right selection of visualization tools and methods, a clear goal, and a thorough understanding of the intended audience [8].

An essential step in implementing data visualization is data cleaning, which involves detecting and removing inaccurate records from a dataset. The quality of data influences the reliability of the visualizations. Any inaccuracies in the data can lead to misleading visuals, potentially resulting in false interpretations and decisions. Consequently, data cleaning is a crucial prerequisite to effective data visualization [8].

Once the data has been cleaned, the next step is data exploration. This involves an initial process of understanding the data through summaries and visual methods. The insights derived from this stage inform the next steps, including the choice of data visualization method [8].

Choosing the right format to visualize the findings is important. The decision is made based on the type of data, target audience, and message to be conveyed. Among other forms of visualization, there are tables, charts, graphs, maps, and timelines. Visualization formats include tables, charts, graphs, maps, and timelines, among others. The selection should simplify complex datasets and make them easier to understand [7].

Finally, finding a suitable medium or platform for presenting the visualization is crucial. The platform should support the selected visualization format and be accessible to the intended audience. Depending on the context, this might be a web page, a printed report, a mobile app, or an interactive display [8].

In the context of manufacturing and Industry 4.0, implementing effective data visualization can greatly improves the monitoring and control of production systems. By tracking and visualizing production system health data, decision-makers can better understand the system's performance, identify areas of concern, and make informed decisions to improve overall equipment effectiveness [6].

In conclusion, effectively implementing data visualization in manufacturing involves a series of steps, from data cleaning and exploration to the selection of appropriate visualization methods, and the choice of a suitable medium. This process, while complex, is a powerful means of leveraging data for better decision-making and greater operational efficiency.

Chapter 3 : Methodology

3.1 Gather Requirements

3.1.1 Assembly Dashboards

Weekly Meetings with my manager and supervisor and Assembly line Manager where we discuss the requirements, the problems, and the feedback. Everything is listed on an open-point topic table.

Table 1: Assembly line Tableau tasks

Assembly line Tableau OPL				
Index	**Details**	**Start Date**	**Status**	**Remark**
1	check the source for scrap rate	16-02-23	Done	Scrap rate = (Count Scrap/(Count Scrap + Count IO)) * 100
2	Losses only 1 digit after the decimal	16-02-23	Done	
3	Clean date wording	16-02-23	Done	
4	The set bar chart the in the same line (RT losses)	16-02-23	Done	
5	Quality loss from as-quote (yellow color bar)	16-02-23	Done	
6	Quality loss error message corrected (failure category) ERR01	16-02-23	Done	Technical Engineer responsible
7	Check errors for all worksheets	16-02-23	Done	RT Quality Detail
8	Access right to All Managers	16-02-23	Done	Dashboards uploaded to the web
9	Supervisor Compare output data with the MES shift book	16-02-23	Done	1st meeting done
10	Bar chart group by days, weeks, months	22-02-23	Done	set meeting with IT colleague

11	Supervisor checks the reason for 26P high scrap rate(Project needed?)	22-02-23	Done	Not relevant to Tableau
12	196P scrap rate of more than 1%	22-02-23	Done	Not relevant to Tableau
13	Y axis adjusts automatically	22-02-23	Done	
14	Optical improvement	22-02-23	Done	
15	Heatmap color - Customized with Assembly Manager	29-02-23	Done	fix ERR01 first
16	MSC2 Qualitat Worksheet missing SAP db	10-03-23	Done	Need connection to Redlake
17	Hint from IT Colleague	24-03-23	Done	Transfer to a new environment
18	Testing of Tableau by user	24-03-23	Done	2 weeks testing
19	Settings for opening page (1 month) for faster loading	24-03-23	Done	
20	Supervisor feedback (Assembly Overview)	26-03-23	Done	-Improve loading -remove the machine filter -start date, end date filter - remthe ove period filter -OEE 2 decimals point -OEE shows every rt, remove time -OEE % two decimals
21	Supervisor feedback (1st meeting)	26-03-23	Done	- improve filters - OEE Quality 2 decimal - add NOK pcs for quality-loss - Change OEE calculation - Check date range (start from 8.00 am to 8.00 am) -create a graph from MES (Pareto Losses) -Value not match MES(FC01: failure in manu)

				-Average Percent -Value does not match MES (RT Loss Detail) -change title
22	Assembly Management Feedback	03-04-23	Done	dashboard
23	Change database query following IT Colleague guideline	10-04-23	Done	

The explanation for each task:

1. Check the source for scrap rate:

    Calculate scrap rate using the formula: Scrap rate = (Count Scrap / (Count Scrap + Count IO)) * 100.

2. Losses only 1 digit after decimal:

    Format the numbers representing losses to display only one digit after the decimal point.

3. Clean date wording:

    Ensure that the date labels and descriptions used in the visualizations are clear and easy to understand.

4. Set bar chart in the same line (RT losses):

    Arrange the bar chart representing losses in a way that they are displayed on the same line for easier comparison.

5. Quality loss from as-quote (yellow color bar):

Highlight quality losses from as-quote data by using a distinct yellow color for the corresponding bar in the chart.

6. Quality loss error message corrected (failure category) ERR01:

   Rectify the error message related to quality loss in the failure category ERR01. Assign the responsibility to the Technical Engineer for correction.

7. Check errors for all worksheets (RT Quality Detail):

   Review and identify any errors or inconsistencies present in the RT Quality Detail worksheet.

8. Access right to all managers:

   Grant access rights to all managers to ensure they can view and interact with the dashboards. Upload the dashboards to a web-based platform for easy access.

9. Supervisor compares output data with MES shift book:

   Conduct the first meeting to allow the supervisor to compare the output data from the visualization with the MES shift book.

10. Bar chart group by days, weeks, and months:

    Schedule a meeting with an IT colleague to discuss and implement the grouping of bar charts based on days, weeks, and months.

11. Supervisor checks the reason for a 26P high scrap rate (Project needed?):

    Determine if a specific project is required to investigate and address the high scrap rate of 26P. This task is not directly relevant to Tableau.

12. 196P scrap rate of more than 1%:

Note that the scrap rate for 196P exceeds 1%. This task is not directly relevant to Tableau.

13. Y-axis adjusts automatically:

Ensure that the y-axis of the visualizations adjusts automatically based on the data to provide an appropriate scale.

14. Optical improvement:

Make visual enhancements to improve the overall appearance and clarity of the dashboards.

15. Heatmap color - Customized with Assembly Manager:

Customize the colors used in the heatmap visualization according to the preferences of the Assembly Manager. However, fix the ERR01 issue first.

16. MSC2 Qualitat Worksheet missing SAP db:

Establish a connection to the Redlake system to retrieve the missing SAP database required for the MSC2 Qualitat worksheet.

17. Hint from an IT colleague:

Act on the hint provided by the IT colleague and proceed with transferring the Tableau environment to a new setup as advised.

18. Testing of Tableau by user:

Allocate two weeks for testing Tableau functionality and verifying that all dashboards and visualizations are working as expected.

19.Settings for opening page (1 month) for faster loading:

Optimize the settings for the opening page to ensure faster loading times, specifically targeting a one-month time frame.

20.Supervisor feedback (Assembly Overview):

Incorporate the following improvements based on the supervisor's feedback:

- Improve loading speed.
- Remove the machine filter.
- Add start date and end date filters.
- Remove the period filter.
- Display OEE with two decimal points.
- OEE should be shown for every RT (Real Time) and remove the time component.
- Display the OEE percentage with two decimal points.

21.Supervisor feedback (1st meeting):

Address the following issues based on the supervisor's feedback from the first meeting:

- Enhance the existing filters.
- Display OEE Quality with two decimal points.
- Add the count of NOK (Not OK) pieces for quality loss analysis.
- Review and modify the OEE calculation as necessary.
- Check the date range to start from 8:00 am to 8:00 am.
- Create a graph using MES (Manufacturing Execution System) data for Pareto Losses.
- Investigate and resolve value discrepancies related to MES, specifically for failure category FC01: failure in manufacturing.
- Include the average percentage in relevant visualizations.

- Correct any title discrepancies.

22. Assembly Management Feedback:

    Consider the following feedback provided by Assembly Management:

    - Adjust the date filter functionality.
    - Separate the failure category ERR01 for a more focused analysis.
    - Modify the Assy Overview visualization to display data per RT instead of per day.
    - Investigate and address discrepancies between NOK values and MES records.
    - Consider the impact of filters on all dashboards.

23. Change database query following IT Colleague guidelines:

    Make the necessary changes to the database query based on the guidelines provided by the IT colleague.

3.2.1 Molding Injector Dashboard

The process of creating effective Data Visualization on Tableau, for molding injectors manufacturing line, requires a complete understanding of the operation and the data available. To gather these requirements effectively, a series of workshops are conducted, enabling a comprehensive exploration of needs and possibilities.

The workshops are designed to be a journey, beginning with a foundational understanding of Tableau and its benefits, moving into identifying the key challenges in the manufacturing line, followed by collective problem-solving, and finally, building up to the actual creation of data-driven visualizations using Tableau. The interactive nature of these workshops ensures that the final product is grounded in real-world needs and has been developed with active input from all participants.

A total of 4 Workshops are conducted to gather requirements:

3.1.2.1 Workshop One: Introduction to Tableau Visualization and its Relevance to Manufacturing Decisions

The initial workshop is designed to create a foundational understanding of Tableau Visualization and demonstrate its potential implications for making informed manufacturing decisions. The session begins with an in-depth introduction to Tableau, including a walkthrough of its core features and functionalities. Participants gain an understanding of how the software can handle complex data sets, transform raw data into digestible formats, and create visually compelling and interactive dashboards.

Once participants have been introduced to the capabilities of Tableau, the workshop continues with demonstrations of its application. The facilitators exhibit how the software is used to create various types of data visualizations. They illustrate how these visualizations can highlight patterns, trends, and outliers, and help in data exploration and discovery. Specific examples relevant to the manufacturing industry such as the assembly line dashboards, are selected to demonstrate the software's functionality. This practical demonstration provides a clear vision of the possibilities offered by Tableau.

3.1.2.2 Workshop Two: Identifying Key Problems

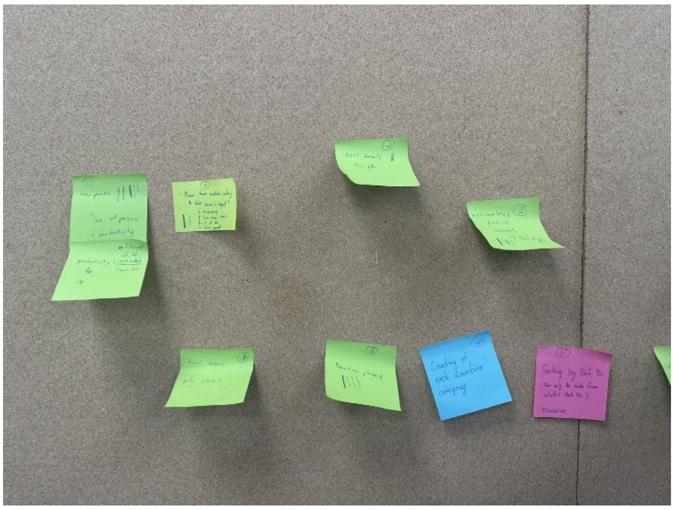

Figure 1 Sticky notes listing problems.

The second workshop focuses on brainstorming and problem identification, crucial elements in the process of requirements gathering. Initially, the workshop facilitator introduces the problem-identification process, setting clear guidelines for the discussion. Participants are then asked to reflect upon their experiences in the manufacturing line and individually list three significant issues on sticky notes. This activity encourages critical thinking and provides a space for participants to voice their concerns.

Each participant is allowed to present their identified problems to the rest of the group. This promotes open communication and facilitates a comprehensive understanding of the various challenges present in the manufacturing line. It also allows participants to learn from each other's experiences and perspectives, thereby creating a collective awareness of the issues at hand.

The workshop concludes with a categorization exercise, where similar problems are grouped. This step helps in the visualization of the scope of the most common issues experienced on the manufacturing floor. It forms the basis for the solution solution-finding the following workshop and ensures that all identified problems are considered when creating the data visualization.

3.1.2.3 Workshop Three: Collective Problem-solving

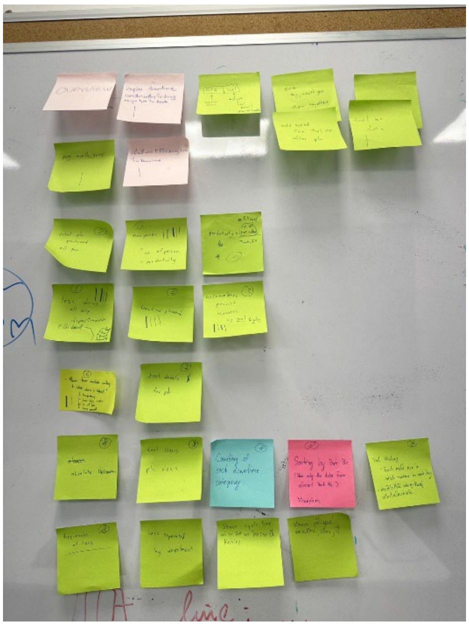

Figure 2 Sticky notes with Solutions

The third workshop leverages the collective intelligence of the participants to find possible solutions for the problems identified in the previous session. The meeting begins with a recap of the issues raised earlier and an overview of the categorized problem areas. This reminder helps to reorient the participants towards the key concerns and help them for the collective problem-solving process.

The main goal of this workshop involves a group discussion aimed at generating potential solutions for each problem category. Participants are encouraged to consider the benefits of different approaches, share best practices, challenge each other's ideas, and draw on their combined expertise and experience. This iterative process allows for a robust exploration of potential solutions and helps to ensure that the resulting proposals are both innovative and practical.

Lastly, the group collectively reviews and ranks the proposed solutions. This is done based on various factors like feasibility, potential impact, and resource requirements. By the end of this workshop, the group will have a prioritized list of solutions that can guide the design of the data visualization tools in the next workshop.

3.1.2.4 Workshop Four: Data-Driven Visualization Creation

The final workshop focuses on translating the gathered insights into data-driven visualizations. It begins with a recap of the prioritized solutions and a discussion on how these can be represented visually using the data available from the manufacturing line's cloud database. The facilitator provides examples of suitable graphs or charts that could be used to represent different types of data and correlations.

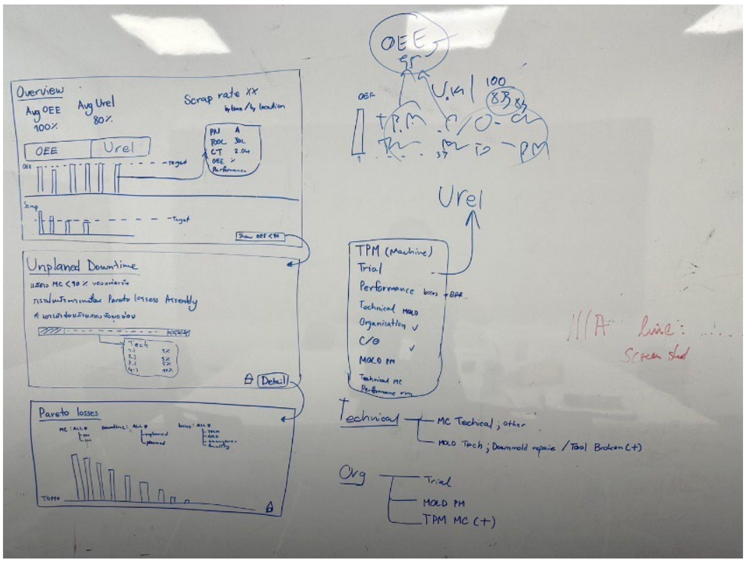

Figure 3 Dashboards drafted on a whiteboard.

