Building a value-assessment framework for 4Industry

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Bachelor Thesis Industrial Engineering and Management

Date of Publication: 26th September 2022

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Preface

Dear Reader

In front of you lies my Bachelor thesis which I conducted to graduate from the bachelor's Industrial Engineering and Management program at the University of Twente. I spent the final semester of this study program researching and executing this thesis at Plat4mation's subsidiary company, 4Industry.

I would like to express my gratitude to Plat4mation for giving me an opportunity to conduct this project in their organization. I would like to thank my company supervisors Arno Lourens Munnik and Anand van Deventer for their collaboration and guidance throughout this project. I would also like to thank all the other members of the 4Industry team for their help and support throughout the project. It was a pleasure to work here.

I would like to thank my university supervisors Dr Abhishta Abhishta and Dr Patricia Rogetzer for helping me in this project with their valuable feedback and for making me think like a researcher.

Lastly, I would like to thank my friends and family for their support and motivation.

I hope you enjoy reading my thesis.

Aditya Bansal

September 2022

Management Summary

Introduction

This research is conducted for Plat4mation's subsidiary company, 4Industry. Based in Utrecht, 4Industry is a connected worker platform, which aims to help manufacturers empower their operators to digitally manage their day-to-day tasks and have instant access to information on the shop floor so that they can do their work faster and better than without such a system. However, an issue for 4Industry is the lack of a standard way to show their customers how this product can add value to their production operations.

Aim

The main goal of this project is to create an analytical methodology that reflects the impact 4Industry brings to its clients in a tangible and measurable way. Currently, there are limited and non-standardized methods in place, which focus only partially on the mentioned impact areas. To facilitate this thesis, the Design Science Research Methodology is selected and the main research question is defined as:

"How to identify quantitative value drivers, that can be easily communicated with the clients of 4Industry?"

Method

A literature review is conducted to learn about value quantification and the method used in manufacturing to track performance. From this step, the process of value quantification is found, which provides a five-step procedure for effective value quantification. It is also discovered that Key Performance Indicators (KPIs) are the universal metrics for the manufacturing industry. So it is decided that 4Industry's value will be quantitatively represented in the form of KPIs whose performance will improve because of using the connected worker platform in their client's production operators.

To search for these KPIs, the following impact areas of 4Industry are identified by understanding the functioning of the connected worker platform:

- Overall Equipment Effectiveness (OEE)
- Safety, Health & Environment (SHE) Culture
- Continuous Improvement (CI) Culture

Next, a search is conducted for KPIs which could be linked to these impact areas and the results are filtered through these two criteria: Relevancy (the KPI should be logically influenceable by 4Industry) and measurability (the KPI should be measurable without requiring extensive setups). However, to more logically argue about the impact, it is decided to create custom sub-level KPIs which 4Industry has a very clear influence on and influence on these sub-KPIs will have an influence on the Industry KPIs. Then focus is put on developing a method to measure all the KPIs, both before and after implementation, so it would be possible to evaluate their performance.

To build the framework, all the KPIs and sub-KPIs are hierarchically visualized under their impact areas through a KPI tree and a detailed analytical description is provided of why the KPIs will improve because of using 4Industry. Apart from that, a tool is also created using Excel to clearly calculate the improvement in OEE through 4Industry. Using this value-assessment framework and the tool, the value of using 4Industry can be communicated in a quantitative way.

Outcome

All the details of this value-assessment framework are neatly summarized in the 4Industry value-stream map, which can be reviewed in Appendix E.

By following the framework defined in this report -

- Customers can make an assessment of where 4Industry could save time and money in their operations.
- Clients can evaluate the tangible improvements to their operations gained through 4Industry
- 4Industry can create records and case studies with their customers to have better use-case and marketing materials.
- 4Industry can improve customer satisfaction rate and expand sales

However, one major limitation of this framework is that there was not an opportunity to validate any of the KPIs using data, so for now it is completely theoretically. Therefore its recommended to 4Industry to conduct further research into validating this framework by gathering data from their clients and evaluating the KPIs. Based on the outcomes, the framework should be iterated to make it more credible.

List of abbreviations

B2B: Business-to-Business

CI: Continuous Improvement

CIL: Clean, Inspect, Lubricate

DSRM: Design Science Research Methodology

IoT: Internet of Things

KPI: Key Performance Indicator

MTBF: Mean Time Between Failure

MTTR: Mean Time To Repair

OEE: Overall Equipment Effectiveness

PPE: Personal Protective Equipment

SHE: Safety, Health and Environment

TPM: Total Productive Maintenance

1. Introduction

The aim of this chapter is to provide information about the problem which the stakeholder of this project faces and formulate an approach to systematically resolve this problem.

1.1. Problem Context

For any startup or established business, it is essential that the product or service they offer can add some value to their customers. This value should be communicable from a perspective that the customer can interpret clearly [1]. Being unable to do so is a potential challenge that an enterprise could face, especially when they launch a new product in the market. Unlike consumer marketplaces, where emotions can be influenced for making a purchase and accountability is low, B2B markets are more diligent because the stakes are higher for them [2]. Here the aim is not only to sell products but also to achieve some outcomes using the product [3]. For instance, a buyer in the market for IT equipment may actually be looking to achieve greater business efficiency. Then the aim of the IT vendor should be to represent how their solution will help in achieving this efficiency and have a methodology with them to numerically show the improvement in efficiency.

This is exactly the problem that the stakeholder of this project is currently facing. Through this thesis, a structured approach will be applied to clearly represent the impact of their product and communicate it in a quantitative way that resonates with the customers in their industry.

1.2. 4Industry Introduction

The stakeholder of this project is Plat4mation, an IT company that is specialized in making workflows based on ServiceNow for their clients. It was founded in 2013 in Utrecht, The Netherlands, with the goal to boost workforce productivity and happiness by implementing solutions that provide great experiences and ensure work flows intelligently across and between organizations. They won the prestigious Global ServiceNow Partner of the Year 2021 award. In 2017, they created a subsidiary company called 4Industry.

4Industry is a Connected Worker Platform built on ServiceNow to support Manufacturing Operations Processes. A connected worker platform is a set of digital tools that can improve the functioning of humans in manufacturing environments. These tools are provided into the hands of the operators through their smartphones or wearables and are used to improve communication, collaboration, information sharing, and support through a digital infrastructure [4].

4Industry’s focus is to make machine operators more effective and efficient by allowing them to seamlessly perform production-, safety- and equipment workflows. In addition, it captures and presents this data in a way that gives management accurate oversight of daily operations, enabling faster decision-making and action management. Currently, different modules of this platform are being used and rolled out at clients and 4Industry is always looking to expand its platform with new customers.

1.3. Action Problem

An action problem can be defined as the discrepancy between the norm and the reality, as perceived by the problem owner [5].

Currently, there is no quantifiable method to communicate the impact of 4Industry. This makes it a challenge to give potential customers clear insights into where this product could add value to their production operations and how this value can be measured. Even existing clients are interested in finding out how much improvement is achieved in their production plants since the implementation of 4Industry. But they are unable to say in which areas is this platform making an impact and by how much. That's why the action problem is-

"No clear way to express the impact of 4Industry"

1.4. Concerned Process

Currently, the process of recruiting new clients and implementing 4Industry can be seen in Figure 1.

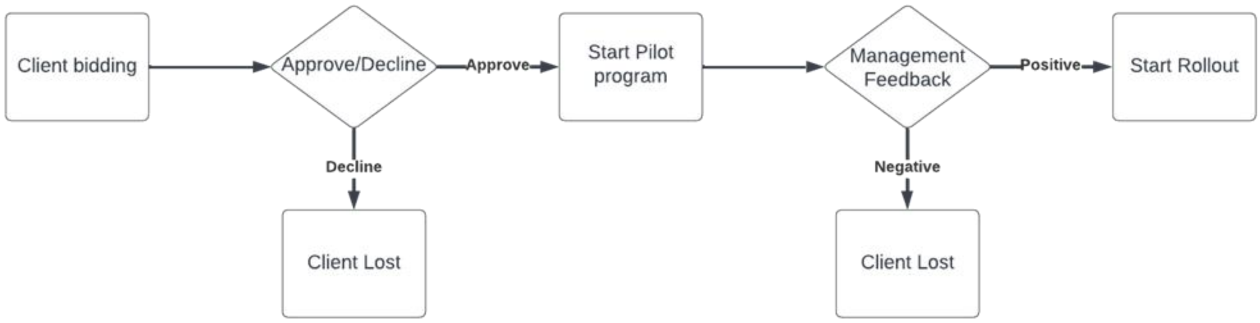

Figure 1: The process of getting a new client

1) Client Bidding: When 4Industry finds potential customers who are interested in the product, the team starts the bidding process and aims to offer the customer an economically competitive proposal.

2) Approve/Decline: Based on the bid provided, the potential customers have the option to accept or reject the proposal. If the customer rejects the proposal, then 4Industry loses the customer.

3) Start Pilot program: If the customer accepts the proposal, then some modules are implemented in one of the factories of the customers as a pilot program. This allows the customer to try out the functionality of 4Industry in their production operations. The client themselves choose the modules which they feel will add the most value to their operations.

4) Management Feedback: Based on the pilot program, the client's management decides if they would like to scale up the implementation of 4Industry. Because currently there is no way to clearly depict the gains through 4Industry, this decision is based on feedback and perceptions felt by operators and managers of the factory. If the management feels that 4Industry doesn't add any value to their operations, then 4Industry losses the customer.

5) Start Rollout: If the management feels that 4Industry has a positive impact on their operations, they then go ahead with a full-scale roll-out of 4Industry. 4Industry aims to globally do this roll-out at all of its client's factories and aims to also establish a link to share information among them.

1.5. Problem Cluster

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1.6. Core Problem

A core problem can be defined as a problem whose solution will make a real difference. This problem should not be caused due to some other problem and shall be resolvable by the stakeholders [5].

As it can be observed from the problem cluster, the lack of quantifiable value drivers is the reason 4Industry cannot clearly express the potential improvements that clients could make in their production operations using their connected worker platform. Currently, there is no knowledge on which metrics should they measure to define their value.

“No quantifiable value drivers are known”

That’s why the research in this project will aim to discover a way to quantify the impact which 4Industry offers to its clients. The results will then help in giving clients clear insights on how this product will assist in improving their operations and by how much.

1.7. Norm and Reality

The norm describes how the situation should ideally be for the company, whereas reality talks about how the situation currently deviates from the ideal situation for the company.

Reality: Currently no quantifiable value drivers are available to make assessments of 4Industry in improving production operations.

Norm: There should be a list of quantifiable value drivers and a method to measure them to assess the improvements made by 4Industry on production operations.

1.8. Research Question

The research question is formulated in such a way that the answer to that would resolve the core problem. With all the information gathered about the current situation and discussions with the problem owner, the main research question is defined as-

“How to identify quantitative value drivers, that can be easily communicated with the clients of 4Industry?”

To help answer the main research question, it has been subdivided into six sub-research questions

Sub Research Question 1: How to quantify value for B2B sales?
Answering this question will help in learning more about value quantification done to drive B2B sales.

Sub Research Question 2: What are the performance measurement methods used in the manufacturing industry?
Answering this question will help in discovering a way to define the quantifiable value drivers.

Sub Research Question 3: In which are of production operations does 4Industry make an impact?

Answering this research question will help in discovering how 4Industry improves production operations and give us areas to look for quantifiable value drivers.

Sub Research Question 4: How to identify the quantitative value drivers with respect to the impact areas?
Answering this question will help in coming up with value drivers and linking them to the impact areas discovered.

Sub Research Question 5: How to measure the quantitative value drivers?
Answering this question will help in creating a methodology to measure the performance of the value-drivers.