The next part of the workshop is highly interactive and hands-on, as participants engage with the Tableau software directly to create prototype visualizations. Participants gain a practical understanding of how data can be manipulated and visualized in Tableau, adding depth to their knowledge from the first workshop. This experience allows participants to experiment with various data visualization techniques and learn how to effectively communicate their identified solutions through these visuals.

In the final segment of this workshop, each group or individual presents their visualization prototype to the rest of the participants. This sharing session is followed by a constructive critique, where participants and facilitators alike provide feedback on the effectiveness, clarity, and utility of the visualizations. This peer review process is vital to ensure the final data visualizations are user-friendly, purposeful, and solution-oriented, providing actionable insights to enhance the efficiency of the molding injectors manufacturing line. Thus, the workshop series finishes with the creation of a set of powerful data visualization tools designed to address the specific needs and challenges identified throughout the process.

3.1.2.5 List of Requirements gathered.

The workshops have resulted in a list of high-priority requirements for the Tableau visualization dashboards, providing a specific and actionable set of targets for the final product. These requirements are presented here in the order of priority:

1. **First Dashboard: Overview**

- This dashboard should provide a high-level overview of the manufacturing process, including average production metrics per day, month, and year.
- A search function to quickly identify the part number (p/n) corresponding to a particular tool number.
- Detailed visualizations for OEE (Overall Equipment Efficiency) and Urel (relative utilization).
- A feature to display and analyze unplanned downtime.
- An efficiency loss indicator, providing insight into lost productivity.

2. **Second Dashboard: Productivity and Total Production**

- Visualization of the total number of parts (p/n) produced by all machines.

- A calculation of productivity that considers the number of personnel involved in the process and the total operating time (time_io). The user should be able to input the number of personnel.

3. **Third Dashboard: Losses and Downtime**

- An interface to display losses divided by responsible departments with a filter-level function for more detailed exploration.

- A feature for visualizing planned downtime.

- Accumulated production visualizations, separated by tool and part number.

4. **Fourth Dashboard: Machine Alarms**

A function to display and analyze alarms from the molding machines, including which alarm occurs most frequently, the time lost due to each alarm (in minutes), the percentage of overall time lost to each alarm, and the amount of scrap associated with each alarm.

5. **Fifth Dashboard: Tool Details**

- Detailed visualizations for each tool, based on part number.
- Different views for tool and part number data for flexible analysis.

6. **Sixth Dashboard: Utilization and Downtime Analysis**

- Visualization of absolute utilization.
- Counting and categorizing each downtime incident.
- Sorting function by part number, displaying data only for selected part numbers.
- A tool history tracker showing which mold has run in each machine and when.
- Frequencies of loss visualizations for a better understanding of common issues.

Each of these requirements contributes to a comprehensive understanding of the manufacturing process and helps to highlight potential areas of improvement. The specified visualizations will offer an in-depth, data-driven perspective on the key aspects of the molding injectors manufacturing line, facilitating better decision-making and increased efficiency.

3.1.3 Traceability Dashboards

Requirements are gathered by studying the main concepts of traceability solutions inside the plant.

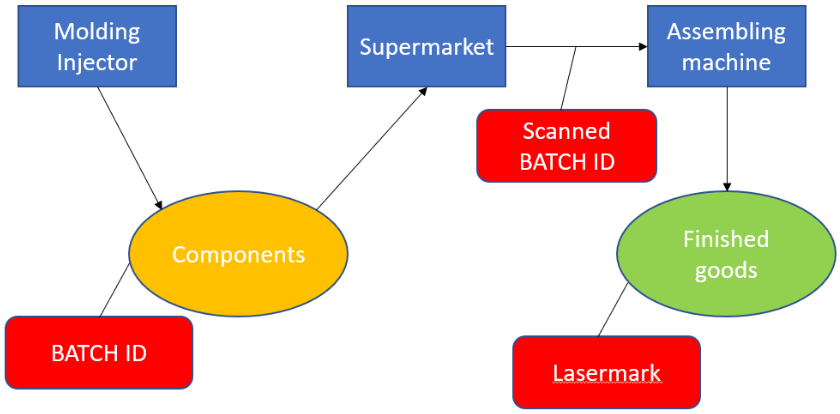

Figure 4 Traceability Concept Diagram

3.1.3.1 Discussing with the Plant's Operators, Managers, and Engineers:

Engaging key personnel was critical to the understanding of the process. Plant operators provided insight into the daily workings of the assembly line, offering perspectives that might not be captured in official documents.

3.1.3.2 Plant Traceability Concept:

This process began with the components produced by molding injectors were given unique batch IDs when they were produced. The details attached to batch ID, such as the component ID, date, and time of production were noted.

During the assembly process, the component labels were scanned before assembly. These labels contained the batch ID and provided a critical data point linking the component to the specific time it was used in the assembly.

Lastly, finished goods were marked with a date and time using a laser, which was essential for the finished product's traceability.

This helped to clearly illustrate the journey of a component from production, through assembly, and finally as part of a finished good. This served as the foundation for the subsequent stages of data collection, preparation, and visualization in Tableau.

3.1.3.3 Customer Complaint

A customer complaint dashboard is needed to trace back with the finished good ID and Laser marked date and time. It is to find the latest possible Batch ID fed into the bunkers before assembling the parts.

3.1.3.4 Internal Complaint

An internal complaint dashboard is used when the quality control department finds defects in the parts and needed to find all the possible defects by using any information that parts should be affected by. A dashboard where large options to filter and show as much data as possible.

3.1.4 International Product Network Dashboards

The requirements of the International Product Network Dashboards for the manufacturing line aim to facilitate a seamless visualization of production data on Tableau. These requirements are derived through active communication with our plant network based in Germany and are adapted to be used across multiple plants globally.

The requirements are as follows:

1. Functional Similarity to Assembly Dashboards

The first version of these dashboards is expected to bear functional similarities to the existing Assembly dashboards. The overall layout, ease of use, and other operational characteristics of the Assembly dashboards will be modeled in the International Product Network Dashboards.

2. Inter-Plant Adaptability

A major requirement is the flexibility and adaptability of the dashboards for use across multiple plants. The dashboards should be designed in such a way that they can accommodate and display data from different plants without any complications or requirements of significant modification.

3. User-Friendly Interface

The dashboards should have a user-friendly interface, making it easy for users to navigate through different sections, understand the information displayed, and interpret the results. It should provide clear, interactive, and visually appealing data visualizations.

3.2 Data Preparation

3.2.1 Extract

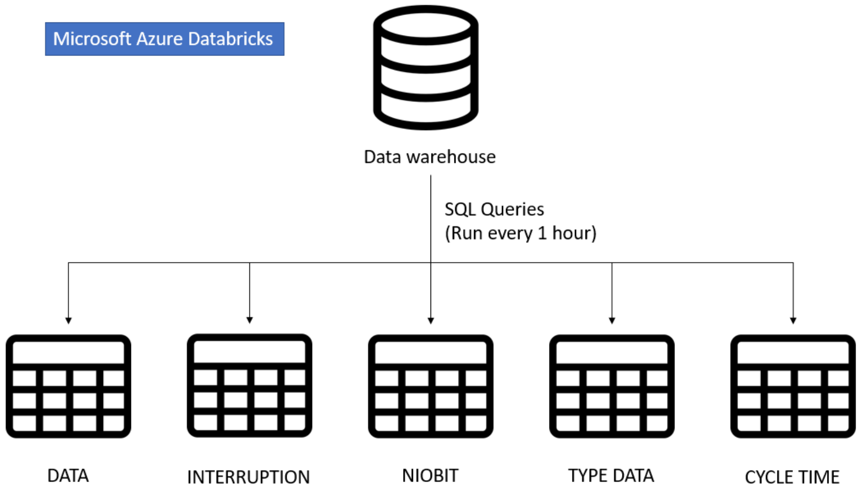

Figure 5 Data Extraction Diagram

The Extract, Transform, Load (ETL) process is critical in the process of data visualization. The 'Extract' stage, which is the focus in this context, is to obtain data from data sources. The data sources are the data warehouses that have already been established by the IT department. Microsoft Azure Databricks, a cloud-based analytics platform, is utilized to access and interact with these data warehouses.

The SQL queries have been developed to filter and pull out data that is specifically relevant to the company's Thailand and Germany plants.

Once the relevant data has been extracted, it is used to generate new tables, further refining and organizing the information for subsequent use. The extracted data is continuously updated. The SQL queries are programmed to run every hour. This scheduling ensures the most up-to-date data is extracted from the databases and made available for transformation and loading as quickly as possible.

In total, there are 11 distinct queries and tables extracted:

1. **Assembly data**

This query is designed to extract crucial data about the assembly machines. It includes information like Shift ID, date, Assembly machine ID, Count ok, Count nok, Target count ok for OEE 100%, Time ok, and Time nok

2. **Assembly interruption**

This query collects data about the periods when assembly machines are not operational or have interruptions. These interruptions are categorized into four categories: Technical, Changeover, Organization, and Quality. Each category offers different insights into the reasons for machine downtime.

3. **Assembly niobit**

This query is designed to log error data from the assembly machines. Errors are categorized according to their station number, providing a detailed understanding of where problems most frequently occur.

4. **Assembly type_data**

This query deals with part number data. It records the various part numbers that are being produced, providing a granular understanding of the assembly process's output.

5. **Molding data**

This query mirrors the Assembly data query but for the molding machines. It extracts similar machine performance data to provide insights into the molding process.

6. Molding interruption

This query is the counterpart to the Assembly Interruption query for the molding machines. It extracts information about the downtime and interruptions experienced by the molding machines, classified into similar categories.

7. Molding-type data

The Molding type data query is analogous to the Assembly type data query, collecting information on the part number data produced by the molding machines.

8. IPN assembly data

This query is similar to the Assembly Data query, but its focus is narrowed to the Thailand and German plants. It provides a regional perspective on machine data.

9. IPN assembly interruption

The IPN Assembly Interruption query collects data on the interruptions experienced by the IPN assembly machines in the Thailand and Germany plants.

10.IPN assembly niobit

The IPN Assembly niobit query extracts error data from the IPN assembly machines in the Thailand and Germany plants, providing a focused understanding of the issues specific to these regions.

11.IPN assembly-type data

This query records the type of parts produced by the IPN assembly machines in the Thailand and Germany plants.

3.2.2 Transform

In this context, we focus primarily on the 'Transform' part of the process. The transformation phase is critical in turning raw data into more meaningful information that can be readily used for further analysis and data visualization.

3.2.2.1 Data Type Conversion

Certain columns of data, such as 'shift id', which were initially extracted as integer (int) data types, were converted into strings. A 'shift id', though numerically represented, doesn't hold any quantitative value but rather serves as a categorical identifier. Treating it as a string simplifies its understanding and prevents its unintended use in quantitative calculations.

3.2.2.2 Implementation of Aliases

Our methodology also includes creating aliases for certain data columns, specifically for machine id, shift id, and unplanned/planned downtime id. Aliasing is a technique in database management, where alternative names are assigned to the columns or data sets in a query. This approach makes the data more intuitive and easier to work with, particularly for non-technical users. This transformation step ensures that our data remains accessible and readable, fostering more effective data analysis.

3.2.2.3 Data Aggregation

We aggregated data such as the time target for each day to provide a summarized, high-level view of the data. By presenting data in this summarized format, we are better able to spot trends, patterns, or anomalies. It also simplifies complex data, making computations quicker and more efficient. This practice underscores our efforts to streamline data analysis by reducing data complexity.

3.2.2.4 Alias for Machine Error Codes

Machine error codes can be complex and hard to interpret without cross-referencing. By creating aliases for these error codes, we've made the error identification process significantly easier. A complex code such as 'ERR12345' could be aliased as 'Motor Failure', making it immediately understandable. By using aliases, we are ensuring a quicker, more intuitive understanding of machine errors, facilitating faster problem-solving and troubleshooting.

3.2.2.5 OEE Calculation

The Formula for OEE Calculation is as follows:

$$OEE\ \% = \frac{OK\ PARTS \times Cycle\ time}{Shift\ time - Planned\ breaks - Planned\ stoppages} \times 100\ \%$$

This calculation already considered the Quality (OK Parts) and the machine's performance is 100%.

The data warehouse already has aggregated the calculation for both the numerator and denominator as follows:

$$TIME\ OK = (OK\ PARTS \times Cycle\ time)$$

And

$$TIME\ Target\ OEE\ 100\% \\ = Shift\ time - Planned\ breaks - Planned\ stoppages$$

Which gives,

$$OEE\% = \frac{TIME\ OK}{TIME\ TARGET\ OEE\ 100\%}$$

3.2.2.6 OEE Target

OEE Target is calculated differently for each machine based on the performance of that machine. Most machines have an OEE target of at least 85%

$$OEE\ Target\ \% = \frac{TIME\ TARGET\ of\ machine}{TIME\ TARGET\ OEE}$$

3.2.2.7 Downtime Percentage

This calculation is quite important for measuring a machine's downtime. Downtime data comes in as a time measure, which can be difficult to interpret. So, converting the downtime as a percentage is as follows,

$$DOWNTIME\% = \frac{DOWNTIME}{DAILY\ TIME\ TARGET\ OEE\ 100\%}$$

This calculation is the benefit of aggregation for daily time targets

3.2.2.8 Efficiency Loss%

Efficiency Loss is the unexplained losses calculated as follows,

$$Efficiency\ loss\% = 1 - (OEE\% + DOWNTIME\% + Quality\ Loss\%)$$

3.2.2.9 Quality Loss%

Quality Loss is calculated as follows,

$$Quality\ Loss\% = \frac{PART\ NOK}{PART\ NOK + PART\ OK}$$

3.2.2.10 Relative Utilization

Relative Utilization is the calculation by including the planned downtimes in the OEE formula.

$$Relative\ Utilization = \frac{PART\ OK \times Cycle\ time}{Shift\ time - planned\ breaks}$$

3.2.3 Load

After undergoing the transformation process, the result data is loaded into the Tableau worksheet tab. Tableau is a powerful tool that allows users to create interactive, dynamic visualizations and dashboards from the data. Loading the data into Tableau ensures that it's available for the next stage of our methodology - designing, filtering, and creating graphs and dashboards.

3.2.4 Synthetic data

As of now, data for traceability dashboards are not yet set up in the database, synthetic data are created in an Excel file separated into two sheets.

3.2.4.1 Molding Traceability

- Component’s number

  The ID of components that are used for assembly.
- Tool number

  The tool’s ID is used in the molding machine.
- Time mold

  The time recorded after a box of components is produced from the molding machine.
- Molding machine

  The molding injector machine ID
- Component’s name

  The component name in the text
- Injection parameter

  The machine’s configuration is used to produce the component.

3.2.4.2 Assembly Traceability

- Bunker name

  Bunker name for feeding components into the Assembly Machine data.
- Time Scanned Bunker

  The time recorded before components are fed into the bunkers.

- Assembly mc

  The Assembly machine ID

- Finished good number.

  The ID of the finished good that is being assembled.

- Component's number

  The ID of components that are used for assembly.

- Batch ID

  The most crucial part of the traceability concept the is batch id for each box of components.

3.3 Design & Iterate via Tableau

3.3.1 Assembly Dashboards

1. Format numerical losses

   Right-click on the "Losses" field in your data source and select 'Default Properties' > 'Number Format'. Choose 'Number (Custom)' and set Decimal places to 1.

2. Clear date wording

   Make sure that the date labels are user-friendly by choosing an easy-to-understand format. You can adjust this by right-clicking on the date field, selecting 'Default Properties', then 'Date Format', and setting it to a readable format such as "March 2023".

3. Align the bar chart

   To set all bar charts in the same line, drag and drop your 'Losses' field into the Columns shelf, and your categorical variable (e.g. 'Product Type') into the Rows shelf.

4. Quality loss color highlight

   In the 'Color' shelf on the Marks card, click on the color legend and assign the color yellow to the quality loss category.

5. Bar chart group by time

   Right-click on the date field and select 'Create' > 'Custom Date'. In the dialogue box, choose the desired part (day, month, year) for grouping.

6. Y-axis adjustment

   Tableau adjusts the y-axis automatically based on the data you're visualizing. Make sure the 'Fixed' option is not selected in the 'Edit Axis' dialogue box.

7. Optical improvement

   Apply visual enhancements like color coding, adjusting transparency, gridlines, labels, and annotations. This is accessible in the 'Marks card' and 'Format' menus.

8. Customize heatmap colors.

   Click on 'Color' on the 'Marks card' and select 'Edit Colors'. Choose the desired color palette based on the Assembly Manager's preference.

9. Faster loading settings

   To ensure faster loading, limit the amount of data loaded by setting a date range filter for the last month in your dataset.

10.Supervisor feedback integration (1^{st} Meeting)

Update the Assembly Overview Dashboard based on the provided feedback. This involves updating filters, formatting numbers, and adjusting display settings. It can be done by using the 'Filters', 'Format', and 'Marks' cards, respectively.

11.Supervisor feedback integration (2^{nd} meeting)

Adjust the dashboards based on the supervisor's feedback. This will require updating filters, creating new visualizations, and correcting discrepancies using Tableau's respective functions (filters, marks, and data source).

12.Assembly Management feedback integration

Amend the dashboards to align with the Assembly Management's feedback. This involves modifying filters, changing visualizations, and resolving discrepancies.

3.3.2 Molding Dashboards

3.3.2.1 First Dashboard: Molding Table Overview

- Create visualizations for daily meetings where a large amount of data can be seen in one view.
- Create a search function using a quick filter on the tool number and corresponding part number fields.
- Create percentage-based data for unplanned downtime.
- Use a red indicator or similar visual cue for OEE NOK rating and NOK scrap.

3.3.2.2 Second Dashboard: Molding Matrix Overview

- Visualize the OEE separated by days for all machines using a table.
- Create a parameter to change between OEE and Urel

3.3.2.3 Third Dashboard: Losses and Downtime

- Visualize unplanned downtime, with bar charts separated by machine number.
- Display accumulated production visualizations, separated by tool and part number, using stacked bar charts or similar.

3.3.2.4 Fourth Dashboard: Molding Overview

- Visualize OEE and Urel from the molding machines using a bar chart and line chart
- Display the OEE rating in green and red color
- Display the OEE target for all machines OEE Target = 90%

3.3.2.5 Fifth Dashboard: Pareto Losses

- Create detailed visualizations for each downtime based on the downtime categories
- Allow for different views of the machine, planned / unplanned downtimes, interruption categories, and OEE / Urel view by using filters for flexible analysis.

3.3.3 Traceability Dashboards

3.3.3.1 Customer Complaint Dashboard

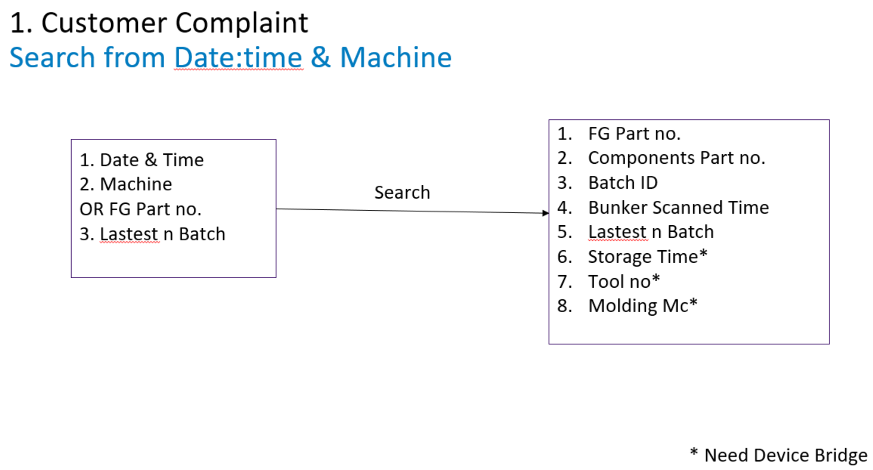

Figure 6 Customer Complaint Dashboard Concept

The primary purpose of the Customer Complaint Dashboard is to present a comprehensive view of customer feedback. Users can interact with this dashboard to find specifics and draw insights from the underlying data.

The dashboard is designed as a table view that displays all relevant data in an easy-to-read format. Furthermore, it includes four filters to help users fine-tune their data view.

1. Date Filter:

    This filter allows users to view data from specific periods. By inputting a range of dates, they can inspect the customer complaints made during that time.

2. Finished Good Part Number:

This filter facilitates searches based on the finished product's ID. It is useful for identifying customer complaints associated with a particular product.

3. Assembly Machine Name:

   This filter enables users to isolate data related to a specific assembly machine.

4. Latest N Batches:

   This filter is designed to provide quick access to the most recent batches. Users can specify the number of recent batches they wish to view, thereby ensuring the information is always up to date.

The goal of the Customer Complaint Dashboard is to allow users to input the latest possible batch ID fed into the bunker. This feature ensures that the information displayed is always the most current and relevant, thereby increasing the dashboard's effectiveness as a decision-making tool.

The design of the Customer Complaint Dashboard will undergo several iterations based on user feedback and additional requirements. This ensures that the dashboard remains flexible and can evolve alongside the manufacturing process it supports.

3.3.3.2 Internal Complaint Dashboard

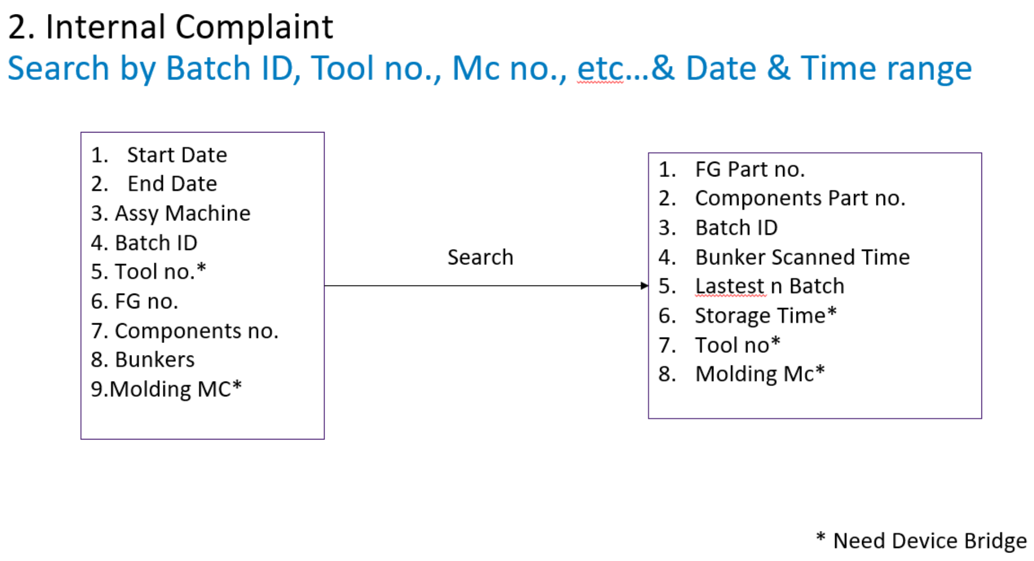

Figure 7 Internal Complaint Dashboard Concept

The Internal Complaint Dashboard was a particularly challenging task. The objective was to showcase as much data as possible while maintaining usability and readability, the solution was to incorporate a range of filters.

The dashboard was organized in a table format with individual columns corresponding to Molding, Component's number, Tool number, Time mold, Molding machine, Component's name, and Injection parameter. However, to enable users to find the root causes of defects, filters were added that could isolate the impacts of different tools or machines on the overall process.

For instance, if a user wants to explore the impacts of a particular tool, they can use the tool number filter. Similarly, to track the performance of a specific molding machine, the molding machine filter can be utilized. These filters were designed to be as inclusive as possible to support broad and specific investigations into defect causation.

Further, the dashboard was also equipped with an option to identify batches that might be impacted due to certain tools or machines. This can be particularly useful in preventive measures and improving the quality control process.

3.3.4 International Product Network Dashboards

Not much modification for most data is from Assembly Dashboards. Except for the following points

3.3.4.1 Shift ID

In Thai plants, there are two 12-hour shifts. While the German plant has three 6 hours shifts. After discussing with the German colleague, we decided to remove the shifts filter completely. So, all shifts are now combined into 1 day.

3.3.4.2 Landing Page

A landing page is required for more professionalism and an intuitive interface. The page consists of filters for plant names, date ranges, and product codes. There are also navigation buttons leading to all dashboards developed.

3.4 Implementation

3.4.1 Time plan

During the project's 4 months at Robert Bosch Hemaraj, only Tableau Molding and IPN dashboards were implemented. While Assembly Dashboards were implemented in 2022 in my cooperative education subject, and Traceability Dashboards will be implemented around the end of the year 2023.

Table 2 Tableau Molding Implementation Timeline

Tableau Molding Implementation	Feb-23	Mar-23	Apr-23	May-23	Jun-23
Gather Requirements					
Data Preparation					
Design Dashboards					
Implementation					
Monitor and Evaluate					

Table 3 Tableau IPN Implementation Timeline

Tableau IPN Implementation	Apr-23	May-23
Gather Requirements		
Data Preparation		
Design Dashboards		
Implementation		

3.4.1 Training Session

A Tableau Molding training session was held before the full implementation of the dashboards. The session required engineers, management, and plant operators to join and train. A 2-hour long training included.

3.4.1.1 Introduction to Tableau

Introduces the usage of Tableau with the Manufacturing process, how it can help with decision-making and time-saving

3.4.1.2 How to use Dashboards.

Training on how to access Tableau Server, the purpose of every dashboard created, and how each filter interacts with the graphs. Also, how one can share the graphs with others via exporting as CSV, pdf, and image files.

3.4.1.3 Exercise

A total of 10 exercises are given to participants to show the ability to use the dashboards to find insights. The given exercises are thought out to cover all the techniques required to get manufacturing insights.

3.4.1.4 Feedback session

Questions and feedback are welcomed at the end of the session, where I can improve my training skills and improve the dashboard's functionality and aesthetics.

3.5 Monitor and Evaluate

After the full implementation of the dashboards, begins the last phase of data visualization. It is to monitor and evaluate the performance of the dashboards by qualitative and quantitative measuring.

3.5.1 Feedback session

Weekly meetings are set up to talk with the users about the dashboards. Questionnaires are created to get specific answers. Questions are listed below.

1. How frequently do you use Tableau dashboards for your work?

2. How easy or difficult is it for you to access and navigate the Tableau dashboards?
3. How well do the dashboards present information in a way that is easy for you to understand?
4. How useful are the filter options in helping you find the information you need?
5. How easy or difficult is it for you to export and share data from the dashboards?
6. Are the dashboards visually appealing and easy to read?
7. Have the dashboards helped you make better decisions in your work?
8. How would you rate the training provided for using the dashboards?
9. Please provide any suggestions for improvements or additional features you would like to see in the dashboards.
10. Any other comments or feedback about the dashboards or the training session?

3.5.2 Cost savings

To calculate the savings for this project, we must identify the time reduction for daily meetings, monthly meetings, problem-solving, root cause finding, and the underlying potential for future machines and products. There has already been recorded data that shared a similar cost savings which we will talk about in chapter 4.

Chapter 4 : Results/ Findings

4.1 Key Findings

4.1.1 Improved Dashboard Loading Time

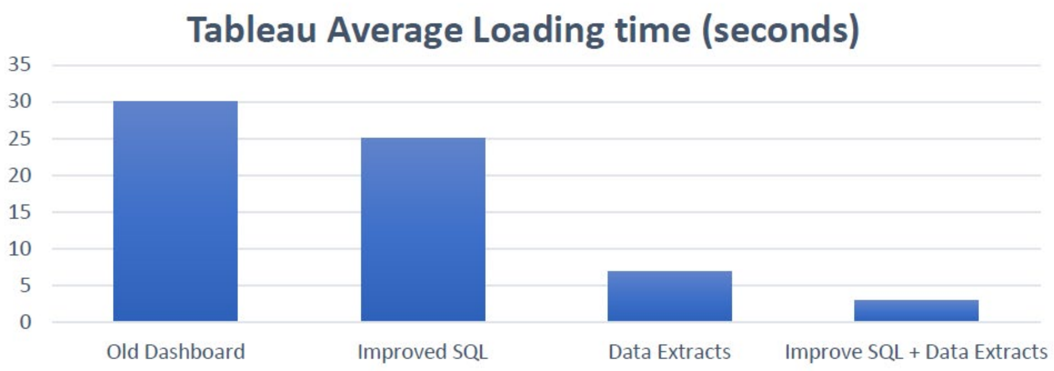

Figure 8 Tableau average loading time

A measure of success for the data visualization solution was the performance of the dashboards, particularly the loading times. Before optimization, slower loading times were a significant challenge, impacting the user experience and overall effectiveness of the dashboards. Through the optimization of SQL queries and the implementation of data extracts, a considerable improvement was achieved. The dashboards loaded faster (from 30 seconds to 2 seconds), providing users with quicker access to information. This enhancement not only improved user experience but also improves decision-making processes.

4.1.2 Clear Requirements through Workshops

The workshops conducted with stakeholders played a crucial role in defining the requirements and understanding the specific needs of the organization. The diverse representation of participants in these workshops, from operators to managers, provided a lot of information. The requirements gathered from these workshops were clear, precise, and closely aligned with the organization's strategic objectives. This ensured that the dashboards were designed to provide the most relevant and actionable insights to the appropriate users.

4.1.3 Simplified Dashboard Designs

The study found that simple dashboard designs with fewer customizable filters were more effective and user-friendly than complicated designs with multiple filters. The simplified designs focused on presenting the most important data and insights, thereby enabling users to quickly understand the information and make informed decisions. This led to an increase in user adoption and utilization of the dashboards, enhancing the overall decision-making process in the organization.