Sub Research Question 6: How can deliverables from this project be used in communicating the value to the clients?
Answering this question will help in evaluating the outcomes of this project.

1.9. Research Design

For this project, the Design Science Research Methodology will be used [6]. The reason to use this methodology is that it focuses on creating an artefact which can be used to solve real problems. In this project, the artefact will be a value-assessment framework, composed of quantifiable value drivers.

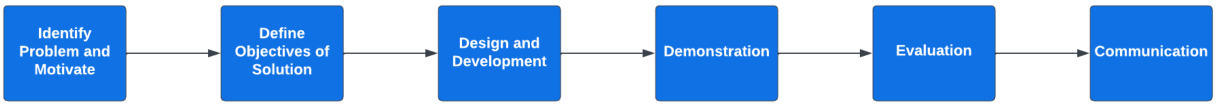

Figure 2: The Design Science Research Methodology

This methodology consists of 6 steps, which can be seen in Figure 3 and are described below with respect to this project.

Step 1: Identify Problem and Motivate
In this step, the problem is identified and the research question is defined. First, some context is provided and the concerned process is explained. Then, all the relevant problems are collected and their cause-effect analysis is made through the Problem Cluster. From this problem cluster, the core problem is identified and to resolve it, the main research question is defined.

Step 2: Define Objectives of Solution
In this step, the objectives of the framework are described and research is conducted to gather knowledge for building the framework.

Step 3: Design and Development
In this step, all the elements for building the value-assessment framework are collected and defined.

Step 4: Demonstration
In this step, the value assessment framework is built using all the information in the previous steps and its justifications are given. Apart from that, a tool which can calculate the impact of 4Industry is built and demonstrated.

Step 5: Evaluation
In this step, the value assessment framework and tool are going to be evaluated. Based on company feedback, it would be understood how it is going to be used and whether it resolves the core problem of this project.

Step 6: Communication
In this step, the aim is to communicate the findings of the research with the stakeholders of this project and other researchers. The previous step of evaluation will help is communicating the results and also describe the limitations of this research. Apart from that, recommendations will also be shared for further research.

1.10. Report Structure

In Table 1, it can be reviewed which research question will be answered in which chapter, with respect to the DSRM steps.

DSRM Step	Chapter	Research Question Answered
Identify Problem and Motivate	1) Introduction	Not Applicable
Define Objectives of Solution	2) Theoretical Framework 3) Determining impact areas for 4Industry	Question 1: How to quantify value for B2B sales? Question 2: What are the performance measurement methods used in the manufacturing industry? Question 3: Where does 4Industry make an impact?
Design and Development	4) Finding the KPIs	Question 4: How to identify the quantitative value drivers with respect to the impact areas? Question 5: How to measure the quantitative value drivers?
Demonstration	5) Mapping the KPIs to impact areas 6) Tool for OEE	Not Applicable
Evaluation	7) Evaluation and Conclusion	Question 6: How can deliverables from this project be used in communicating the value to the clients?
Communication		

Table 1: The Report Structure

1.11. Deliverables

The goal of this project is a value-assessment framework which can analytically represent the value which 4Industry would bring to their clients production operations. This will be composed of three components-

- Report: This will be a detailed report which would go through the steps taken in this project to create the value assessment framework. It would document all the key decisions made and discuss the properties and relations of the value drivers in detail.
- One Pager: This one-pager would provide an overview of the value drives and summarize the value assessment framework. The aim of this one-pager for 4Industry is to quickly explain to its clients how their product will help in improving their production operations.
- Tool: This would be a tool, which would be able to calculate the impact of 4Industry using the defined value drivers.

1.12. Chapter Summary

In this chapter, the focus is put on understanding the problem which a company has and coming up with a plan to solve this problem. An introduction is given about 4Industry and the challenge they are facing. The reason and effects of this challenge are explored with the help of a problem cluster, which leads to the discovery of the core problem which needs to be resolved. To resolve it, research questions are formulated and the Design Science Research Methodology is chosen to facilitate this project. Towards the end, a description is provided of the report structure and the intended deliverable.

2. Theoretical Framework

In this section, it will be aimed to answer the first and second sub-research questions, 'How to quantify value for B2B sales' & 'What are the performance measurement methods used in the manufacturing industry?', and gather other relevant information for this project.

To do so, relevant literature and online sources will be reviewed and using them the concerned information will be defined.

2.1. Value Quantification

In this section, the aim is to discover a methodology for value quantification for B2B products or services.

Value can be defined as the benefit that a customer will receive from using a product or service which they purchase from an organization. Usually, this is represented in the form of value drivers, which are factors of a product or service that will increase their value to the customers by providing benefits like reducing cost, enhancing revenue, or giving an emotional benefit. For a product, they can be a differentiating capability that makes it more appealing to the customers. By identifying as many value drivers as possible, an enterprise can boost its position in the marketplace and gain a competitive edge. To continuously add and improve value, a business should constantly monitor the changes in demand and consumer behaviour and create new value drivers which can cater to these new needs [7].

IT vendors, especially in B2B markets are expected to quantify their value for the customers. A study conducted by E&Y, in which they surveyed 100 IT buyers concluded that 81 percent expect vendors to provide a quantified value position in financial terms [8].

According to [9], the process of value quantification consist of five steps, as summarized in Figure 4.

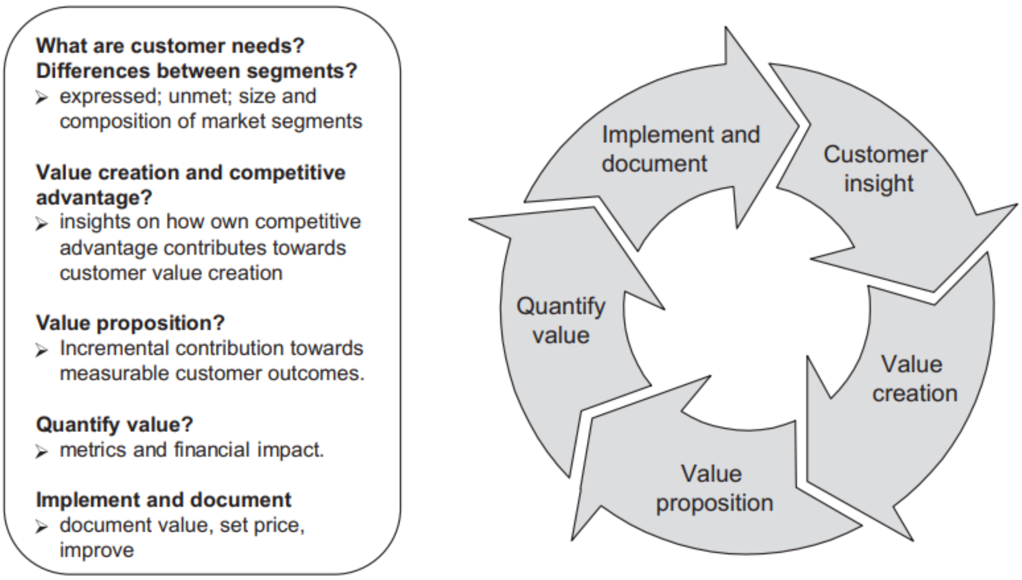

Figure 3: The process of value quantification[9]

Customer insight: The first step can be defined as listening to a customers and interpreting their unmet needs or goals which a product or service could fulfil.

Value creation: In the second step, the focus is put on translating the value drivers of a product or service into the success metrics which the customer is looking for. This way, value can be communicated in a language which the customers can understand.

Value proposition: Step three is focused on using a value proposition to show customers how their product or service could help in resolving these unmet needs. A value proposition is a list of value drivers that a product or service provides to its customers. It is essential that this value proposition is relevant in understanding what the customers want and clearly shows the competitive advantage that the value drivers offer.

Quantify value: In step four, the aim should be to convert the value drivers in the value proposition into customer benefits, in the form of metrics. These metrics can be financial or process based. This way customers will be able to analytically interpret a product's impact on their organization.

Implement and document: The fifth step is concerned with realizing the value within the customers' organization and documenting the outcomes for evaluations and improvements.

The benefits of well-crafted quantified value propositions during the bidding process are higher prices and higher bid rates. Plus, there tends to be a shift from price to reaching the quantified performance improvements. To achieve these improvements, customers and suppliers have to closely work together. Thus a close-knit collaborative nature is formed in the supplier-customer relationship and this leads to better customer service and customer loyalty [9].

In this section, the meaning of value was understood and a methodology was discovered for value quantifications. This methodology offers this project the theory needed to quantify the value of 4Industry.

2.2. Performance Measures in Manufacturing

In this section, the aim is to show how performance is measured in the manufacturing industry.

Performance measurement can be defined as the collection and analysis of data to generate information on the performance of a system or organization. Performance measurements are critical for the tracking, management and improvement of the competitive performance of manufacturing organizations [10]. In this industry, the most universally used metrics for performance measures are Key Performance Indicators (KPIs).

A KPI can be defined as a quantifiable measure, which provides an indication of performance [22]. Its value can be related to data collected or calculated for any process or activity. They are usually used to provide decision-makers information on how well their business is doing in achieving its goals.

In manufacturing, KPIs are used to track many different performance areas like quality, efficiency, cost, inventory etc. Companies themselves chose a range of these performance measures based on their strategic intentions and the competitive environment in which their business operates. However, organizations should aim to measure all the aspects of their manufacturing productivity, because focusing on just one aspect might create an unfair assessment of the situation and lead to wrong decision-making [11].

From this section, it can be concluded that KPIs are the universal metrics for the manufacturing industry and the value drivers created for 4Industry should be linked with these KPIs. Based on this information, it is decided to define value drivers of 4Industry as KPIs whose performance will improve after implementing the connected worker platform.

2.3. Digital Manufacturing and Connected Worker Platform

In this section, the aim is to discover how new digital technologies are improving the performance of the manufacturing industry.

Digital Manufacturing is the application of digital technologies in the manufacturing operations of an organization. These technologies can be used to create a smart factory in which all systems are connected to form an integrated environment, which can use real-time data analytics to optimize the manufacturing process. The benefits of this are that it can help in increasing efficiency, eliminating bottlenecks, improving quality and creating a more suitable work environment for the next generation of the workforce [12,13]. Studies have shown that the use of digital technologies has the potential for cost reductions of up to 20% and productivity increases of up to 50% [14].

These technologies are part of the greater paradigm shift to the fourth industrial revolution, better known as Industry 4.0. It aims to unlock the full potential of automation by utilizing smart technologies. This is based on four core principles [15]-

1) Interconnection: Homogeneous communication by connecting all devices and minds in the factory through leveraging modern technologies like IoT.

2) Information transparency: Information is regularly collected from every point in the manufacturing process, enabling more informed decision-making.

3) Technical assistance: Intelligent systems aim to make tasks and operations easier and safer for the operators.

4) Decentralized decisions: Cyber-physical systems that are capable of autonomously conducting tasks and decision-making.

A part of this revolution are connected worker platforms like 4Industry. Connected worker platforms are digital software tools that aim to improve the way employees work in manufacturing operations. They are embedded into hand-held or wearable devices and aim to replace paper-based operations.

They are created over a cloud-based management system, which acts as a central database to store data, work instructions, standard operating procedures, knowledge and other relevant information which can be instantly accessed and shared.

The benefit of using a connected worker platform is that communication and control can be improved while working in highly complex and variable industrial settings [16]. With an increasingly hybrid and distributed workforce, it better connects on-site and remote teams. Plus for managers, it offers managers insights to improve business processes which are dependent on workers. These platforms can be used to bring improvements for a wide range of use cases like quality, safety, training, maintenance etc. [4].

From this section, we can conclude that connected worker platforms are digital tools that help to empower the next generation of the manufacturing workforce.

2.4. Total Productive Maintenance (TPM)

In this section, the aim is to show how the TPM benefits manufacturing organizations.

TPM is a Japanese philosophy, that strategizes operations in which everyone in the facility participates in maintenance activities rather than just the maintenance teams. It is an innovative approach to maintenance that aims to optimize equipment efficiency, reduce breakdowns and encourage autonomous maintenance. TPM puts an emphasis on maintenance as a vital part of the business. Its initiative target to enhance competitiveness by encompassing a structural approach to change the mindset of employees. Focus is put on communication as TPM mandates collaboration between operators, maintenance people and engineers [23].

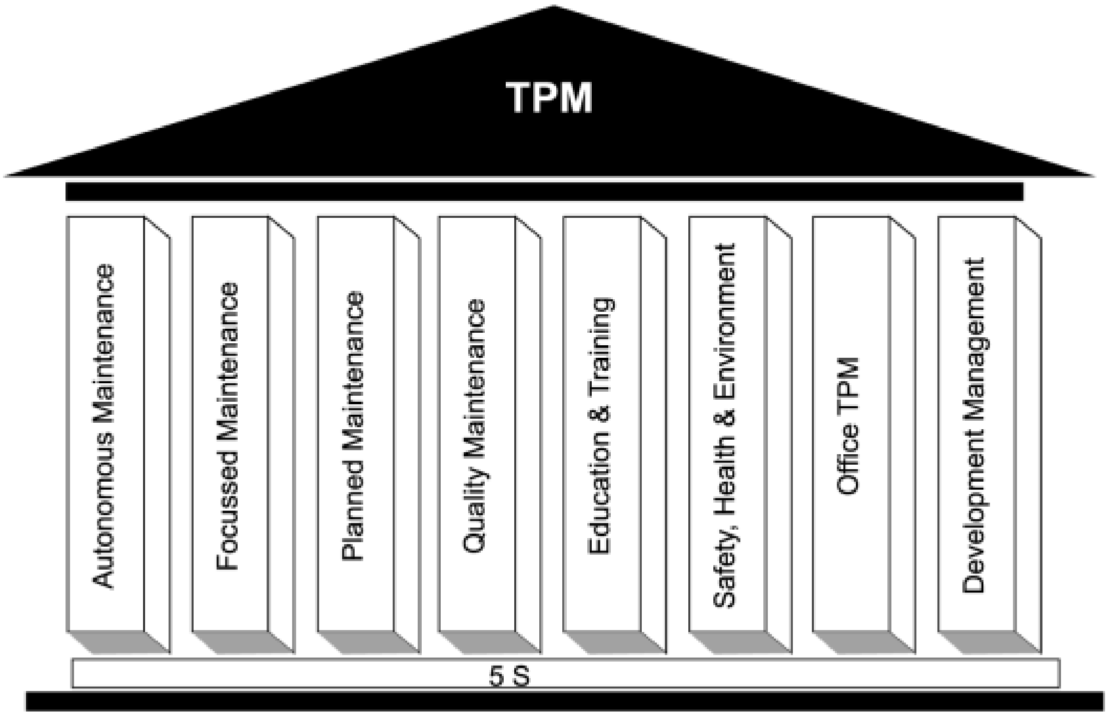

Figure 4: The eight pillars of TPM [23]

TPM consists of eight pillars, which can be seen in Figure 5. Below is a description of each of them [23, 24]:

Autonomous Maintenance: Fostering responsibility on operators to perform routine maintenance and upkeep of the assets they work with.

Focused Maintenance: Systematic approach to the elimination of losses and improvement of system efficiency.

Planned Maintenance: Planning effective maintenance schedules based on measured failure rates and improving MTBF and MTTR.

Quality Maintenance: Aim to achieve zero defects by applying scientific and statistical techniques to identify and eliminate them.

Education & Training: Development of necessary knowledge among workers to achieve the TPM goals.

Safety, Health & Environment: Ensuring a safe working environment to eliminate incidents, accidents and injuries.

Office TPM: Extending the principles of TPM beyond the production plant into other areas like administration, scheduling, logistics etc.

Development Management: Using knowledge gained through TPM into developing more efficient new products or equipment.

TPM is considered a world-class approach and its effective implementation can lead to better OEE, higher productivity, fewer breakdowns, better quality and better utilization of the workforce. Case studies have shown significant improvements of metrics like maintenance cost, incident rates, energy costs, defect rates, inventory reduction etc. after implementing TPM programs [25].

From this section, it can be concluded that correctly implementing a TPM program will provide a positive and effective result for an organization.

2.5. Chapter Summary

In this chapter, the aim was to collect relevant knowledge which would help in proceeding with this project. First, literature is reviewed about value quantification and a five-step value quantification cycle is discovered, which can be used to quantify the value of 4Industry. Next, its investigated how performance is evaluated in the manufacturing industry, so a metric to quantify could be identified. It was learned that the common performance metric in manufacturing are KPIs and hence the quantified value drivers for 4Industry must be in some form of KPIs. After discussions with the stakeholders, it was decided that the value drivers of 4Industry shall be KPIs whose performance shall improve because of using the connected worker platform. Then it was reviewed how digital technologies and connected worker platforms are benefiting manufacturing organizations and finally, the benefits of implementing TPM were understood.

3. Determining the Impact areas for 4Industry

In this section, the aim is to answer the third research question, 'In which area of production operation can 4Industry make an impact?'.

The digital manufacturing platform 4Industry will be investigated to understand its functioning and discover which areas of production operations can it have an impact on.

3.1. Understanding 4Industry

As briefly mentioned in Chapter 1, 4Industry is a connected worker platform that aims to digitalize operations in the production environment. It offers operators, supervisors and management the opportunity to manage all aspects of day-to-day activities on the shop floor, by analyzing, continuously improving and working safely to reach world-class manufacturing. This is done by using modern technologies such as Cloud, Mobile, IoT and Machine Learning, all in a unified platform. Some functionalities of 4Industry will be discussed to have a better understanding of how it works.

In Figure 6, through a comparison between manual and digital operations, it can be witnessed how digitalization can save time and improve efficiency.

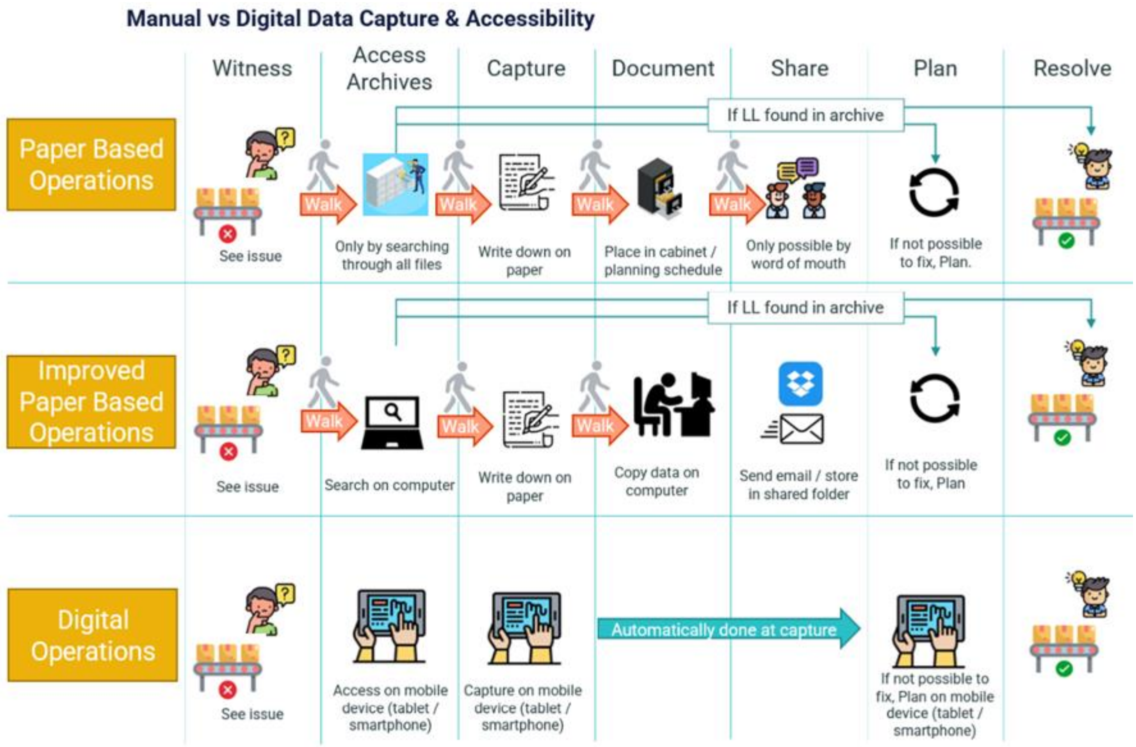

Figure 5: Paper Based vs Digital Operations [17]

In this example, in which an operator has to report a deviation in the production line, in case of a completely paper-based operation, he has to spend time travelling to different locations and manually searching for documentation. Even in case, the operation has some digital tools embedded, he still has to spend time manually entering and storing data in it. When compared to a fully digital operation enabled by 4Industry, the operator has to only use his smartphone and capture the deviation in the production line by the means of an app. This app consists of a knowledge management system, which would automatically register the deviation and suggest solutions or checklists from its existing knowledge database. And in case the operator is unable to solve the issue, he can quickly share all the information about the deviation and raise a ticket with the relevant maintenance team. So in this case he does not have to travel anywhere or search through archives, and can quickly register and possibly resolve the issue just through his device.

Long planned stops increase the downtime of production lines. To resolve them, 4Industry offers digital Standard Operating Procedures (SOPs), which can be made intuitive and interactive by adding images and videos to them. This can help in limiting the downtime to a minimum as operators will be able to resolve the issues by conducting maintenance in a standardized way.

Another useful feature of the connected worker platform is the ability to perform a digital root-cause analysis. The learnings from this analysis can be updated in the knowledge database and shared with different factories of a client and even the equipment vendors.

Apart from efficiency, focus is also put on making the work environment safer. The app provides operators a safety checklist to ensure all cautions are taken for hazardous work. Safe work permits can also be digitally signed to save time. Just like deviations, safety issues can also be registered and resolved using the app. The platform also facilitates safety auditing and offers a dashboard of safety issues and performances, so the Safety teams at clients can make more informed decisions for making their workplaces safer.

All the functionality discussed above and much more is possible through the eight distinct modules, which are based on the eight pillars of TPM [18], which can be seen in Figure 7.

Figure 6: The modules of 4Industry [17]

Each of these modules digitalizes different processes in the production operations and clients can choose which modules they wish to roll out in their factories. Therefore through the help of this platform, in Figure 8, it can be seen how 4Industry believes it can make work easier for the different types of workers in the manufacturing environment.