4.1.4 Enhanced User Experience through Training

The provision of manuals and training sessions significantly improved the user experience with the dashboards. Users reported a better understanding of the functionalities and how to interpret the data presented on the dashboards. The training sessions, with comprehensive manuals, allows users to fully utilize the dashboards, leading to increased usage and a deeper appreciation of the value of data in decision-making processes.

4.1.5 Importance of Feedback

The continuous process of incorporating feedback into the dashboards' development and improvement was another key finding of the study. Feedback from users played a crucial role in refining the dashboards and making them more relevant and user centric. This iterative process of improvement ensured that the dashboards remained effective and continued to deliver valuable insights over time.

4.2 Cost Savings

4.2.1 Improvement Projects

Improvement projects can be found faster and used for data analysis during the improvement process. Total savings of at least 150k THB annually depend on the impact of the downtime causes.

4.2.2 Total Productive Maintenance Improvements

Reduced TPM by 135 minutes per month, increasing production of 52k pcs more per year. 540 minutes of half a setter and POV reduced. Estimated savings of 25k THB annually.

4.2.3 Organizational findings

Increase findings of organizational improvement topics. Estimated savings for a finding: 18k – 38k THB.

Chapter 5 : Conclusion

5.1 Key findings with literature review.

Based on the key findings and the literature review on data visualization, several important points stand out that provide insight into the effective application of data visualization tools and methods in the field.

Firstly, the literature review emphasized the importance of data cleaning as an essential step for effective data visualization [8]. The key findings supported this, as the optimized SQL queries and implementation of data extracts, which improved the loading times of the dashboards, could be considered a part of this cleaning process.

The literature also highlighted the significance of choosing the right visualization methods [7]. The key findings are closely related, showing that simplified dashboard designs and clarity of requirements, gathered through workshops, were more effective and user-friendly. The simplicity and clarity of the data presentation led to an increase in user adoption and the overall effectiveness of the decision-making process.

The literature underlined the necessity of a platform for data visualization, accessible to the intended audience [8]. This is consistent with the key findings, which demonstrated that comprehensive manuals and training sessions significantly improved the user experience. Providing users with tools to understand the functionalities of the dashboards led to increased usage and an enhanced appreciation of data visualization's value in decision-making processes.

Finally, both the literature review and key findings highlighted the importance of continual improvement in data visualization. While the literature focused on leveraging data for better decision-making and greater operational efficiency, the key findings showed that the incorporation of feedback played a crucial role in refining the dashboards and ensuring their relevance over time.

In conclusion, the key findings confirm the arguments presented in the literature review. Data visualization in the manufacturing sector, when implemented effectively, can greatly enhance the monitoring and control of production systems. It can provide decision-makers with a better understanding of system performance and enable them to make informed decisions to improve overall operational efficiency. Furthermore, the key findings offer practical insights into the real-world application of these theoretical principles, highlighting the importance of optimization, clear requirement definition, simple design, user training, and continual improvement based on feedback.

5.2 Potential savings

Data visualization, when properly utilized by all users, can unlock significant cost savings, and bolster an enhanced culture of Industry 4.0 transparency. The potential for savings is inherently dynamic and, given our present perspective, is not yet precisely forecastable.

5.3 Limitations

A significant limitation lies in the fact that the accuracy of the data portrayed depends heavily on the operator's input. If there's incorrect or inconsistent data input, it can lead to misrepresentation of information on the Tableau dashboard. This can significantly affect the reliability of insights and the decision-making process based on the visualized data.

Furthermore, Tableau's dashboards may not be universally appealing or user-friendly for all users involved. Despite the data representation these dashboards offer, some individuals may still prefer the simplicity and familiarity of traditional manual reports. This preference can stem from a range of factors, including resistance to change, lack of training or understanding of the Tableau system, or simply personal comfort with conventional data presentation formats.

5.4 Future Research

5.4.1 Continuation of Traceability Dashboards:

As part of our timeline for the implementation of the traceability concept, we plan to continue the development and refinement of our traceability dashboards. These platforms allow us to monitor, track, and analyze critical manufacturing data in real time, offering insights that can drive improved decision-making and process optimization.

5.4.2 Predictive Maintenance

To proactively manage and minimize downtime, the concept of Predictive Maintenance should be explored further. By leveraging artificial intelligence and machine learning algorithms, we aim to predict future downtime, enabling preemptive measures to be taken to maintain operational efficiency. Such an approach could significantly reduce unexpected failures and their associated costs.

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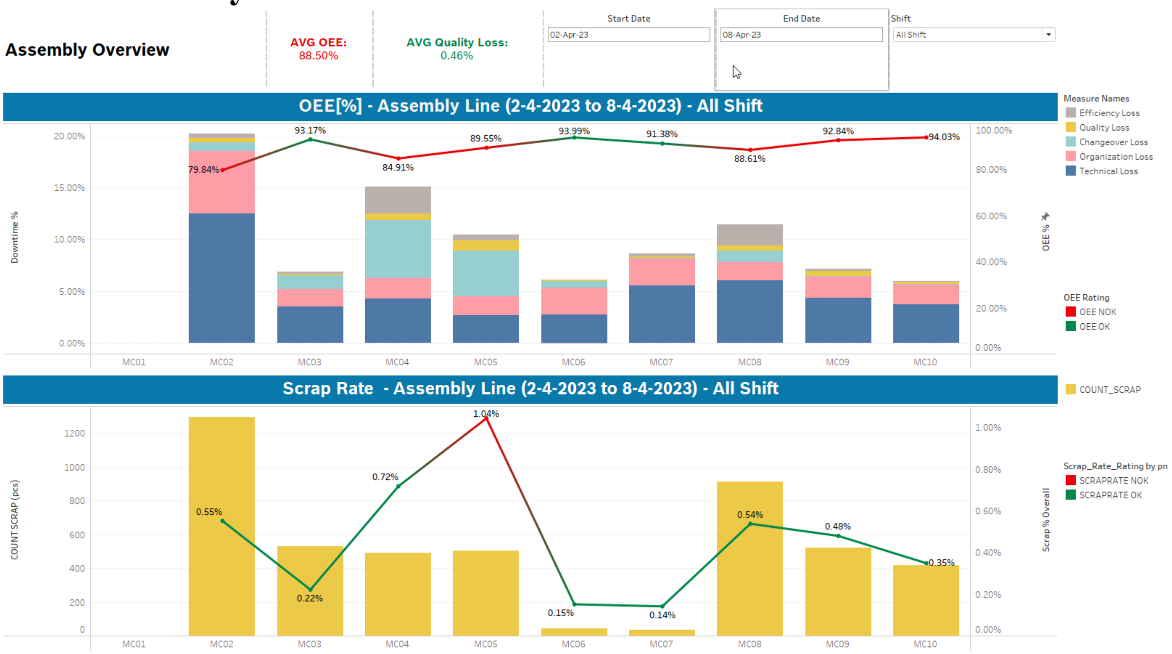
Appendices

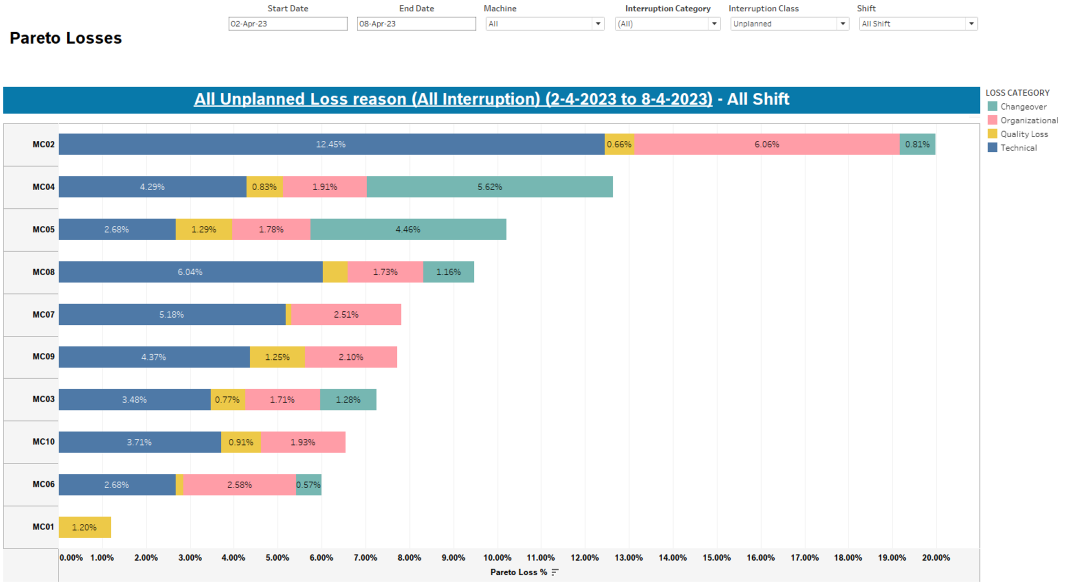
Appendix A: Tableau Dashboards

1. Assembly Overview

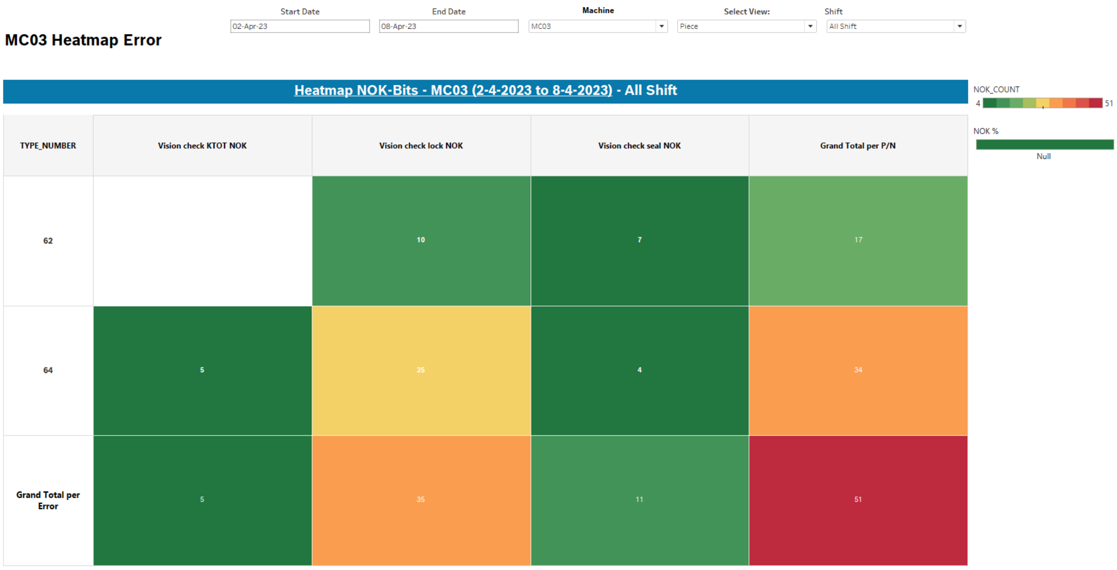


2. Overview by time

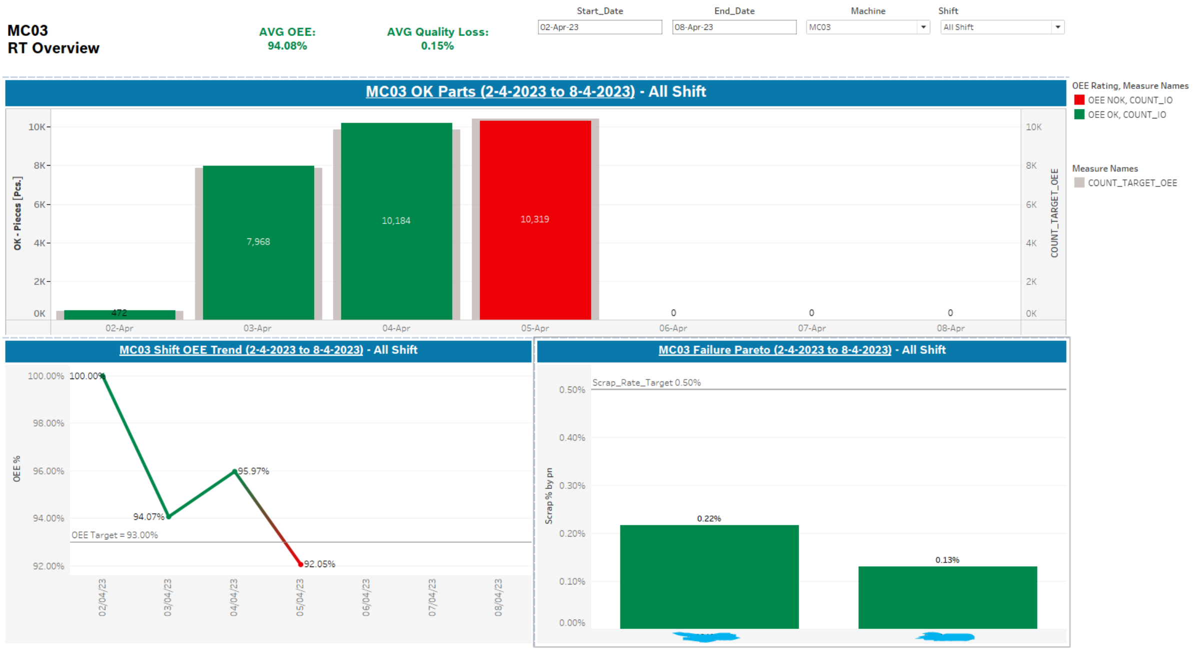
3. Pareto Losses



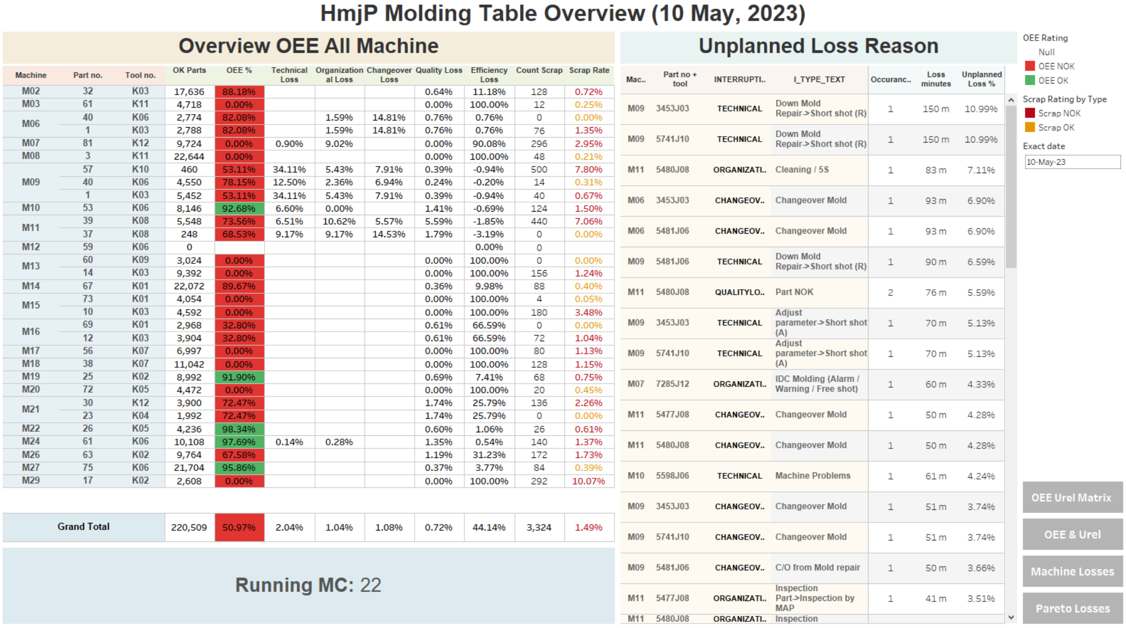
4. Heatmap



5. RT Overview



6. Molding Table Overview



HmjP Molding Table Overview (10 May, 2023)