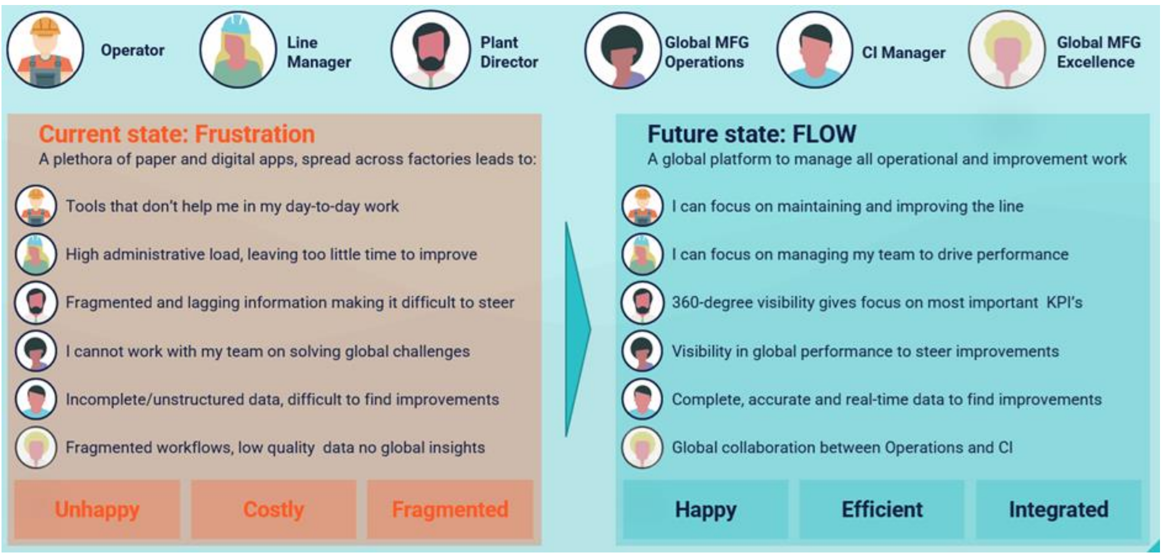

Figure 7: How 4Industry helps different types of employees [17]

3.2. The Impact Areas

In this project, the impact areas are defined as the metric group of production operations, where 4Industry can provide some positive value and improve their performance.

With the understanding of 4Industry, interviews were conducted with the stakeholders in the organization to identify the impact areas. After several discussions in which the modules were reviewed and industry requirements were checked, it was concluded that the following three are the impact areas of 4Industry:

3.2.1 Overall Equipment Effectiveness (OEE)

OEE is a measure of how well manufacturing assets are being utilized, i.e. how efficient the production lines are running. It is a product of availability loss, performance loss and quality loss. 100% OEE would be a production line that never stops (100% availability), operates at maximum speed (100% performance) and produces only good parts (100% quality). Measuring OEE is a crucial and therefore a common exercise within the manufacturing industry, as it gives important insights into where improvements are needed. Table 2 shows the six main losses of any production plant [19]. The impact that 4industry has on these six losses will be shown to reflect how 4Industry can improve the OEE.

Overall Equipment Effectiveness	Six Big Losses (TPM)
Availability Loss	Unplanned Stops
	Planned Stops
Performance Loss	Small Stops
	Slow Cycles
Quality Loss	Production Rejects
	Startup Rejects

Table 2: Breakdown of OEE [19]

3.2.2 Safety, Health and Environment (SHE) CULTURE

SHE is concerned with the practical aspects of protecting the environment and maintaining the health and safety of employees. It aims to implement organized efforts and procedures that discover workplace hazards, prevent accidents and exposure to dangerous situations and substances. Another focus is to train employees in PPE use, accident prevention, emergency preparedness, and accident response [26].

SHE is important because it protects people, and is often strictly regulated by the government. To encourage and track SHE culture, there are multiple modules built into 4Industry to facilitate knowledge sharing around SHE issues and reduce the number of incidents and accidents that occur on the shop floor.

3.2.3 Continuous Improvement (CI) Culture

Continuous Improvement is a term used within the industry to describe the focus on improving any part of the operations on a continuous basis with the involvement of every employee—not only a specific person/department nor only during specific periods like audits. It is still common for organizations to have dedicated CI teams due to the lack of a user-friendly process where Improvement Ideas (IIs) can be registered, assessed, and tracked by everyone.

Given the mobile functionality of 4Industry, everyone on the shopfloor can take part in this culture by means of a user-friendly mobile application. As a broader group of people (operators, shift leaders, supervisors, office staff, and managers) are able to register new IIs, more ideas and specifically more diverse ideas can be registered.

3.3. Chapter Summary

In this chapter, the aim was to understand the functionality of 4Industry and identify its impact areas. To do so, an in-depth look into how the connected worker platform works and what features it has are investigated. By doing so, it was better understood how this product helps on the shop floor and with this information, three impact areas were discovered: OEE, SHE Culture and CI Culture. Now, focus can be put into discovering KPIs which can be linked to these impact areas.

4. Finding the KPIs

This chapter is aimed at answering the fourth research question, 'How to identify the quantitative value drivers with respect to the impact areas?' and the fifth research question, 'How to measure the quantitative value drivers?'

4.1. The search for KPIs

The first step in this process is to understand which KPIs are known and used within the manufacturing industry. To determine this, a combination of relevant literature and industry expert sources were consulted.

For each of the three impact areas defined in Chapter 3, a separate search is conducted. The search led to discovering a large number of KPIs which can be used to manage and improve manufacturing operations. However, every KPI discovered cannot be concluded as a value-driver of 4Industry.

4.2. KPI Filtering

It is important to note that not all KPIs discovered can be impacted by 4Industry, nor can all of them be measured accurately. Therefore, a set of criteria is necessary to filter the list of KPIs that are relevant for this study. In consultation with industry experts within Plat4mation (the company that owns and implements 4Industry), a selection criteria—as shown in Table 3—will facilitate in the KPI filtering process.

Criteria	Description	Example
Relevance	It must contribute to any of the three Impact Areas and it must be influenceable by 4Industry.	**MTTR** is relevant because it can be directly linked to OEE (unplanned stops) and can be influenced by 4Industry **Asset Turnover** is not relevant because it can't be linked to any of the impact areas and can't be influenced by 4Industry
Measurability	The KPI should be measurable in an objective and quantifiable way, not needing an extensive or expensive set-up.	**Time taken for scheduled maintenance** can easily be measured in 4Industry by looking at the open and close timestamps in the database **Manufacturing Lead Time** (Manufacturing Lead-time = pre-processing + processing + post-processing) is a metric that requires measurements to be conducted in different locations, some of which cannot be accessed or influenced by 4Industry

Table 3: Criteria for KPI Filtering

4.3. KPI Categorizing

Categorization of the KPIs is made to structure the outcome in a way that makes it both useful and understandable. The first level of categorization are the three Impact Areas as already mentioned (OEE, SHE Culture and CI Culture).

All KPIs impacting OEE will be linked with one (or more) of the six losses. A second level of categorization is then made as some KPIs will have a direct influence on the OEE (like time-saving), while others will have only an indirect impact (like knowledge sharing). Below follows a description of how these two groups are distinguished:

1. Directly Impacting OEE: These are the KPIs that will directly influence OEE as they can directly influence one of the six losses. They will always have the unit of time.
For example, if MTTR improves by 12 units of time, then it can be concluded that the unplanned stop also reduces by 12 units of time.

2. Indirectly Impacting OEE: These are the KPIs whose measured improvement can only be correlated to improving OEE with logical reasoning. The exact influence in value cannot be shown, because they don't have a unit of time.
For example: If the quality of knowledge articles improves from a score of 3.5 to 4.5, it can be argued they would help fix issues quickly and reduce the unplanned stop, but this improvement in 1 point cannot be translated into units of time by which the unplanned stop would reduce.

Additionally, each KPI is assigned a measuring unit and indicator of what a good value would be.

4.4. Industry KPIs

In Table 4, Table 5 and Table 6, the final list of KPIs discovered can be reviewed. These are relevant and measurable and can be linked to one of the three impact areas.

Impact Area OEE

KPI	Unit	KPI Category	Indicator
Changeover Time is the time it takes to transition a machine or production line from working on one product to another	Time	Direct OEE	The lower, the better
Time taken for planned maintenance is the measurement of the time it takes to complete a scheduled maintenance task	Time	Direct OEE	The lower, the better
Planned maintenance percentage measures the number of Planned Maintenance tasks in comparison to all Maintenance tasks	Percentage	Indirect OEE	The higher, the better
Mean Time To Repair (MTTR) measures the average time it takes to troubleshoot and repair an equipment failure	Time	Direct OEE	The lower, the better
Number of Knowledge Articles created is a measure of new knowledge articles	Amount	Indirect OEE	The higher, the better

added to the knowledge database of a client			
Quality of Knowledge Articles is the measure of how useful a knowledge article is to an operator	Score	Indirect OEE	The higher, the better
Operator Efficiency is the time spent doing value-added tasks divided by the total time an operator is on duty	Percentage	Indirect OEE	The higher, the better
Setup Time is the time spent adjusting the settings on a machine so that it is ready to process a job	Time	Direct OEE	The lower, the better

Table 4: Industry KPIs linked to Impact Area OEE

Impact Area SHE Culture

KPI	Unit	Indicator
Health and Safety Incidence Rate measures the incidents that happen during employee work hours	Rate	The lower, the better
Lost Time Incident Frequency measures the injuries that occur in the workplace that result in an employee's inability to work the next full work day, which occur in a given period relative to the total number of hours worked	Rate	The lower, the better
Results of Audits measure the score achieved after conducting a safety audit	Score	The higher, the better
Employee Turnover It is the measures the number of employees who quit compared to the total number of employees over a period of time	Rate	The lower, the better
Time taken to resolve incident measures the time taken to resolve a safety incident or hazard	Time	The lower, the better

Table 5: Industry KPIs linked to Impact Area SHE Culture

Impact Area CI Culture

KPI	Unit	Indicator
Number of improvement ideas implemented measures the improvement ideas that are implemented in the production environment	Amount	The higher, the better

Table 6: Industry KPIs linked to Impact Area CI Culture

4.5. 4Industry sub-KPIs

Performance of the KPIs presented in the previous section could depend on multiple factors, some of which 4Industry can improve and some which it can't. For example, the KPI 'Employee Turnover' could depend on factors like wages and compensation, which 4Industry has no control over. However, it could also be influenced by things like how safe someone feels at their job or how stress-free their job is, which 4Industry can Influence.

That is why it is decided to create a defined spectrum of sub-KPIs on which 4Industry has a clear impact. These KPIs will be then linked to the industry KPIs that was discovered in the previous section.

In Table 7, Table 8 and Table 9, an overview of the sub-KPIs can be found, categorized the same as the Industry KPIs.

Impact Area OEE

KPI	Unit	KPI Category	Indicator
Time Taken to perform CIL is the measure of the time spent in completing a changeover	Time	Direct OEE	The lower, the better
Number of times Operators perform Maintenance activities is the measurement of times operators present on the shop floor perform corrective maintenance activities	Amount	Indirect OEE	The higher, the better
Number of CIL Conducted is the total number of Cleaning, Inspection and Lubrication (CIL) conducted on equipment in a production operation	Amount	Indirect OEE	The higher, the better
Number of Maintenance instructions saved is the total amount of new corrective maintenance instructions saved	Amount	Indirect OEE	The higher, the better
Time Taken for maintenance team to react is the measurement of the time taken by the maintenance team to start working on a task after being registered	Time	Direct OEE	The lower, the better
Average Time taken to access Knowledge articles is the perception of time based on operator feedback when searching for knowledge articles	Score	Indirect OEE	The lower, the better
Time taken to Resolve Deviation is the measurement of the time taken to resolve a deviation that has happened	Time	Direct OEE	The lower, the better

Time Taken to Register Deviation is the measurement of the time taken by the operator to register a deviation that has happened	Time	Direct OEE	The lower, the better
Time Taken to complete routine task	Time	Direct OEE	The lower, the better
Time Taken to conduct Root cause analysis is the measurement of the time spent conducting a root cause analysis	Time	Direct OEE	The lower, the better
Number of root-cause analysis required is the measurement of the number of root cause analyses being conducted in the manufacturing plant	Amount	Indirect OEE	The lower, the better
Number of Task required to resolve Deviation is the measurement of the number of tasks required to resolve a deviation	Amount	Indirect OEE	The lower, the better

Table 7: 4Industry sub-KPIs linked to Impact Area OEE

Impact area SHE Culture

KPI	Unit	Indicator
Number of Preventive Actions taken measures the number of precautionary actions taken to make the production environment safer.	Amount	The higher, the better
Employee sense of safety is the measurement of how safe an operator feels in his production environment	Score	The higher, the better
Employee Happiness/Satisfaction is the measurement of how happy and satisfied an operator feels at his work	Score	The higher, the better

Table 8: 4Industry Sub-KPIs linked to Impact Area SHE Culture

Impact area CI Culture

KPI	Unit	Indicator
Number of improvement ideas submitted measures the amount of improvements ideas being registered by every person on the shop floor who has 4Industry	Amount	The higher, the better
Number of improvement ideas shared across facilities measures the number of improvement ideas that are shared between different production plants in an organization	Amount	The higher, the better

Table 9: 4Industry sub-KPIs linked to Impact Area CI Culture

4.6. Measuring the KPIs

The goal is to come up with a measurement methodology for the KPIs, both before and after the implementation of 4Industry. The reasoning for before 4Industry is so that baseline measurements can be conducted. A baseline measure can be defined as the data before any objective action is applied to it. It aims to establish the starting point of any process or metric, from which the improvements are calculated [21]. The reason to conduct this baseline measurement for the KPIs is so that it can be shown to clients how much improvement has been made after implementing 4Industry.

To determine this, discussions were held with the stakeholders in the company and also with some of their clients to determine how and which KPIs are currently being measured. For measuring after 4Industry implementation, it was discussed with the technical consultants, configurations for which KPIs are possible to directly measure in 4Industry. In the end, the following methods are discovered for measuring all the KPIs

4.6.1 4Industry sub-KPIs

From Table 10, it can be understood how some of the 4Industry sub-KPIs shall be measured both, before and after the implementation of 4Industry and whether measuring them in 4Industry is possible. To review this for all the sub-KPIs, please refer Appendix B.

KPI	Before 4Industry	After 4Industry	Is it possible to measure in 4Industry
Time taken to perform CIL	SP: 1st step of CIL EP: Last step of CIL	SP: Start of task EP: End of task	Yes
Number of times Operators perform Maintenance activities	Counter: how many maintenance WI available for and used by operators?	Counter: nr of records (incidents with maintenance category but solved by operator)	Yes
Number of CIL conducted	Counter: how many CIL's available for and used by operators?	Counter: how many maintenance CIL's stored as assessment/job	Yes
Number of Maintenance instructions saved	Counter: how many maintenance WI available for and used by operators?	Counter: nr of records(articles with maintenance category and access)	Yes

Table 10: 4Industry sub-KPIs measurement methodology

4.6.2 Industry KPIs

From Table 11, it can be understood how some of the Industry KPIs shall be measured both, before and after the implementation of 4Industry and whether measuring them in 4Industry is possible. To review this for all Industry KPIs, please refer Appendix B.

KPI	Before 4Industry	After 4Industry	Is it possible to measure in 4Industry
Changeover time	SP: 1st step of CO EP: Last step of CO	SP: Start of job EP: End of job	Yes
Time Taken for Planned Maintenance	SP: Start time of planned stop EP: End time of planned stop	SP: Start time of planned stop EP: End time of planned stop	No
Planned maintenance percentage	(Planned Maintenance task/All maintenance task) in specific time frame	(Planned Maintenance task/All maintenance task) in specific time frame	No
Mean Time To Repair (MTTR)	SP: Equipment related defect is registered EP: Equipment related defect is resolved	SP: Equipment related defect is registered EP: Equipment related defect is resolved	Yes

Table 11: Industry KPIs measurement methodology

4.7. Chapter Summary

In this chapter, the aim was to discover KPIs which can be linked to one of the three impact areas of 4Industry. To search for them. literature and industry-expert sources were consulted and this lead to a pool of KPIs. To filter them, two criteria were set up: relevancy and measurability. Using these criteria, a discovery is made of KPIs which are commonly used in the manufacturing industry. However, it was realized that performance on these KPIs can be influenced by multiple factors, some of which 4Industry can't influence. So to better represent 4Industry contribution, custom sub-KPIs that 4Industry can clearly impact are created and they are linked to the industry KPIs. The focus was then put into discovering a way to measure all the KPIs, both before and after the implementation of 4Industry. To do so, discussions were held with relevant individuals who held knowledge about this. In the end, a table was created which would provide how to measure them and whether this measurement is possible in 4Industry.

5. Mapping the KPIs to Impact areas

In this section, the aim is to build the framework. Relation between the Industry KPIs and the 4Industry sub-KPIs will be defined and visualized. For the visualization, a KPI tree is used. After that, for each KPI logical reasoning is stated to explain why their performance will improve because of 4Industry.

5.1. KPI Tree

A KPI tree is a visualization technique in which an organization's goals can be broken down into more granular outcomes with relevant KPIs, or metrics. This helps in establishing a clear cause-and-effect relationship between the metrics and can provide a structured overview to reach the goal [20].

In Figure 9, the KPI tree represents the KPIs with their respective impact areas. It can be observed, that there are two levels of KPIs. The 4Industry sub-KPIs are linked to either one or multiple Industry KPIs. For the impact area OEE, the Industry KPIs are further linked to one of the six losses, because the target is to improve them, whereas in the case of impact area SHE Culture and CI Culture, the target is to improve the industry KPIs themselves.

The contributions of the 4Industry sub-KPIs *Time taken to register deviation* and *Time taken to resolve deviation* is spilt because only equipment-related deviations can be linked to MTTR, whereas non-equipment-related belong to Operator Efficiency.

Each KPIs characteristics are also defined by using small icons next to them. The characteristics defined are the measuring unit, the indicator value and whether they can be measured in 4Industry.

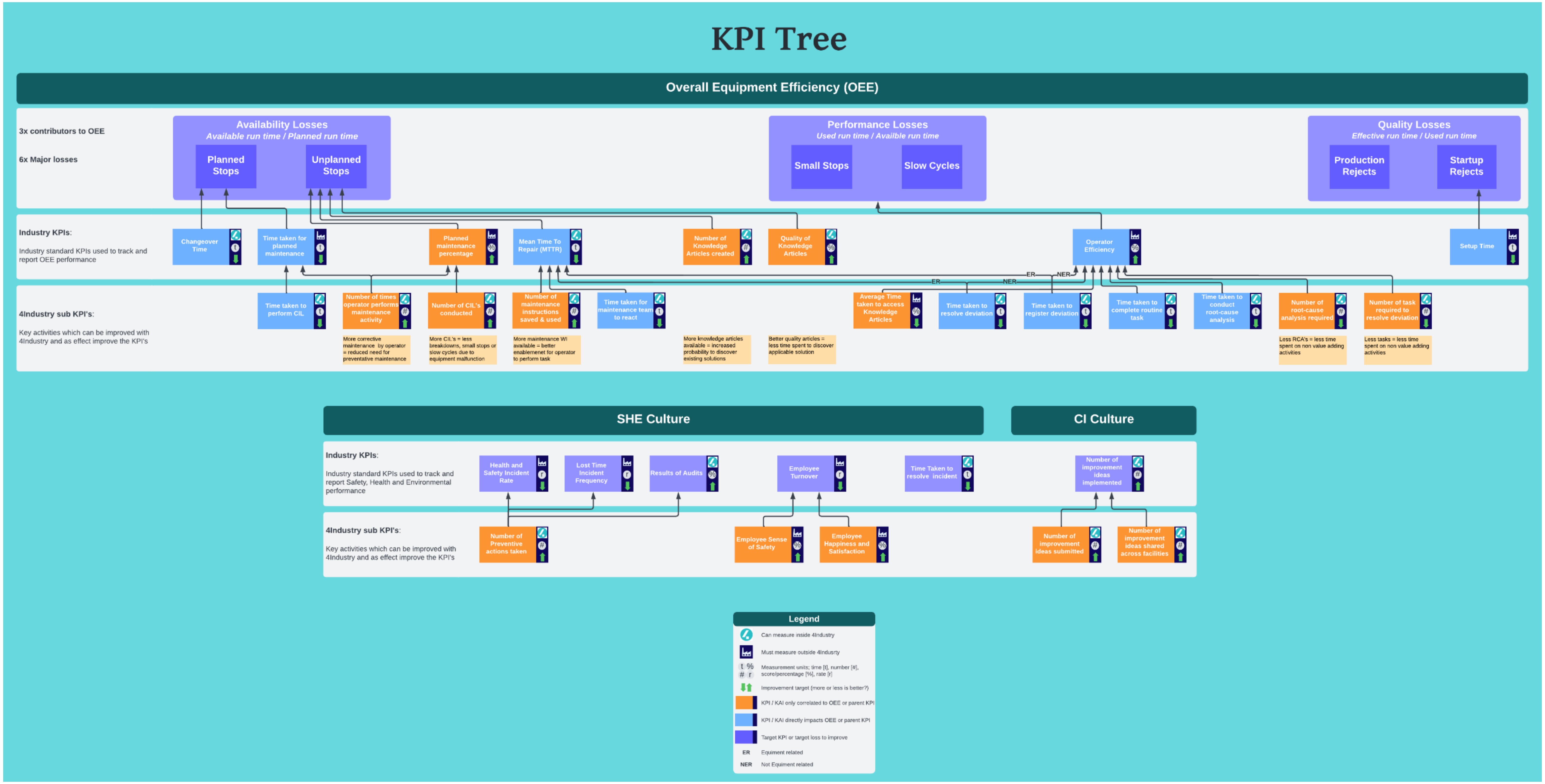

Figure 8: KPI Tree representing impact area of 4Industry

5.2. KPI Performance improvement justification

The KPI Tree has hierarchically represented the relationship between KPIs. Now, the reasoning will be provided as to why these KPIs will improve because of 4Industry through the following tables. Before doing so, let's define the columns of the table:

Logical Reasoning: This column will explain why using 4Industry will improve KPI performance

Condition: This column explains how 4Industry must be used to gain the improvement

Impact: This column discusses how will the improvement in the KPI will improve the target loss or culture

5.2.1. 4Industry Sub-KPIs

In Table 12, it can be clearly understood why will 4Industry improve some of the sub-KPIs and the conditions in which the digital manufacturing platform has to be used to achieve that improvement. To review this for all the sub-KPIs, please refer Appendix D.

Loss and/or impact area	KPI	Logical Reasoning	Condition	Impact
OEE (Planned Stop)	Time Taken to perform CIL	If operators can quickly access clear instructions for the changeover on their phones, they don't have to spend time searching for this information	• All CIL checklists to be saved as Jobs/assessment s	Is CIL is conducted quicker = the production line will be more quickly ready for operations = less planned stop
OEE (Unplanned Stop)	Number of times Operators perform Maintenance activities	If operators can perform corrective maintenance through accessing knowledge base, the MTTR should be quicker cause we don't have to wait for maintenance team to visit the shop floor	• Knowledge articles are available in the mobile app in the hands of the operator • Step by step procedure available in the app	If more operators perform corrective maintenance = maintenance time will be quicker = less unplanned stop
SHE	Number of Preventive actions taken	Because of better insights, the SHE team will be able to make data-driven preventive actions	• Dashboard insights to review the places which need major improvement/are hotspots of incidents	If more preventive action are taken = lesser are the chances of accidents or

			• Continuous Improvement, ideas gathering for improving SHE	incidents to happen
CI	Number of Improvement ideas submitted	The modules of 4Industry allow everyone on the shop floor to share their ideas through the app	• Easy to register idea through operator phone	If more ideas are submitted = more improvements possible

Table 12: 4Industry sub-KPIs improvement justification

5.2.2. Industry KPIs

In Table 13, it can be clearly understood why will 4Industry improve some of the Industry KPIs through contributions from the underlying sub-KPIs or through conditions in which the digital manufacturing platform has to be used to achieve that improvement. To review this for all the Industry KPIs, please refer Appendix D.