Overview OEE All Machine

Machine	Part no.	Tool no.	OK Parts	OEE %	Technical Loss	Organizational Loss	Changeover Loss	Quality Loss	Efficiency Loss	Count Scrap	Scrap Rate
M02	32	K03	17,636	88.18%				0.64%	11.18%	128	0.72%
M03	61	K11	4,718	0.00%				0.00%	100.00%	12	0.25%
M06	40	K06	2,774	82.08%		1.59%	14.81%	0.76%	0.76%	0	0.00%
	1	K03	2,788	82.08%		1.59%	14.81%	0.76%	0.76%	76	1.35%
M07	81	K12	9,724	0.00%	0.90%	9.02%		0.00%	90.08%	296	2.95%
M08	3	K11	22,644	0.00%				0.00%	100.00%	48	0.21%
M09	57	K10	460	53.11%	34.11%	5.43%	7.91%	0.39%	-0.94%	500	7.80%
	40	K06	4,550	78.15%	12.50%	2.36%	6.94%	0.24%	-0.20%	14	0.31%
	1	K03	5,452	53.11%	34.11%	5.43%	7.91%	0.39%	-0.94%	40	0.67%
M10	53	K06	8,146	92.68%	6.60%	0.00%		1.41%	-0.69%	124	1.50%
M11	39	K08	5,548	73.56%	6.51%	10.62%	5.57%	5.59%	-1.85%	440	7.06%
	37	K08	248	68.53%	9.17%	9.17%	14.53%	1.79%	-3.19%	0	0.00%
M12	59	K06	0						0.00%	0	
M13	60	K09	3,024	0.00%				0.00%	100.00%	0	0.00%
	14	K03	9,392	0.00%				0.00%	100.00%	156	1.24%
M14	67	K01	22,072	89.67%				0.36%	9.98%	88	0.40%
M15	73	K01	4,054	0.00%				0.00%	100.00%	4	0.05%
	10	K03	4,592	0.00%				0.00%	100.00%	180	3.48%
M16	69	K01	2,968	32.80%				0.61%	66.59%	0	0.00%
	12	K03	3,904	32.80%				0.61%	66.59%	72	1.04%
M17	56	K07	6,997	0.00%				0.00%	100.00%	80	1.13%
M18	38	K07	11,042	0.00%				0.00%	100.00%	128	1.15%
M19	25	K02	8,992	91.90%				0.69%	7.41%	68	0.75%
M20	72	K05	4,472	0.00%				0.00%	100.00%	20	0.45%
M21	30	K12	3,900	72.47%				1.74%	25.79%	136	2.26%
	23	K04	1,992	72.47%				1.74%	25.79%	0	0.00%
M22	26	K05	4,236	98.34%				0.60%	1.06%	26	0.61%
M24	61	K06	10,108	97.69%	0.14%	0.28%		1.35%	0.54%	140	1.37%
M26	63	K02	9,764	67.58%				1.19%	31.23%	172	1.73%
M27	75	K06	21,704	95.86%				0.37%	3.77%	84	0.39%
M29	17	K02	2,608	0.00%				0.00%	100.00%	292	10.07%
Grand Total			220,509	50.97%	2.04%	1.04%	1.08%	0.72%	44.14%	3,324	1.49%

Running MC: 22

Unplanned Loss Reason

Mac..	Part no + tool	INTERRUPTI..	I_TYPE_TEXT	Occuranc..	Loss minutes	Unplanned Loss %
M09	3453J03	TECHNICAL	Down Mold Repair->Short shot (R)	1	150 m	10.99%
M09	5741J10	TECHNICAL	Down Mold Repair->Short shot (R)	1	150 m	10.99%
M11	5480J08	ORGANIZATI..	Cleaning / 5S	1	83 m	7.11%
M06	3453J03	CHANGEOV..	Changeover Mold	1	93 m	6.90%
M06	5481J06	CHANGEOV..	Changeover Mold	1	93 m	6.90%
M09	5481J06	TECHNICAL	Down Mold Repair->Short shot (R)	1	90 m	6.59%
M11	5480J08	QUALITYLO..	Part NOK	2	76 m	5.59%
M09	3453J03	TECHNICAL	Adjust parameter->Short shot (A)	1	70 m	5.13%
M09	5741J10	TECHNICAL	Adjust parameter->Short shot (A)	1	70 m	5.13%
M07	7285J12	ORGANIZATI..	IDC Molding (Alarm / Warning / Free shot)	1	60 m	4.33%
M11	5477J08	CHANGEOV..	Changeover Mold	1	50 m	4.28%
M11	5480J08	CHANGEOV..	Changeover Mold	1	50 m	4.28%
M10	5598J06	TECHNICAL	Machine Problems	1	61 m	4.24%
M09	3453J03	CHANGEOV..	Changeover Mold	1	51 m	3.74%
M09	5741J10	CHANGEOV..	Changeover Mold	1	51 m	3.74%
M09	5481J06	CHANGEOV..	C/O from Mold repair	1	50 m	3.66%
M11	5477J08	ORGANIZATI..	Inspection Part->Inspection by MAP	1	41 m	3.51%
M11	5480J08	ORGANIZATI..	Inspection			

OEE Rating
Null
OEE NOK
OEE OK
Scrap Rating by Type
Scrap NOK
Scrap OK
Exact date
10-May-23
OEE Urel Matrix
OEE & Urel
Machine Losses
Pareto Losses

7. Molding Matrix Overview

HmjP Molding Matrix Overview

AVG OEE
57.56%

Target OEE
> 90.00%

Start date: 03-May-23

End date: 10-May-23

Select View: OEE

Null
OEE NOK
OEE OK

OEE Matrix

Machine	03-May-23	04-May-23	05-May-23	06-May-23	07-May-23	08-May-23	09-May-23	10-May-23	Grand Total
M01	0.00%	0.00%	0.00%			0.00%	0.00%		0.00%
M02	82.32%		61.12%	100.00%	100.00%	87.04%	89.68%	88.18%	89.22%
M03	0.00%	0.00%	0.00%			0.00%	0.00%	0.00%	0.00%
M04	0.00%	0.00%	0.00%			0.00%			0.00%
M05	95.89%	53.13%	91.72%	100.00%	100.00%	91.41%			91.22%
M06	0.00%	84.50%	100.00%			96.38%		82.08%	83.28%
M07	100.00%	97.88%	92.93%	96.97%	91.36%	98.33%	17.09%	0.00%	76.20%
M08	0.00%	0.00%	0.00%			0.00%	0.00%	0.00%	0.00%
M09			100.00%	0.00%				66.32%	55.51%
M10		98.19%	99.54%			94.38%	96.25%	92.68%	95.56%
M11	98.89%	98.05%	99.25%		91.99%	99.90%	98.87%	73.56%	95.32%
M12	0.00%	45.99%	98.41%		91.53%	98.09%	98.34%		67.29%
M13		0.00%	0.00%			0.00%		0.00%	0.00%
M14			34.33%	100.00%	100.00%		55.74%	89.67%	80.46%
M15	63.49%	0.00%	0.00%				0.00%	0.00%	10.58%
M16			0.00%				0.00%	32.80%	6.56%
M17	87.29%	97.13%				83.50%	0.00%	0.00%	59.20%
M18	0.00%	0.00%				0.00%	0.00%	0.00%	0.00%
M19	92.16%		0.00%			0.00%	34.93%	91.90%	43.23%
M20	37.21%	36.54%	2.67%			0.00%	0.00%	0.00%	9.89%
M21	84.64%		76.30%			69.08%	87.20%	72.47%	78.00%
M22			67.79%		99.92%			98.34%	83.24%
M23	84.47%	93.63%	52.89%	99.65%			92.52%		81.97%
M24	99.58%	99.10%		98.41%	100.00%	73.46%	98.75%	97.69%	95.23%
M25	43.90%		100.00%	100.00%	100.00%		17.79%		81.18%
M26	42.91%		89.71%	100.00%	100.00%			67.58%	85.37%
M27		100.00%		100.00%	97.95%	100.00%	100.00%	95.86%	99.60%
M28	24.97%	98.52%	96.34%	100.00%	100.00%	54.17%	0.00%		67.05%
M29	91.02%							0.00%	45.51%
Grand Total	53.53%	53.65%	47.10%	96.73%	98.70%	54.91%	43.74%	50.97%	57.56%

Table Daily View

OEE & Urel

Machine Losses

Pareto Losses

8. Molding Machine Overview

HmjP Molding Machine Overview

AVG OEE:
57.56%

AVG Urel:
52.69%

Start date: 03-May-23

End date: 10-May-23

OEE and Urel % (3 May 2023 to 10 May 2023)