Loss and/or impact area	KPI	Sub KPIs or Conditions	Logic	Impact
OEE(Planned Stop)	Changeover time	Conditions • All CO instructions to be saved as Jobs	Because of all instructions being stored in the operators phone, they can quickly lookup and start the process	If less time is spent on changeover = the planned stop will be less
OEE (Planned Stop)	Time Taken for Planned Maintenance	Time taken to perform CIL	If a CIL can be done quicker, then the assigned planned maintenance can be finished quicker	If less time is spent on planned maintenance = the planned stop will be less
		Number of times Operators perform maintenance activities	If operators can do the planned maintenance themselves, then no time has to be spent waiting for the maintenance team	

SHE	Health and Safety Incidence Rate	No of Preventive actions taken	If more preventive actions are taken, then the chances of an incident happening should reduce	If Health and safety incident rate decreases = indication of a safer workplace
CI	Number of improvement ideas implemented	Number of improvement ideas submitted	If more ideas are submitted, more of them can be implemented after assessment	If more improvement ideas are implemented = indication of a better CI program
		Number of implemented ideas shared across facilities	If more ideas are shared across facilities, more of them will be implemented	

Table 13: Industry KPIs improvement justification

5.3. Chapter Summary

In this chapter, emphasis is put on arranging all the KPIs selected and providing logical reasoning as to why 4Industry shall improve their performance. To arrange and visualize them, a KPI tree is used. This map clearly represents the KPIs and sub-KPIs under each impact area and the links between them. After building this map, the focus is put on explaining why each KPI will improve and the conditions under which the digital manufacturing platform has to be used to gain this improvement.

6. Tool for showing OEE contribution

In the previous sections, setting up the KPI-based value assessment framework is completed. The stakeholders of this project are now interested in creating a tool through which they can determine the contribution of 4Industry in improving OEE, by displaying a breakdown under each loss of contributing KPIs. In this section, the focus will be on developing such a tool.

6.1. Aim

The reason for making this tool is so that the data from the measured KPIs can be input to represent OEE improvements. Clients already have their own MES systems which are used to check improvements/decrements in OEE, however, the OEE is dependent on multiple factors, all of which cannot be influenced by 4Industry. That is why, to represent the contributions of 4Industry in influencing OEE, a tool will be made, which would compile the performance of KPIs and represent the improvements from them into one of the three losses of OEE. Using this tool, 4Industry will be able to credibly show and argue for the improvements they have made for sure in their clients' OEE.

6.2. Design and Development

Functional Requirements

Functional requirements are used to describe what the tool should be capable of doing for the end users. In this case, the tool should be able to take in data on KPI performance, both before and after the implementation of 4Industry. Using this data, the tool should provide an overview of how much each KPI has improved/deteriorated. Apart from that, the KPIs which are in the unit of time shall be relevantly summed up to show their contribution to one of the three losses of OEE. Finally, the tool should also provide a breakdown of all the KPIs per loss, whether their contribution be directly (as their unit is time) or only through correlation (as their unit is not time). Apart from this, it shouldn't be too challenging to operate and should be easily navigable by the end users.

Technical Requirements

The tool shall be able to compute arithmetic functions quickly to provide an overview of KPI performance and loss contribution. It should be able to appropriately adjust changes in the entire system when changes are made to the input data.

Based on the requirements discussed above, it was decided to use Microsoft Excel to build the tool. This is because it is software which is used universally in the industry and all stakeholders and clients of 4Industry are well versed in it. Apart from that, it is able to quickly do the arithmetic calculations and is customizable as per the tool requirements.

So using excel, the required OEE calculation tool was made, which can be reviewed in Figure 10. In the further sections, it would be explained how the tool works.

4Industry sub-KPI	Input Before 4Industry	Input After 4Industry	Equipment Related or non-Equipment related
Time Taken to perform CIL	30	22	Not Applicable
Time Taken for maintenance team to react	13	9	Not Applicable
Time Taken to resolve deviation	28	20	ER
Time taken to register deviation	7	5	ER
Time Taken to complete routine task	12	8	Not Applicable
Time Taken to conduct root-cause analysis	11	8	Not Applicable
Number of times operators perform maintenance activities	13	17	Not Applicable
Number of CILs conducted	4	7	Not Applicable
Number of instructions saved and used	0	5	Not Applicable
Average Time taken to access Knowledge Articles	2	4	Not Applicable
Number of root-cause analysis required	12	7	Not Applicable
Number of task required to resolve deviation	13	8	Not Applicable

Industry KPI	Input Before 4Industry	Input After Industry	Independent from sub KPI
Changeover Time	56	25	Not Applicable
Time taken for planned maintenance	25	17	0
MTTR	24	15	0
Operator Efficiency	40	30	3
Setup Time	11	9	Not Applicable
Planned maintenance percentage	63	78	Not Applicable
Number of Knowledge Articles created	14	23	Not Applicable
Quality of Knowledge Articles	2	4	Not Applicable

		Availiability Loss				Performance Loss				Quality Loss	
		Planned Stop	Unplanned Stop							Startup Reject	
		39	14			10				2	
Changover Time	Time Taken for planned Maintencae		Planned maintenance percentage	MTTR		Number of Knowledge Articles created	Quality of Knowledge Articles	Operator Efficiency		Setup Time	
31	8	8	15	10	14	8	9	10	7	2	
Time Taken to perform CIL	Number of times operators perform maintenance activities	Number of CILs conducted	Number of instructions saved and used	Time Taken for maintenance team to react	Average Time taken to access Knowledge Articles	Time Taken to resolve deviation	Time taken to register deviation	Time Taken to complete routine task	Time Taken to conduct root-cause analysis	Number of root-cause analysis required	Number of task required to resolve deviation
8	4	3	5	4	2	8	2	4	3	5	5

Planned Stop	39
Changeover Time	31
Time Taken for Planned Maintenance	0
Time Taken to perform CIL	8
Number of times operator performs maintenance activity	4

Unplanned Stop	14
Planned maintenance percentage	15
MTTR	0
Number of Knowledge Articles created	8
Quality of Knowledge Articles	9
Number of times operator performs maintenance activity	4
Number of CILs conducted	3
Time Taken for maintenance team to react	4
Time Taken to resolve deviation	8
Time taken to register deviation	2

Performance Loss	10
Operator Efficiency	3
Average Time taken to access Knowledge Articles	2
Time Taken to resolve deviation	0
Time taken to register deviation	0
Time Taken to complete routine task	4
Time Taken to conduct root-cause analysis	3
Number of root-cause analysis required	5
Number of task required to resolve deviation	5

Startup Reject	2
Setup Time	2

Legend	
	Actual Measurement
	Certain Improvement
	Plausible improvement

Figure 9: Tool Overview

6.3. Input

For using the tool, input has to be made of KPI performance, both before and after implementation of 4Industry, and in case of Time taken to register deviation and Time taken to resolve deviation, it has to be specified whether it is equipment related or non-equipment related. For now, these inputs are manually made by the operators. The input interface is shown in Figure 11.

4Industry sub-KPI	Input Before 4Industry	Input After 4Industry	Equipment Related or non-Equipment related
Time Taken to perform CIL	30	22	Not Applicable
Time Taken for maintenance team to react	13	9	Not Applicable
Time Taken to resolve deviation	28	20	ER
Time taken to register deviation	7	5	ER
Time Taken to complete routine task	12	8	Not Applicable
Time Taken to conduct root-cause analysis	11	8	Not Applicable
Number of times operators perform maintenance activities	13	17	Not Applicable
Number of CILs conducted	4	7	Not Applicable
Number of instructions saved and used	0	5	Not Applicable
Average Time taken to access Knowledge Articles	2	4	Not Applicable
Number of root-cause analysis required	12	7	Not Applicable
Number of task required to resolve deviation	13	8	Not Applicable

Industry KPI	Input Before 4Industry	Input After 4Industry	Independent from sub KPI
Changeover Time	56	25	Not Applicable
Time taken for planned maintenance	25	17	0
MTTR	24	15	0
Operator Efficiency	40	30	3
Setup Time	11	9	Not Applicable
Planned maintenance percentage	63	78	Not Applicable
Number of Knowledge Articles created	14	23	Not Applicable
Quality of Knowledge Articles	2	4	Not Applicable

Figure 10: Input for the tool

6.4. KPI and loss performance overview

After inputting the data, the tool calculates the difference between the before and after value of the KPIs. This difference can be seen in the light blue cells of the spreadsheet. Apart from the difference, the tool is also programmed to clearly show the contribution of sub-KPIs to the Industry KPIs. For example, for the KPI of MTTR, the calculated difference for the metric is found to be 7 units of time. However, in the KPI framework, it was explained that 4Industry improves MTTR through some sub-KPIs. When the contribution of these sub-KPIs is summed, the metric is improved by 14 units of time. Through this type of breakdown, 4Industry can argue that in reality, the digital manufacturing platform made a certain improvement of the metric by 14 units of time, but due to some external factors, the actual measurement of the metric is discovered to be 7 units of time. All such certain improvements of the Industry KPIs can be seen in the light green cells of the spreadsheet.

Finally, the three losses of OEE are further calculated by summing the contributing sub-KPIs and industry KPIs, which have the units of time. Therefore using this tool, 4Industry can confidently argue that it improved Planned stop by 39 units of time, Unplanned Stop by 14 units of time, Performance loss by 10 units of time and Startup rejects by 2 units of time.

Availiability Loss		Performance Loss	Quality Loss
Planned Stop	Unplanned Stop		Startup Reject
39	14	10	2

Changover Time	Time Taken for planned Maintencae		Planned maintenance percentage	MTTR		Number of Knowledge Articles created	Quality of Knowledge Articles	Operator Efficiency		Setup Time
31	8	8	15	9	14	8	9	10	7	2

Time Taken to perform CIL	Number of times operators perform maintenance activities	Number of CILs conducted	Number of instructions saved and used	Time Taken for maintenance team to react	Average Time taken to access Knowledge Articles	Time Taken to resolve deviation	Time taken to register deviation	Time Taken to complete routine task	Time Taken to conduct root-cause analysis	Number of root-cause analysis required	Number of task required to resolve deviation
8	4	3	5	4	2	8	2	4	3	5	5

Figure 11: KPI and Loss Performance

6.5. KPI Contribution per loss

The tool also lists per loss the contributing KPIs and sub-KPIs. This way, it can be quickly discovered from where did the improvements in the loss come from. The loss is basically the sum of all the directly contribution KPIs. This means it is sure that at least this much improvement is achieved, however in reality the improvement might be even higher due to the contribution of the KPIs which can only be correlated.

Planned Stop	39
Changeover Time	31
Time Taken for Planned Maintenance	0
Time Taken to perform CIL	8
Number of times operator performs maintenance activity	4

Unplanned Stop	14
Planned maintenance percentage	15
MTTR	0
Number of Knowledge Articles created	8
Quality of Knowledge Articles	9
Number of times operator performs maintenance activity	4
Number of CILs conducted	3
Time Taken for maintenance team to react	4
Time Taken to resolve deviation	8
Time taken to register deviation	2

Performance Loss	10
Operator Efficiency	3
Average Time taken to access Knowledge Articles	2
Time Taken to resolve deviation	0
Time taken to register deviation	0
Time Taken to complete routine task	4
Time Taken to conduct root-cause analysis	3
Number of root-cause analysis required	5
Number of task required to resolve deviation	5

Startup Reject	2
Setup Time	2

Figure 12: KPI Contribution per loss

6.6. Improvements

In this section, it will be discussed how to potentially improve this tool.

First of all, it could be made visually more appealing and have a better interface. More information could be embedded into the spreadsheet like instructions and what the tool does. Currently, data has to be entered in manually and this can be a tedious process. To make it more efficient, it would be better to automate it. The tool could be connected to 4Industry and it would automatically provide data for making the calculations. It is also possible to change the platform of this tool from Excel to a more advanced dashboarding software, as they will provide business intelligence tools which can bring better insights from the data and find hidden trends. This type of information can help in showing which KPIs have a better potential for improvement and 4Industry consultants can better configure and train operators in features to improve that KPI.

6.7. Chapter Summary

In this chapter, the aim was to develop a tool, which could clearly show how much improvement is made to OEE by 4Industry, using the KPIs in the framework. After defining the requirements of this tool, it is decided to use Microsoft Excel to develop the tool. Using basic arithmetic functions the tool is made and can now show how the three losses of OEE have improved and by how much since the implementation of 4Industry.

7. Evaluation and Conclusion

In this chapter, the aim is to answer the sixth research question, 'How can deliverables from this project be used in communicating the value to the clients?' and reflect on the research approach taken in this thesis.

7.1. Evaluation

In the previous chapters, the value assessment framework and a tool were made. Now focus will be put on understanding how these deliverables can be used by the company. To find out, discussions were done with the consultants and sales department of 4Industry.

All the research and findings for creating the value-assessment framework have been summarized in detail in the 4Industry value stream map, as seen in Appendix E. Now, this map will be used to clearly show potential customers which processes could improve in their production plants after implementing 4Industry. This can help the customer in making an assessment on whether 4Industry is something for them and where could it save them time and money. Apart from that, all the details in the map can be used for justifications and answering questions that the customers might come up with.

If the customer decides to go ahead with the roll-out, measurements for the KPIs will be made and the improvements will be shown. This way, the customer will be able to see the impact clearly and this would improve their customer satisfaction rate and increase the chances of further roll-out for 4Industry.

After this project, the company plans to already start implementing this framework with one of its clients. The plan is to first make baseline measurements of the KPIs in a factory where 4Industry isn't being currently used. After making the baseline measurements, 4Industry will be rolled out there and after some time, the measurements for the KPIs will be conducted again, to evaluate the difference and represent the impact of using the connected worker platform. So this will allow them to test this framework and create an implementation strategy using the outcomes, and then it can be replicated in every new factory where 4Industry is implemented.

Over time, data for these KPIs can be aggregated from multiple locations and case studies can be made with clients. This will enable them to create historical records based on this framework. This will give the company more credibility for using their product and better marketing material to attract more customers.

By numerically representing the improvements of these KPIs and also showing their contributions in improving OEE using the tool, the company can now clearly show its clients how using 4Industry has benefitted their production operations. So this value-assessment framework and tool is a reusable asset for the company, which would potentially help them drive sales and transparently show the benefits to their clients.

7.2. Conclusion

Whenever a new product or service is launched in the market, organizations need a way to show their target customer base what value it would offer to them. For customers in B2B markets, it is vital that they can understand how a product or service would add value to their organization and prefer to see this value quantitatively, so they can evaluate whether investing in it would be worth it.

This was an issue that 4Industry was facing, they did not have a quantitative way to communicate to their clients how and where their digital manufacturing platform adds benefits. Through this thesis project, the aim was to build a value-assessment framework for them in a quantified way. To do so, the main research question was "How to identify quantitative value drivers, that can be easily communicated with the clients of 4Industry?" To facilitate this thesis, the Design Science Research Methodology was selected as it is focused on building an artefact and in this project the intended artefact is a value-assessment framework. To further proceed, the main research question was broken down into six sub-research questions, which shall be reviewed one by one.

1) How to quantify value for B2B sales?
The reason for asking this research question was to gain knowledge about value quantification. A literature review was conducted and a five-step value quantification cycle was discovered. The focus of this process is to discover the unmet needs of customers and resolve them through the product or service while providing a measurable benefit from resolving them. This step-by-step approach can act as a framework for any firm in the B2B market and provided the background theory for creating the value-assessment framework in this project. For more details, please refer Chapter 2.

2) What are the performance measurement methods used in the manufacturing industry?
The reason for asking this research question was to find a method which already exists in the industry because for effective value communication, it has to be in a language that the customer would understand. For answering this question, a literature review was conducted. In the end, it was discovered that Key Performance Indicators (KPI) are the main method of reviewing and tracking performance in the manufacturing industry. So it was concluded that the value which 4Industry provides should be communicable in the form of KPIs. Finally, it was decided that the value drivers will be KPIs whose performance will improve because of using 4Industry on the shop floor. For more details, please refer Chapter 2.

3) In which area of production operations does 4Industry make an impact?
The reason to ask this question was to discover areas in production operations where 4Industry makes improvements by facilitating better workflows. To do so, the digital manufacturing platform was investigated in detail and its modules were understood. From this study of the platform, three impact areas were concluded: Overall Equipment Efficiency, Safety, Health & Environment Culture and Continuous Improvement Culture. For more details please refer Chapter 3.

4) How to identify the quantitative value drivers with respect to the impact areas?
This question aimed to search and filter KPIs with respect to the three impact areas. To do so, literature and expert online sources were consulted, which lead to a pool of different KPIs. To filter through them, two criteria were defined: relevancy and measurability. After this, a final list of Industry standard KPIs were ready. However, to more concretely show the impact, it was decided to create custom sub-level KPIs, which can be more concretely influenced using 4Indusrty and their influence would influence the industry KPIs. Finally, the relations between the KPIs and sub-KPIs are logically explained and mapped using a KPI tree. For more details please refer to Chapter 4 and Chapter 5.

5) How to measure the quantitative value drivers?
This question aimed to have a clear way of measuring each of the KPIs. To do so, discussions were held with relevant parties to identify how each of these KPIs shall be measured. Apart from that, a tool was also built to measure the impact of 4Industry on OEE. For more information, please refer Chapter 4 and Chapter 6.

6) How can deliverables from this project be used in communicating the value to the clients?
This question aimed to evaluate the outcomes of this research and identify how these outcomes can be used to address the core problem of this thesis: No quantifiable value

drivers are known. By the end of this research, a KPI-based value-assessment framework is created and summarized in detail through the 4Industry value stream map in Appendix E. Using this, potential customers and clients can be given a quick review of which metrics and processes will improve because of 4Industry and by how much. So now it is possible to show the impacts of this product in a tangible way. For more information, please refer Chapter 7.

Through the above six questions, the core problem and main research question are resolved by the creation of the KPI-based value-assessment framework. Now the company can clearly show its value drivers to customers and create analytical assessments of using 4Industry in their production operations.

7.3. Recommendations

In this section, recommendations for the company will be shared.

4Industry should use the value stream map as one of its main marketing materials because it offers a great overview of what value it can bring to its clients and includes all important details which can explain why this value can be achieved.

When bidding with new customers, 4Industry should ensure to understand what customers hope to achieve using their product. Then it should look into how those targets could be defined by the KPIs in this framework or create new KPIs if possible.

In fact, 4Industry should also be open to discovering other KPIs which could potentially fit into this framework, especially if they add new modules and functionalities. They could also come up with custom client-specific KPIs, this way clients can focus on targets they envisioned to improve using a digital manufacturing platform.

7.4. Improvements

In this section, it will be discussed how the value-assessment framework could be improved.

Due to time constraints, there wasn't an opportunity to validate the KPIs by measuring them at clients of 4Industry. That's why currently this framework is entirely theoretical and in reality not all KPIs might perform the way discussed. Therefore, the company should aim to validate and iterate this framework by evaluating KPI performance at different clients. This process will add more credibility to the framework.

Currently, the framework only accounts for processes or scores which would improve on the shop floor, however, it doesn't give any financial implications, i.e. it doesn't explain what types of cost could be saved and by how much. So it is left to the clients to determine the financial implications of using 4Industry. To better convince them, the framework could be expanded to also represent how costs can be saved or more revenue generated can be generated because of using the connected worker platform.

Apart from the above-mentioned, at this point, there are no other improvements that the project stakeholders can think of. However, as the framework will be used with clients, the company should be open to receiving potential feedback or criticism about this framework and aim to address them appropriately.

7.5. Reflection

In this section, the research approach of this thesis will be reflected.

The main objective of this project was to create a method to quantitatively communicate the value of a supplier in the B2B market. For doing so, a structured approach is applied based on the value quantification cycle. This process can be applied to any product or service, where the customers are looking to analytically interpret the benefits.

The approach taken in this thesis can be replicated for any study aiming to quantify value or build a performance measurement system. This is because this research systematically provides guidelines on how to define and create measurable metrics which are used to build such systems or quantify value.

From this research, the biggest learning for a company like 4Industry is that it is essential to understand the goals of your customer and cater your product or service into achieving these goals. A methodology to evaluate the achievement of these goals should be clearly in place to track success. Apart from that, focus should also be put into making good collaborative customer relationships to better define and reach such goals.

In this project, all the research was conducted within the bounds of the company. Another way to approach this project could be one which would involve the active participation of the clients of 4Industry. Interviews could be conducted with them to understand what they hope to achieve using 4Industy and the framework could be built based on that. However, given that different customers will have different goals, it might not be suitable for creating a universal framework which can be used with every customer. Regardless, their insights would be helpful and as further work, it's recommended to 4Industry to reach out to their clients and customize this framework with respect to their goals.

7.6. Limitations

In this section, some limitations of this research shall be discussed.

The KPI-based framework is completely theoretical, as due to time constraints, there was not an opportunity to operationalize and validate the KPIs with data. Therefore, in reality, not every KPI might perform the way it is argued in this research. In this project, most of the decisions were made after interviews or discussions, and limited empirical evidence was used. So there could be a chance of personal bias or misinterpretations of information in the process.

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Appendix

Appendix A - Primary list of KPIs and filtering methodology conducted on them

KPI	Relevant	Measurable	In Final Selection
Availability (Uptime / (Uptime + Downtime)	No	Yes	No
Plant Downtime	No	Yes	No
Changeover Time	Yes	Yes	Yes
Manufacturing Lead Time (Manufacturing Lead-time = preprocessing + processing + post-processing)	Yes	No	No
Employee Turnover	Yes	Yes	Yes
Manufacturing Cycle Efficiency	No	Yes	No
Operator Efficiency	Yes	Yes	Yes
Resource Capacity	No	No	No
Quality of Knowledge article	Yes	Yes	Yes
Demand Forecasting	No	No	No
Preventive maintenance compliance	No	Yes	No
Mean Time Between Failures (MTBF)	No	Yes	No
Percentage of wrench time	Yes	No	No
Unscheduled downtime	No	Yes	No
Total maintenance cost	No	Yes	No
Health and Safety Incidence Rate	Yes	Yes	Yes
Lost Time Incident Frequency (Rate)	Yes	Yes	Yes
Manufacturing Cost	No	Yes	No
Planned maintenance percentage	Yes	Yes	Yes
Results of Audits	Yes	Yes	Yes
Asset Turnover	No	Yes	No
Number of improvement ideas implemented	Yes	Yes	Yes
Scrap Rate	No	Yes	No

Number of Knowledge Articles Created	Yes	Yes	Yes
Average Time Taken to access knowledge article	Yes	Yes	Yes
First Pass Yield	No	Yes	No
Mean Time To Repair (MTTR)	Yes	Yes	Yes
Customer Return Rate	No	Yes	No
Defect Density	No	Yes	No
On – Time Completion	No	Yes	No
Productive Days %	No	No	No
Setup Time	Yes	Yes	Yes
Autonomous maintenance	Yes	No	No
Average employee overtime hours	No	Yes	No
Maintenance Backlog	No	Yes	No
Energy Cost Per Unit	No	No	No
Time Taken to Resolve Incident	Yes	Yes	Yes
Total Cycle Time	No	Yes	No

Table 14: KPI Filtering methodology

From Table 14 it can be reviewed which KPIs were considered both relevant and measurable, and therefore selected for the final KPI framework.