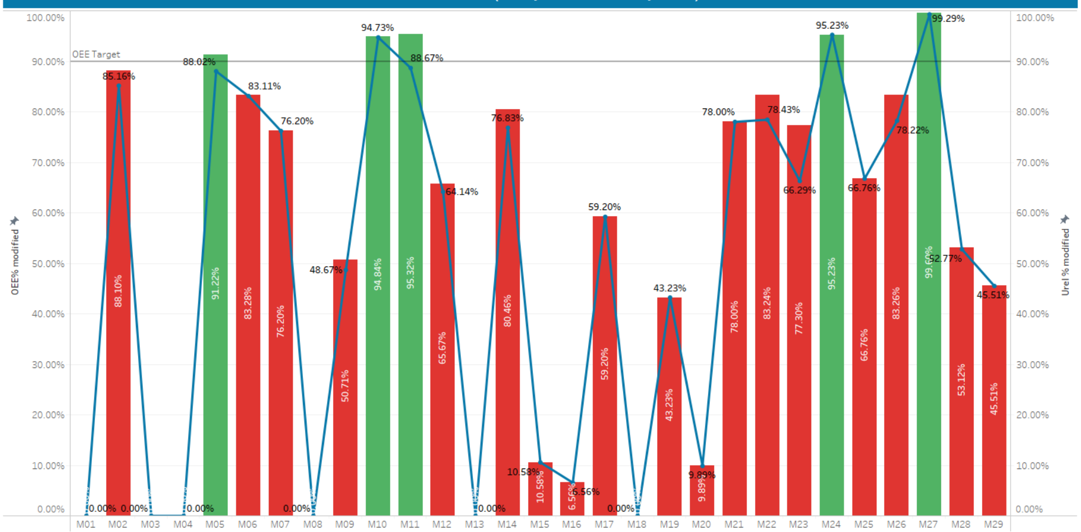


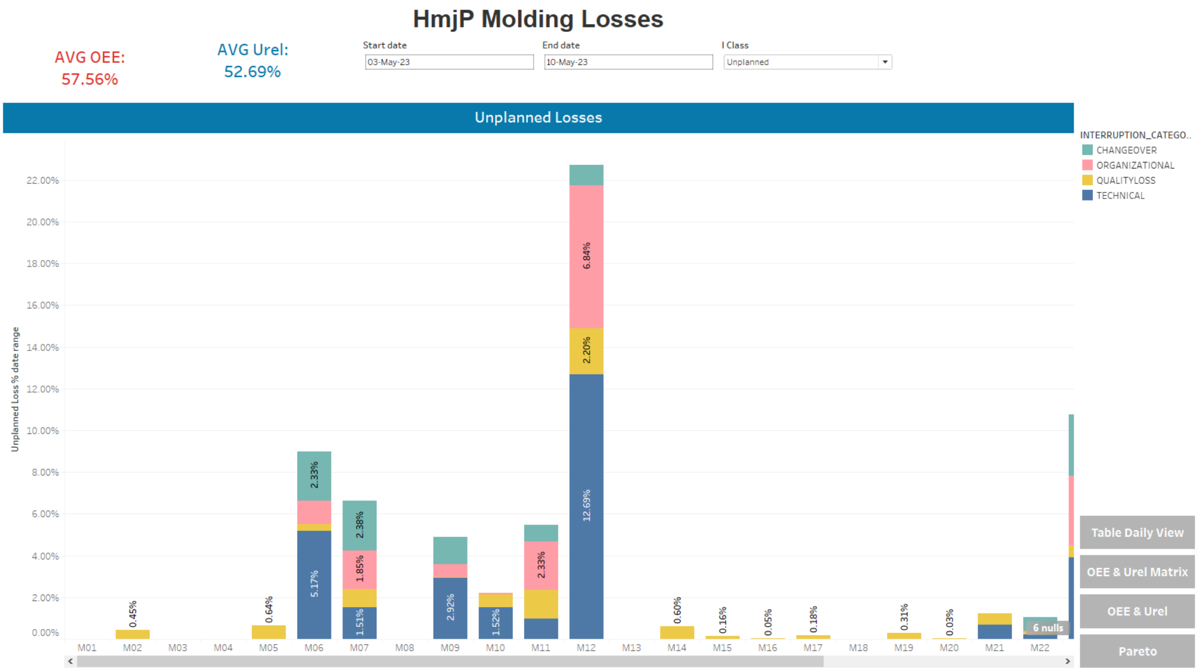
Table Daily View

OEE & Urel Matrix

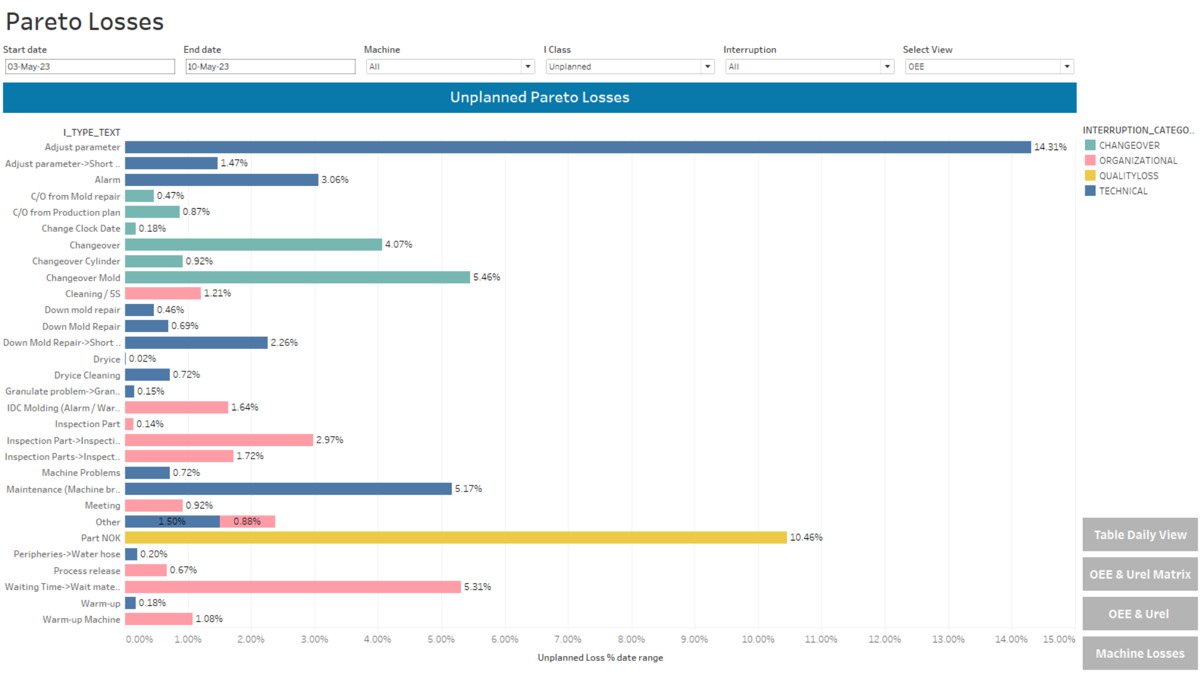
Machine Losses

Pareto Losses

9. Molding Losses



10. Pareto Losses



11. Customer Complaint

Customer Complaint

Assembly Mc: (All)
Date & Time: 5/2/2023 3:20:00 PM
Last scanned: 3

Latest Component Batch before 02-May-23 3:20:00 PM

Assembly Mc	Fg No	Bunker Name	Compo No	Tool No	Molding Mc	QTY	Batch Id	Storage time hour	Time Scanned
MC04	2	KTOT	14	J04	M03	2,000	665455337	164	02-May-23 4:45:00 AM
				J10	M04	150	665455337	11	02-May-23 4:45:00 AM
MC05	24	Dry Seal	11	J06	M04	2,000	665455343	94	02-May-23 11:30:00 AM
							665455341	96	02-May-23 9:05:00 AM
				J16	M10	300	665455343	151	02-May-23 11:30:00 AM
		KTOT	48	J05	M05	1,000	665455342	118	02-May-23 11:00:00 AM
							665455340	120	02-May-23 9:00:00 AM
				J15	M09	150	665455342	127	02-May-23 11:00:00 AM
MC06	1	KTOT	19	J01	M01	150	665455329	92	01-May-23 10:00:00 AM
							665455328	96	01-May-23 9:00:00 AM
				J02	M04	150	665455330	74	01-May-23 11:00:00 AM
		KTUT	24	J03	M02	300	665455333	119	01-May-23 12:00:00 PM
							665455332	119	01-May-23 10:10:00 AM
							665455331	121	01-May-23 9:10:00 AM
		Radial Seal	12	J04	M03	2,000	665455339	144	01-May-23 3:30:00 PM
							665455338	145	01-May-23 11:30:00 AM
				J12	M06	150	665455339	73	01-May-23 3:30:00 PM
		Secondary Lock	13	Null	Null	1,000	665455335	Null	01-May-23 11:30:00 AM

12. Internal Complaint

Internal Complaint

Filter Search

Batch Id	Compo Name	Compo No	Tool No	Molding Mc	QTY	Injection Param..	Fg No	Bunker Name	Assembly Mc	Date Mold	Time Mold	Date Scan	Time Scan	Storage Time hour
665455328	KTOT	19	J01	M01	150	SGM010001J01..	1	KTOT	MC06	27-Apr-23	09:00	01-May-23	09:00	96
665455329	KTOT	19	J01	M01	150	SGM010001J01..	1	KTOT	MC06	27-Apr-23	14:00	01-May-23	10:00	92
665455330	KTOT	19	J02	M04	150	SGM010001J01..	1	KTOT	MC06	28-Apr-23	09:00	01-May-23	11:00	74
665455331	KTUT	24	J03	M02	300	SGM010001J01..	1	KTUT	MC06	26-Apr-23	08:00	01-May-23	09:10	121
665455332	KTUT	24	J03	M02	300	SGM010001J01..	1	KTUT	MC06	26-Apr-23	11:00	01-May-23	10:10	119
665455333	KTUT	24	J03	M02	300	SGM010001J01..	1	KTUT	MC06	26-Apr-23	13:00	01-May-23	12:00	119
665455337	KTOT	12	J10	M04	150	SGM010001J01..	1	Radial Seal	MC06	02-May-23	15:30	01-May-23	09:02	30
		14	J10	M04	150	SGM010001J01..	2	KTOT	MC04	02-May-23	15:30	02-May-23	04:45	11
	Radial Seal	12	J04	M03	2,000	SGM010001J01..	1	Radial Seal	MC06	25-Apr-23	08:00	01-May-23	09:02	145
		14	J04	M03	2,000	SGM010001J01..	2	KTOT	MC04	25-Apr-23	08:00	02-May-23	04:45	164
665455338	KTOT	12	J11	M05	150	SGM010001J01..	1	Radial Seal	MC06	03-May-23	16:00	01-May-23	11:30	53
		15	J11	M05	150	SGM010001J01..	3	KTOT	MC04	03-May-23	16:00	03-May-23	05:59	11
	Radial Seal	12	J04	M03	2,000	SGM010001J01..	1	Radial Seal	MC06	25-Apr-23	10:30	01-May-23	11:30	145
		15	J04	M03	2,000	SGM010001J01..	3	KTOT	MC04	25-Apr-23	10:30	03-May-23	05:59	187
665455339	KTOT	12	J12	M06	150	SGM010001J01..	1	Radial Seal	MC06	04-May-23	16:30	01-May-23	15:30	73
		16	J12	M06	150	SGM010001J01..	4	KTOT	MC04	04-May-23	16:30	04-May-23	07:14	9
	Radial Seal	12	J04	M03	2,000	SGM010001J01..	1	Radial Seal	MC06	25-Apr-23	15:30	01-May-23	15:30	144
		16	J04	M03	2,000	SGM010001J01..	4	KTOT	MC04	25-Apr-23	15:30	04-May-23	07:14	208
665455340	KTOT	17	J05	M05	1,000	SGM010001J01..	5	KTOT	MC04	27-Apr-23	09:00	05-May-23	08:29	191
			J13	M07	150	SGM010001J01..	5	KTOT	MC04	05-May-23	17:00	05-May-23	08:29	9
		48	J05	M05	1,000	SGM010001J01..	24	KTOT	MC05	27-Apr-23	09:00	02-May-23	09:00	120
			J13	M07	150	SGM010001J01..	24	KTOT	MC05	05-May-23	17:00	02-May-23	09:00	80
665455341	Dry Seal	11	J06	M04	2,000	SGM010001J01..	24	Dry Seal	MC05	28-Apr-23	09:00	02-May-23	09:05	96
		18	J06	M04	2,000	SGM010001J01..	6	KTOT	MC04	28-Apr-23	09:00	06-May-23	09:44	192
	KTOT	11	J14	M08	150	SGM010001J01..	24	Dry Seal	MC05	06-May-23	17:30	02-May-23	09:05	104
		18	J14	M08	150	SGM010001J01..	6	KTOT	MC04	06-May-23	17:30	06-May-23	09:44	8
665455342	KTOT	20	J05	M05	1,000	SGM010001J01..	7	KTOT	MC04	27-Apr-23	13:00	07-May-23	10:59	237
			J15	M09	150	SGM010001J01..	7	KTOT	MC04	07-May-23	18:00	07-May-23	10:59	8
		48	J05	M05	1,000	SGM010001J01..	24	KTOT	MC05	27-Apr-23	13:00	02-May-23	11:00	118
			J15	M09	150	SGM010001J01..	24	KTOT	MC05	07-May-23	18:00	02-May-23	11:00	127
665455343	Dry Seal	11	J06	M04	2,000	SGM010001J01..	24	Dry Seal	MC05	28-Apr-23	13:30	02-May-23	11:30	94
		21	J06	M04	2,000	SGM010001J01..	8	KTUT	MC04	28-Apr-23	13:30	08-May-23	12:14	239
	KTUT	11	J16	M10	300	SGM010001J01..	24	Dry Seal	MC05	08-May-23	18:30	02-May-23	11:30	151
		21	J16	M10	300	SGM010001J01..	8	KTUT	MC04	08-May-23	18:30	08-May-23	12:14	6

Filters bar

Batch Id

Fg No

Compo No

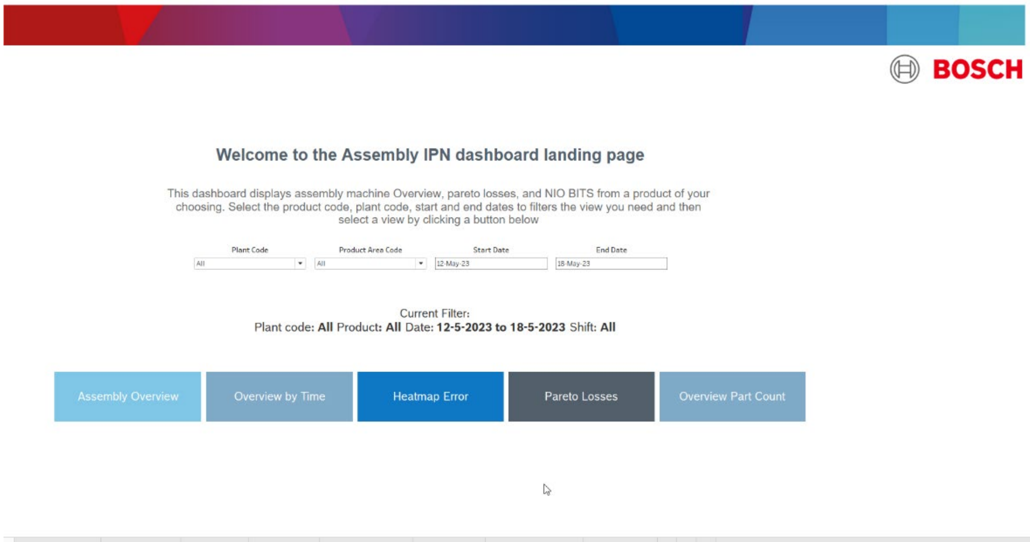
Molding filter

Start Date Mold: 01-Apr-23
Start time Mold: 00:00
End Date Mold: 31-May-23
End time Mold: 23:59
Tool No: (All)
Molding Mc: (All)

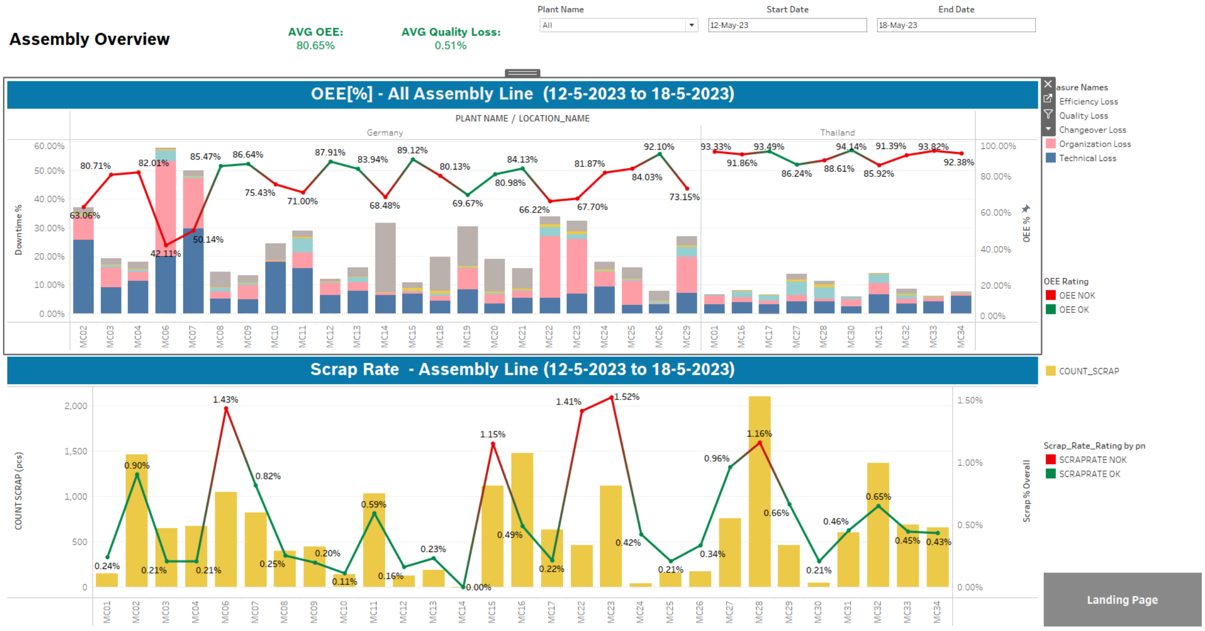
Assembly filter

Start Date Scan: 01-Apr-23
Start time scan: 00:00
End Date Scan: 31-May-23
End time Scan: 23:59
Assembly Mc: (All)
Bunker Name: (All)

13. IPN Landing Page

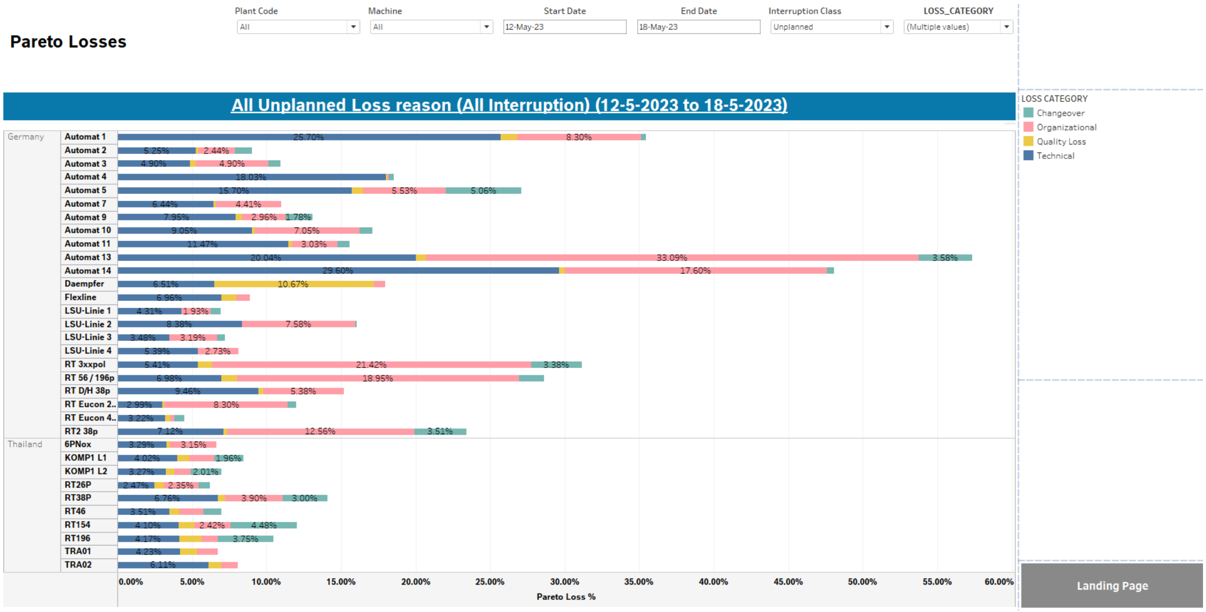


14. IPN Assembly Overview



15. IPN Overview by Time

16. IPN Pareto Losses



Streamlining Manufacturing Process with Tableau: A Data Visualization Approach

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***Abstract*— This project undergoes the implementation of data visualization for the manufacturing operation through multiple tools such as Tableau, and Azure Databricks. The process consists of five main steps: gathering requirements, data preparation, design & iteration implementation, and monitoring and evaluating the result. Shopfloor management KPIs are calculated, and the traceability concept is also introduced. Key findings revolve around the impact of dashboard loading time, Clear requirements through workshops, simplified dashboard designs, enhanced user experience through training, and the importance of feedback. Cost savings are calculated to be 213k THB annually.**

Keywords—manufacturing, data visualization, data streamlining, assembly, molding, traceability

I. INTRODUCTION

The manufacturing industry faces growing challenges in the era of Industry 4.0, requiring innovative solutions to harness the power of data for intelligent decision-making. This paper explores the implementation of a comprehensive data visualization solution using Tableau, integrated with SQL and Azure Databricks, to enhance process efficiency and cost savings in the manufacturing sector. By focusing on the development of specialized dashboards, this study demonstrates the potential of data visualization to provide stakeholders with valuable insights and revolutionize the manufacturing industry.

A. Background and Context

1) Robert Bosch: Robert Bosch is a multi-national engineering company founded in Germany by Robert Bosch himself (Fig.1). The company business can be categorized into 4 main sectors.

a) *Mobility Solutions*
b) *Industrial Technology*
c) *Consumer Goods*
d) *Energy and Building Technology*

Robert Bosch Automotive Technologies Thailand Co., Ltd. is in the Mobility Solutions sector. The plant produced connectors and fuel ejector valves for tier-one companies.

Robert Bosch's connectors manufacturing line is separated into two operations: Molding and Assembly. The process

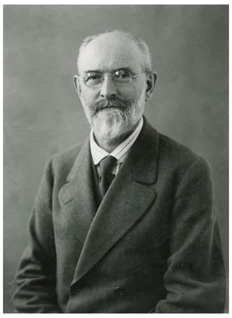


Fig. 1. Robert Bosch

starts by running the plastic granulate through the pipes into molding injectors, where high temperatures melt the granulate into a liquid state and then shoot out into a mold. Thus, creating the main plastic part for the connector. Next, the part is stored inside the supermarket until it is taken out to the assembling machine, where both in-house parts and supplier parts are assembled to create a finished product.

Robert Bosch has a time plan to introduce i4.0 technologies to the plant. Data visualization in Tableau is one of the main topics.

This project this entirely develop under the direct resources of Robert Bosch Automotive Technologies Thailand Co., Ltd., specifically, for the Hemaraj plant. This Data visualization will take advantage of the manufacturing data from the connectors' manufacturing process. It lies on the implementation timeline of the company's Industrial 4.0 projects.

2) Industrial 4.0: The 4th Industrial Revolution, a term used in every industry, mostly manufacturing. It is when a huge change in the system where technologies such as the Internet of Things, along with big data, play a pivotal role in the manufacturing processes, forever changing the system to suit the new world. Many manufacturers are trying to implement technologies to increase their productivity, produced parts, and reduce the gap between the physical and digital worlds.

Data visualization played a main role in the revolution. By taking advantage of the big data concept and data analytics tools, highly impactful data can be critical to any company nowadays. Thus, everyone is trying to implement data-driven tools and solutions to build their competitive edge over the competition in the market.

3) Data Visualization: Data visualization is one of the crucial processes in data science. It is a practice of displaying or sharing useful data and insights in a manner that viewers can interpret and make data-driven decisions effectively.

Data visualization for manufacturing processes requires a lot of lot resources to streamline data into dashboards for engineers and management. In Robert Bosch Hemaraj, many resources are ready at their disposal, waiting for a data visualization expert to take a serious look at the data and make something great both for the people and for the future I4.0 role of the company.

B. *Problem Statement*

The problem statement for this research project is based on the limitations of existing data visualization solutions in the manufacturing industry. The main problem lies in the inability of traditional reports and spreadsheets to provide real-time and comprehensive insights into the manufacturing process. These traditional methods are often fragmented, lack interactivity, and fail to present the data in a visually intuitive manner.[1]

Construction industry research has identified that problems in various domains, including people, organization, and process, contribute to inefficiencies. Similar challenges can be observed in the manufacturing sector, where complexities and the unique nature of the manufacturing process give rise to a range of issues. Streamlining the manufacturing process requires addressing these problems and improving decision-making through better data visualization tools.[2]

In summary, the problem statement in this thesis revolves around the lack of effective data visualization solutions in the manufacturing sector. The goal is to develop a comprehensive data visualization system using Tableau, SQL, and Azure Databricks to provide real-time insights and improve decision-making in the manufacturing process.[4]

C. *Objectives*

The objective for this project is to find an effective way to implement data visualization for manufacturing operations. This project will result in key findings of data visualization process. The main benefits targeted are to improve the manufacturing process, reduce operators' manual tasks, and increase cost savings.

II. LITERATURE REVIEW

Data visualization, especially in the manufacturing sector, is a rapidly developing field, grounded by advancements in technology and the increasing availability of large datasets. Implementing data visualization effectively, however, requires careful planning, the right selection of visualization tools and methods, a clear goal, and a thorough understanding of the intended audience [8].

An essential step in implementing data visualization is data cleaning, which involves detecting and removing inaccurate records from a dataset. The quality of data influences the reliability of the visualizations. Any inaccuracies in the data can lead to misleading visuals, potentially resulting in false interpretations and decisions. Consequently, data cleaning is a crucial prerequisite to effective data visualization [8].

Once the data has been cleaned, the next step is data exploration. This involves an initial process of understanding the data through summaries and visual methods. The insights derived from this stage inform the next steps, including the choice of data visualization method [8].

Choosing the right format to visualize the findings is important. The decision is made based on the type of data, target audience, and message to be conveyed. Among other forms of visualization, there are tables, charts, graphs, maps, and timelines. Visualization formats include tables, charts, graphs, maps, and timelines, among others. The selection should simplify complex datasets and make them easier to understand [7].

Finally, finding a suitable medium or platform for presenting the visualization is crucial. The platform should support the selected visualization format and be accessible to the intended audience. Depending on the context, this might be a web page, a printed report, a mobile app, or an interactive display [8].

In the context of manufacturing and Industry 4.0, implementing effective data visualization can greatly improve the monitoring and control of production systems. By tracking and visualizing production system health data, decision-makers can better understand the system's performance, identify areas of concern, and make informed decisions to improve overall equipment effectiveness [6].

In conclusion, effectively implementing data visualization in manufacturing involves a series of steps, from data cleaning and exploration to the selection of appropriate visualization methods, and the choice of a suitable medium. This process, while complex, is a powerful means of leveraging data for better decision-making and greater operational efficiency.

III. METHODOLOGY

A. *Gather Requirements:*

1) Assembly Dashboards: Weekly Meetings with the colleague and supervisor and Assembly line Manager where we discuss the requirements (TABLE I), the problems, and the feedback. Everything is listed on an open-point topic table.

Assembly line Tableau OPL				
Index	**Details**	**Start Date**	**Status**	**Remark**
1	check the source for scrap rate	16-02-23	Done	Scrap rate = (Count Scrap/(Count Scrap + Count IO)) * 100
2	Losses only 1 digit after the decimal	16-02-23	Done	
3	Clean date wording	16-02-23	Done	
4	The set bar chart in the same line (RT losses)	16-02-23	Done	

5	Quality loss from as-quote (yellow color bar)	16-02-23	Done	
6	Quality loss error message corrected (failure category) ERR01	16-02-23	Done	Technical Engineer responsible
7	Check errors for all worksheets	16-02-23	Done	RT Quality Detail
8	Access right to All Managers	16-02-23	Done	Dashboards uploaded to the web
9	Supervisor Compare output data with the MES shift book	16-02-23	Done	1st meeting done
10	Bar chart group by days, weeks, months	22-02-23	Done	set meeting with IT colleague
11	Supervisor checks the reason for 26P high scrap rate(Project needed?)	22-02-23	Done	Not relevant to Tableau
12	196P scrap rate of more than 1%	22-02-23	Done	Not relevant to Tableau
13	Y axis adjusts automatically	22-02-23	Done	
14	Optical improvement	22-02-23	Done	
15	Heatmap color - Customized with Assembly Manager	29-02-23	Done	fix ERR01 first
16	MSC2 Qualitat Worksheet missing SAP db	10-03-23	Done	Need connection to Redlake
17	Hint from IT Colleague	24-03-23	Done	Transfer to a new environment
18	Testing of Tableau by user	24-03-23	Done	2 weeks testing
19	Settings for opening page (1 month) for faster loading	24-03-23	Done	
20	Supervisor feedback (Assembly Overview)	26-03-23	Done	-Improve loading -remove the machine filter -start date, end date filter - remthe ove period filter -OEE 2 decimals point -OEE shows every rt, remove time -OEE % two decimals
21	Supervisor feedback (1st meeting)	26-03-23	Done	- improve filters - OEE Quality 2 decimal - add NOK pcs for quality-loss - Change OEE calculation - Check date range (start from 8.00 am to 8.00 am) -create a graph from MES (Pareto Losses) -Value not match MES(FC01: failure in manu) -Average Percent -Value does not match MES (RT Loss Detail) -change title
22	Assembly Management Feedback	03-04-23	Done	dashboard
23	Change database query following IT Colleague guideline	10-04-23	Done	

TABLE I. ASSEMBLY LINE TABLEAU TASK

2) *Molding Injector Dashboards*

a) Workshop One: Introduction to Tableau Visualization and its Relevance to Manufacturing Decisions: The initial workshop is designed to create a foundational understanding of Tableau Visualization and demonstrate its potential implications for making informed manufacturing decisions. The session begins with an in-depth introduction to Tableau, including a walkthrough of its core features and functionalities. Participants gain an understanding of how the software can handle complex data sets, transform raw data into digestible formats, and create visually compelling and interactive dashboards.

b) Workshop Two: Identifying Key Problems: The second workshop focuses on brainstorming and problem identification, crucial elements in the process of requirements gathering. Initially, the workshop facilitator introduces the problem-identification process, setting clear guidelines for the discussion. Participants are then asked to reflect upon their experiences in the manufacturing line and individually list three significant issues on sticky notes. This activity encourages critical thinking and provides a space for participants to voice their concerns.

Each participant is allowed to present their identified problems (Fig. 2.). to the rest of the group. This promotes open communication and facilitates a comprehensive understanding of the various challenges present in the manufacturing line. It also allows participants to learn from each other's experiences and perspectives, thereby creating a collective awareness of the issues at hand.

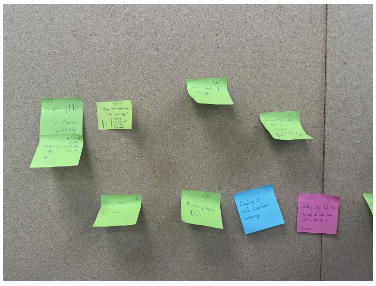
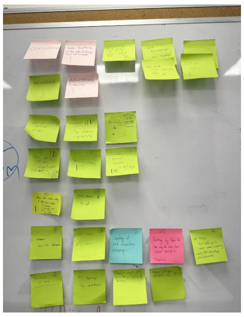


Fig. 2. Sticky notes listing problems.

c) Workshop Three: Collective Problem-solving: The third workshop leverages the collective intelligence of the participants to find possible solutions for the problems identified in the previous session. The meeting begins with a recap of the issues raised earlier and an overview of the categorized problem areas. This reminder helps to reorient the participants towards the key concerns and primes them for the collective problem-solving process.

The main goal of this workshop involves a group discussion aimed at generating potential solutions for each problem category. Participants are encouraged to consider the benefits of different approaches, share best practices, challenge each other's ideas, and draw on their combined expertise and experience. This iterative process allows for a robust exploration of potential solutions and helps to ensure that the resulting proposals are both innovative and practical.

Fig. 3. Stick notes with Solutions.



Lastly, the group collectively reviews and ranks the proposed solutions. This is done based on various factors like feasibility, potential impact, and resource requirements. By the end of this workshop, the group will have a prioritized list of solutions that can guide the design of the data visualization tools in the next workshop.

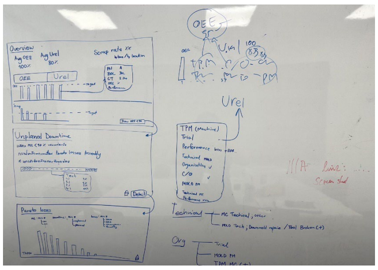


Fig. 4. Dashboards drafted on a whiteboard

d) Workshop Four: Data-Driven Visualization Creation: The final workshop focuses on translating the gathered insights into data-driven visualizations. It begins with a recap of the prioritized solutions and a discussion on how these can be represented visually using the data available from the manufacturing line's cloud database. The facilitator provides examples of suitable graphs or charts that could be used to represent different types of data and correlations.

3) Traceability Dashboards

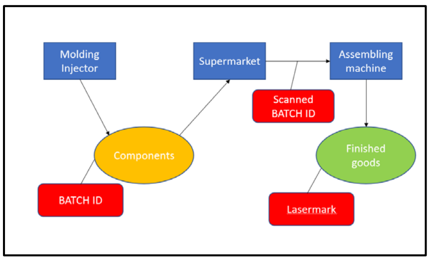


Fig. 5. Traceability Concept Diagram

a) Discussing with the Plant's Operators, Managers, and Engineers: Engaging key personnel was critical to the understanding of the process. Plant operators provided insight into the daily workings of the assembly line, offering perspectives that might not be captured in official documents.

b) Plant Traceability Concept: This process began with the components produced by molding injectors were given unique batch IDs when they were produced. The details attached to batch ID, such as the component ID, date, and time of production were noted.

During the assembly process, the component labels were scanned before assembly. These labels contained the batch ID and provided a critical data point linking the component to the specific time it was used in the assembly.

Lastly, finished goods were marked with a date and time using a laser, which was essential for the finished product's traceability.

This helped to clearly illustrate the journey of a component from production, through assembly, and finally as part of a finished good. This served as the foundation for the subsequent stages of data collection, preparation, and visualization in Tableau. (Fig. 5.)

c) Customer Complaint: A customer complaint dashboard is needed to trace back with the finished good ID and Laser marked date and time. It is to find the latest possible Batch ID fed into the bunkers before assembling the parts

d) Internal Complaint: An internal complaint dashboard is used when the quality control department finds defects in the parts and needed to find all the possible defects by using any information that parts should be affected by. A dashboard where large options to filter and show as much data as possible.

4) International Product Network Dashboards: The requirements of the International Product Network Dashboards for the manufacturing line aim to facilitate a seamless visualization of production data on Tableau. These requirements are derived through active communication with our plant network based in Germany and are adapted to be used across multiple plants globally.

a) Functional Similarity to Assembly Dashboards

The first version of these dashboards is expected to bear functional similarities to the existing Assembly dashboards. The overall layout, ease of use, and other operational characteristics of the Assembly dashboards will be modeled in the International Product Network Dashboards.

b) Inter-Plant Adaptability A major requirement is the flexibility and adaptability of the dashboards for use across multiple plants. The dashboards should be designed in such a way that they can accommodate and display data from different plants without any complications or requirements of significant modification.

c) User-Friendly Interface: The dashboards should have a user-friendly interface, making it easy for users to navigate through different sections, understand the information displayed, and interpret the results. It should provide clear, interactive, and visually appealing data visualizations.

B. Data Preparation

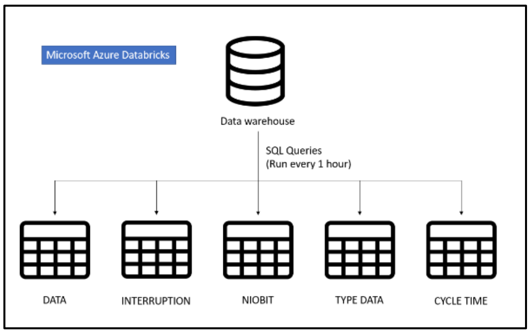


Fig. 6. Data Extraction Diagram

1) Extract: SQL queries have been developed to filter and pull-out data that is specifically relevant to the company's Thailand and Germany plants.

Once the relevant data has been extracted, it is used to generate new tables, further refining and organizing the information for subsequent use. The extracted data is continuously updated. The SQL queries are programmed to run every hour. This scheduling ensures the most up-to-date data is extracted from the databases and made available for transformation and loading as quickly as possible.

2) Transform: In this context, we focus primarily on the 'Transform' part of the process. The transformation phase is critical in turning raw data into more meaningful information that can be readily used for further analysis and data visualization.

3) Load: Loading the data into the Tableau worksheet tab isn't just a process of data transfer. It involves a deliberate structuring of the data within the platform, aligning with the requirements of Tableau for effective data visualization. It's during this process that the data takes on a format that enables seamless interaction within the Tableau environment. Then transformed data is loaded into the Tableau worksheet tab, which will be used to design gn, filter graphs, and dashboards for the next step.

4) Synthetic Data: Data for traceability as of now, are not available yet. Thus, mock data are created in an excel file which included all the necessary information for the traceability concept.

C. Design & Iterate via Tableau

1) Assembly Dashboards

a) Format numerical losses: Right-click on the "Losses" field in your data source and select 'Default Properties' > 'Number Format'. Choose 'Number (Custom)' and set Decimal places to 1.

b) Clear date wording: Make sure that the date labels are user-friendly by choosing an easy-to-understand format. You can adjust this by right-clicking on the date field, selecting 'Default Properties', then 'Date Format', and setting it to a readable format such as "March 2023".

c) Align the bar chart: To set all bar charts in the same line, drag and drop your 'Losses' field into the Columns shelf, and your categorical variable (e.g. 'Product Type') into the Rows shelf.

d) Quality loss color highlight: In the 'Color' shelf on the Marks card, click on the color legend and assign the color yellow to the quality loss category.

e) Bar chart group by time: Right-click on the date field and select 'Create' > 'Custom Date'. In the dialogue box, choose the desired part (day, month, year) for grouping.

f) Y-axis adjustment: Tableau adjusts the y-axis automatically based on the data you're visualizing. Make sure the 'Fixed' option is not selected in the 'Edit Axis' dialogue box.

g) Optical improvement: Apply visual enhancements like color coding, adjusting transparency, gridlines, labels, and annotations. This is accessible in the 'Marks card' and 'Format' menus.

h) Customize heatmap colors.: Click on 'Color' on the 'Marks card' and select 'Edit Colors'. Choose the desired color palette based on the Assembly Manager's preference.

i) Faster loading settings: To ensure faster loading, limit the amount of data loaded by setting a date range filter for the last month in your dataset.

j) Supervisor feedback integration (1st Meeting): Update the Assembly Overview Dashboard based on the provided feedback. This involves updating filters, formatting numbers, and adjusting display settings. It can be done by using the 'Filters', 'Format', and 'Marks' cards, respectively.

k) Supervisor feedback integration (2nd meeting): Adjust the dashboards based on the supervisor's feedback. This will require updating filters, creating new visualizations, and correcting discrepancies using Tableau's respective functions (filters, marks, and data source).

l) Assembly Management feedback integration: Amend the dashboards to align with the Assembly Management's feedback. This involves modifying filters, changing visualizations, and resolving discrepancies.

2) Molding Dashboards

a) First Dashboard: Molding Table Overview:

- Create visualizations for daily meetings where a large amount of data can be seen in one view.
- Create a search function using a quick filter on the tool number and corresponding part number fields.
- Create percentage-based data for unplanned downtime.
- Use a red indicator or similar visual cue for OEE NOK rating and NOK scrap.

b) Second Dashboard: Molding Matrix Overview:

- Visualize the OEE separated by days for all machines using a table.
- Create a parameter to change between OEE and Urel

c) Third Dashboard: Losses and Downtime:

- Visualize unplanned downtime, with bar charts separated by machine number.
- Display accumulated production visualizations, separated by tool and part number, using stacked bar charts or similar.

d) Fourth Dashboard: Molding Overview:

- Visualize OEE and Urel from the molding machines using a bar chart and line chart.
- Display the OEE rating in green and red color.
- Display the OEE target for all machines OEE Target = 90%

e) Fifth Dashboard: Pareto Losses:

- Create detailed visualizations for each downtime based on the downtime categories.
- Allow for different views of the machine, planned / unplanned downtimes, interruption categories, and OEE / Urel view by using filters for flexible analysis.

3) Traceability Dashboards

a) Customer Complaint Dashboard: The primary purpose of the Customer Complaint Dashboard is to present a comprehensive view of customer feedback. Users can interact with this dashboard to delve into specifics and draw insights from the underlying data.

The dashboard is designed as a table view that displays all relevant data in an easy-to-read format. Furthermore, it includes four filters to help users fine-tune their data view.

b) Internal Complaint Dashboard: The Internal Complaint Dashboard was a particularly challenging task. The objective was to showcase as much data as possible while maintaining usability and readability, the solution was to incorporate a range of filters.

The dashboard was organized in a tabular format with individual columns corresponding to Molding, Component's number, Tool number, Time mold, Molding machine, Component's name, and Injection parameter. However, to enable users to find the root causes of defects, filters were added that could isolate the impacts of different tools or machines on the overall process.

For instance, if a user wants to explore the impacts of a particular tool, they can use the tool number filter. Similarly, to track the performance of a specific molding machine, the molding machine filter can be utilized. These filters were designed to be as inclusive as possible to support broad and specific investigations into defect causation.

Further, the dashboard was also equipped with an option to identify batches that might be impacted due to certain tools or machines. This can be particularly useful in preventive measures and improving the quality control process.

4) International Product Network Dashboards

a) Shift ID: In Thai plants, there are two 12-hour shifts. While the German plant has three 6 hours shifts. After discussing with the German colleague, we decided to remove the shifts filter completely. So, all shifts are now combined into 1 day.

b) Landing Page: A landing page is required for more professionalism and an intuitive interface. The page consists of filters for plant names, date ranges, and product codes. There are also navigation buttons leading to all dashboards developed.

D. Implementation

1) Timeplan: During the project's 4 months at Robert Bosch Hemaraj, only Tableau Molding (TABLE II.)and IPN dashboards were implemented. While Assembly Dashboards were implemented in 2022 in my cooperative education subject, and Traceability Dashboards will be implemented around the end of the year 2023.

Tableau Molding Implementation	Feb-23	Mar-23	Apr-23	May-23	Jun-23
Gather Requirements	■	■			
Data Preparation		■			
Design Dashboards		■	■		
Implementation				■	
Monitor and Evaluate				■	■

TABLE II. TABLEAU MOLDING IMPLEMENTATION TIMEPLAN

2) Training Session: A Tableau Molding training session was held before the full implementation of the dashboards. The session required engineers, management, and plant operators to join and train. A 2-hour long training included.

E. Monitor and Evaluate

After the full implementation of the dashboards, begins the last phase of data visualization. It is to monitor and evaluate the performance of the dashboards by qualitative and quantitative measuring.

1) Feedback session: Weekly meetings are set up to talk with the users about the dashboards. Questionnaires are created to get specific answers.

2) Cost savings: To calculate the savings for this project, we must identify the time reduction for daily meetings, monthly meetings, problem-solving, root cause finding, and the underlying potential for future machines and products. There has already been recorded data that shared a similar cost savings which we will talk about in chapter 4.

IV. RESULTS/ FINDINGS

A. Key Findings

1) Improved Dashboard Loading Time

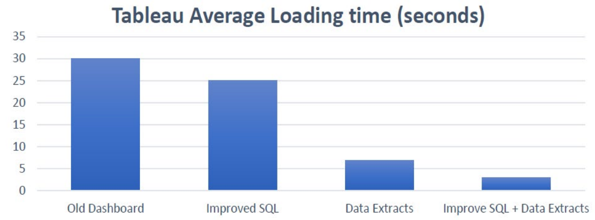


Fig. 7. Chart comparison for Tableau loading time

A measure of success for the data visualization solution was the performance of the dashboards, particularly the loading times. Before optimization, slower loading times were a significant challenge (Fig. 7.), impacting the user experience and overall effectiveness of the dashboards. Through the optimization of SQL queries and the implementation of data extracts, a considerable improvement was achieved. The dashboards loaded faster (from 30 seconds to 2 seconds), providing users with quicker access to information. This enhancement not only improved user experience but also improves decision-making processes.

2) Clear Requirements through Workshops: The workshops conducted with stakeholders played a crucial role in defining the requirements and understanding the specific needs of the organization. The diverse representation of participants in these workshops, from operators to managers, provided a lot of information. The requirements gathered from these workshops were clear, precise, and closely aligned with the organization's strategic objectives. This ensured that the dashboards were designed to provide the most relevant and actionable insights to the appropriate users.

3) Simplified Dashboard Designs: The study found that simple dashboard designs with fewer customizable filters were more effective and user-friendly than complicated designs with multiple filters. The simplified designs focused on presenting the most important data and insights, thereby enabling users to quickly understand the information and make informed decisions. This led to an increase in user adoption and utilization of the dashboards, enhancing the overall decision-making process in the organization.

4) Enhanced User Experience through Training: The provision of manuals and training sessions significantly improved the user experience with the dashboards. Users reported a better understanding of the functionalities and how to interpret the data presented on the dashboards. The training sessions, with comprehensive manuals, allows users to fully utilize the dashboards, leading to increased usage and a deeper appreciation of the value of data in decision-making processes.

5) Importance of Feedback: The continuous process of incorporating feedback into the dashboards' development and improvement was another key finding of the study. Feedback from users played a crucial role in refining the dashboards and making them more relevant and user-centric. This iterative process of improvement ensured that the dashboards remained effective and continued to deliver valuable insights over time.

B. Cost Savings

1) Improvement Projects: Improvement projects can be found faster and used for data analysis during the improvement process. Total savings of at least 150k THB annually depend on the impact of the downtime causes.

2) Total Productive Maintenance Improvements: Reduced TPM by 135 minutes per month, increasing production of 52k pcs more per year. 540 minutes of half a setter and POV reduced. Estimated savings of 25k THB annually.

3) Organizational findings: Increase findings of organizational improvement topics. Estimated savings for a finding: 18k – 38k THB.

V. CONCLUSION

A. Key findings with literature review.

Based on the key findings and the literature review on data visualization, several important points stand out that provide insight into the effective application of data visualization tools and methods in the field.

Firstly, the literature review emphasized the importance of data cleaning as an essential step for effective data visualization [8]. The key findings supported this, as the optimized SQL queries and implementation of data extracts, which improved the loading times of the dashboards, could be considered a part of this cleaning process.

The literature also highlighted the significance of choosing the right visualization methods [7]. The key findings are closely related, showing that simplified dashboard designs and clarity of requirements, gathered through workshops, were more effective and user-friendly. The simplicity and clarity of the data presentation led to an increase in user adoption and the overall effectiveness of the decision-making process.

The literature underlined the necessity of a platform for data visualization, accessible to the intended audience [8]. This is consistent with the key findings, which demonstrated that comprehensive manuals and training sessions significantly improved the user experience. Providing users with tools to understand the functionalities of the dashboards led to increased usage and an enhanced appreciation of data visualization's value in decision-making processes.

Finally, both the literature review and key findings highlighted the importance of continual improvement in data visualization. While the literature focused on leveraging data for better decision-making and greater operational efficiency, the key findings showed that the incorporation of feedback played a crucial role in refining the dashboards and ensuring their relevance over time.

In conclusion, the key findings confirm the arguments presented in the literature review. Data visualization in the manufacturing sector, when implemented effectively, can greatly enhance the monitoring and control of production systems. It can provide decision-makers with a better understanding of system performance and enable them to make informed decisions to improve overall operational efficiency. Furthermore, the key findings offer practical insights into the real-world application of these theoretical principles, highlighting the importance of optimization, clear requirement definition, simple design, user training, and continual improvement based on feedback.

B. *Potential savings*

Data visualization, when properly utilized by all users, can unlock significant cost savings, and bolster an enhanced culture of Industry 4.0 transparency. The potential for savings is inherently dynamic and, given our present perspective, is not yet precisely forecastable.

C. *Limitations*

A significant limitation lies in the fact that the accuracy of the data portrayed depends heavily on the operator's input. If there's incorrect or inconsistent data input, it can lead to misrepresentation of information on the Tableau dashboard. This can significantly affect the reliability of insights and the decision-making process based on the visualized data.

Furthermore, Tableau's dashboards may not be universally appealing or user-friendly for all users involved. Despite the data representation these dashboards offer, some individuals may still prefer the simplicity and familiarity of traditional manual reports. This preference can stem from a range of factors, including resistance to change, lack of training or understanding of the Tableau system, or simply personal comfort with conventional data presentation formats.

D. *Future Development*

1) Continuation of Traceability Dashboards: As part of our timeline for the implementation of the traceability concept, we plan to continue the development and refinement of our traceability dashboards. These platforms allow us to monitor, track, and analyze critical manufacturing data in real time, offering insights that can drive improved decision-making and process optimization.

2) Predictive Maintenance: To proactively manage and minimize downtime, the concept of Predictive Maintenance should be explored further. By leveraging artificial intelligence and machine learning algorithms, we aim to predict future downtime, enabling preemptive measures to be taken to maintain operational efficiency. Such an approach could significantly reduce unexpected failures and their associated costs.

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. Poom Konghuayrob for guiding me and allowing me to continue my work here at Robert Bosch Automotive.

I also like to give my deepest thanks to Mr. Bartosch Spitza, who has been giving me tremendous knowledge and experience.

Thanks to the engineering team who have always helped me with difficult tasks and made this project possible.

Finally, I would like to thank my mom, my dad, and Panadda Luckananukul for always being supportive no matter the circumstances. Thank you, truly.

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