Appendix B – Measuring the KPIs

4Industry sub-KPIs

From Table 15, it can be understood how the 4Industry sub-KPIs shall be measured both, before and after the implementation of 4Industry and whether measuring them in 4Industry is possible.

KPI	Before 4Industry	After 4Industry	Is it possible to measure in 4Industry
Time taken to perform CIL	SP: 1st step of CIL EP: Last step of CIL	SP: Start of task EP: End of task	Yes
Number of times Operators perform Maintenance activities	Counter: how many maintenance WI available for and used by operators?	Counter: nr of records (incidents with maintenance category but solved by operator)	Yes
Number of CIL conducted	Counter: how many CIL's available for and used by operators?	Counter: how many maintenance CIL's stored as assessment/job	Yes
Number of Maintenance instructions saved	Counter: how many maintenance WI available for and used by operators?	Counter: nr of records(articles with maintenance category and access)	Yes
Time Taken for maintenance team to react	SP: Moment maintenance is notified EP: Moment maintenance team reacts	SP: Assigned to maintenance EP: State changed to WIP	Yes
Average time taken access Knowledge Articles	Calculated score from survey	Calculated score from assessment	No
Time taken to Resolve deviation	SP: 1st info captured EP: when defect resolved	SP: Deviation registered EP: Deviation resolved	Yes
Time Taken to Register Deviation	SP: 1st info captured EP: info available to start resolving	SP: Deviation draft EP: Deviation registered	Yes

Time Taken to Complete a task or routine	SP: start of task EP: end of task	SP: task opened EP: task closed	Yes
Time taken to conduct root cause analyses	SP: start of RCA EP: RCA reviewed	SP: RCA opened EP: RCA closed	Yes
Number of root-cause analysis required	Counter: how many RCA's performed in certain time frame	Count nr of records (RCA's) in certain time frame	Yes
Number of Tasks required to resolve Deviation	Counter: how many tasks performed to close deviation	Count nr of records with deviation as source	Yes
Number of Preventive actions taken	Counter: preventative actions performed	Count nr of records (preventative actions) with SHE issue as source	Yes
Employee sense of safety	Calculated score from survey	Calculated score from assessment	No
Employee Happiness/Satisfaction	Calculated score from survey	Calculated score from assessment	No
Number of Improvement ideas submitted	Counter: Ideas submitted	Count nr of records (II's)	Yes
No of improvement ideas shared from across facilities	Counter: ideas shared with other plants	Count nr of records (II's) shared globally	Yes

Table 15: 4Industry sub-KPIs measurement methodology

For the KPIs which will be measured via survey, the surveys can be reviewed in Appendix C.

Industry KPIs

From Table 16, it can be understood how the Industry KPIs shall be measured both, before and after the implementation of 4Industry and whether measuring them in 4Industry is possible.

KPI	Before 4Industry	After 4Industry	Is it possible to measure in 4Industry
Changeover time	SP: 1st step of CO EP: Last step of CO	SP: Start of job EP: End of job	Yes

Time Taken for Planned Maintenance	SP: Start time of planned stop EP: End time of planned stop	SP: Start time of planned stop EP: End time of planned stop	No
Planned maintenance percentage	(Planned Maintenance task/All maintenance task) in specific time frame	(Planned Maintenance task/All maintenance task) in specific time frame	No
Mean Time To Repair (MTTR)	SP: Equipment related defect is registered EP: Equipment related defect is resolved	SP: Equipment related defect is registered EP: Equipment related defect is resolved	Yes
Number of Knowledge Articles created	Counter: how many knowledge articles available for and used by operators?	Counter: nr of records (knowledge articles)	Yes
Quality of Knowledge Articles	Calculated score from survey	Calculated score from assessment	Yes
Operator Efficiency	Time spent on value added activities/Total time	Time spent on value added activities/Total time	No
Setup Time	SP: Last step of CO EP: 1st part OK	SP: Last step of CO EP: 1st part OK	No
Health and Safety Incident Rate	Formula - (Number of injuries and illnesses X 200,000) / Employee hours worked	Formula- (Number of injuries and illnesses X 200,000) / Employee hours worked	No
Lost Time Incident Frequency	Formula - ([Number of lost time injuries in the reporting period] x 1,000,000) / (Total hours worked in the reporting period)	Formula - ([Number of lost time injuries in the reporting period] x 1,000,000) / (Total hours worked in the reporting period)	No
Results of Audits	Audit score calculation	Assessment Score calculation	Yes

Employee Turnover	Formula – (Number of Employees who left/((Number of Employees at the beginning + Number of Employees at the end)/2) X 100	Formula – (Number of Employees who left/((Number of Employees at the beginning + Number of Employees at the end)/2) X 100	No
Time Taken to resolve incident	SP: 1st info captured EP: when incident resolved	SP: Incident registered EP: Incident resolved	Yes
Number of improvement ideas implemented	Existing method	Count nr of records	Yes

Table 16: Industry KPIs measurement methodology

Appendix C – Surveys for quantifying KPIs

KPI – Employee Happiness/Satisfaction

Employee Happiness/Satisfaction (after 4Industry)

Please fill the following survey for us to assess Employee Happiness/Satisfaction

1: Strongly Disagree
2: Disagree
3: Somewhat Agree
4: Agree
5: Strongly Agree

aditya.bansal@plat4mation.com (not shared) Switch account

* Required

Has implementation of 4Industry help reduce frustation at your work? *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made your work easier?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made communication easier?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry improved your job satisfaction?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

KPI – Employee sense of safety

Employee Sense of Safety (after 4Industry)

Please fill the following survey for us to assess Employee Sense of Safety

1: Strongly Disagree
2: Disagree
3: Somewhat Agree
4: Agree
5: Strongly Agree

aditya.bansal@plat4mation.com (not shared) Switch account

Has implementation of 4Industry enabled you to access safety knowledge/instructions more easily?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made you feel safer at your workplace?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made it easier to raise concern about SHE issue

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry increased your willingness in reporting SHE issues

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

KPI – Average time taken to access knowledge articles

Knowledge sharing and Access time (after 4Industry)

Please fill the following survey for us to assess Knowledge mangement

1: Strongly Disagree
2: Disagree
3: Somewhat Agree
4: Agree
5: Strongly Agree

aditya.bansal@plat4mation.com (not shared) Switch account

Has implementation of 4Industry made it easier to find potential solutions to solve a problem?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made it faster to find potential solution to solve a problem?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry made Is it easier to access documentation for your work?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Has implementation of 4Industry encouraged you to document your solutions?

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Appendix D – Logical Reasoning

4Industry sub-KPIs logic

From Table 17, it can be clearly understood why will 4Industry improve the mentioned sub-KPIs and the conditions in which the digital manufacturing platform has to be used to achieve that improvement.

Loss and/or impact area	KPI	Logical Reasoning	Condition	Impact
OEE (Planned Stop)	Time Taken to perform CIL	If operators can quickly access clear instructions for the changeover on their phones, they don't have to spend time searching for this information	• All CIL checklists to be saved as Jobs/assessment s	Is CIL is conducted quicker = the production line will be more quickly ready for operations = less planned stop
OEE (Unplanned Stop)	Number of times Operators perform Maintenance activities	If operators can perform corrective maintenance through accessing knowledge base, the MTTR should be quicker cause we don't have to wait for maintenance team to visit the shop floor	• Knowledge articles are available in the mobile app in the hands of the operator • Step by step procedure available in the app	If more operators perform corrective maintenance = maintenance time will be quicker = less unplanned stop
OEE (Unplanned stop)	Number of CIL conducted	Because of tracking and check listing, more CIL can be conducted and completed. The more regularly CIL are conducted, the lower is the probability of equipment failure	• Checklisting available on mobile app • Pre-sorted CIL task for the operators shift	If more CIL are conducted = less probability breakdown = less chances of unplanned stop
OEE (Unplanned stop)	Number of Maintenance instructions saved & used	The more Maintenance instructions are saved in the database, the more maintenance activities operators will be able to	• Digitalized storage of all maintenance Task in the mobile app in the hands of the operator	If more maintenance instructions are saved = operators can perform maintenance themselves =

		perform themselves instead of waiting for Maintenance team		time saved from waiting for maintenance team = less unplanned stop
OEE (Unplanned Stop)	Time Taken for maintenance team to react	Because information can be shared more quickly with the maintenance team, they will be able to react faster to solving a deviation	• Better information provided by operator (pictures, report)	Less time taken for maintenance team to react = more quickly unplanned stop can be resolved = less unplanned stop
OEE (Unplanned Stop)	Average time taken access Knowledge Articles	Because of the UI and Database of 4Industry, operators should be able to more quickly access Knowledge	• Store lessons learned as knowledge articles • Link knowledge article with equipment / failure mode	If knowledge articles can be accessed quicker = deviations can be resolved quicker = less unplanned stop
OEE (Small Stops, Slow Cycles)	Time taken to Resolve deviation	Because of the large database of solutions available in 4Industry, e.g. better task management and easier information flow, problems can be resolved quicker.	• Suggested solutions based on related deviations from the past • Filtering based on criteria like failure mode, equipment etc. • Instant messaging communication linked to deviation	Less time spent to resolve issues = less time spent on non-value added activities
OEE (Small stops, Slow cycles)	Time Taken to Register Deviation	Because of the app and UI of 4Industry, Deviation registration should be quicker	• Use the mobile UI interface	Less time to register deviation = less time spent on non-

				value added activities.
OEE (Slow Cycles)	Time Taken to Complete a routine task	Because of digitalization, certain workflows will be quicker and it is easier to follow long instructions digitally (step-by-step format)	• Relevant routine tasks to be saved as assessments/jobs	If less time is spent to complete task or routine = more valued added task or routine can be done in the same amount of time
OEE (Small Stops/Slow Cycles)	Time taken to conduct root cause analyses	Because of the dedicated modules in 4Industry, it should be faster to conduct root cause analyses	• Dedicated Root-cause analysis module, offering structed approach to operators through their mobile app • Easy to retrieve and share data	Less time spent on root cause analyses = more time available for value added activities
OEE (Slow Cycles)	Number of root cause analysis required	Because of growing knowledge of solutions for deviations, over time there shouldn't be a need to diagnose and conduct RCA for every deviation. Hence the number of required RCA should reduce.	• Suggested solutions based on related analysis from the past • Filtering based on criteria like failure mode, equipment etc.	Less root cause analyses required = less time spent on RCA = more time available for value – added activities
OEE (Unplanned Stop)	Number of Tasks required to resolve Deviation	Because of 4Industry, better task and action management will be achieved ; knowledge growth will allow solving deviations with less tasks	• Suggested solutions based on related deviations from the past • Filtering based on criteria like failure mode, equipment etc.	Less tasks required to resolve deviation = less time spent fixing deviation = less time spent on unplanned stop
SHE	Number of Preventive actions taken	Because of better insights, the SHE team will be able to	• Dashboard insights to review the places which	If more preventive action are

		make data-driven preventive actions	need major improvement/are hotspots of incidents • Continuous Improvement, ideas gathering for improving SHE	taken = lesser are the chances of accidents or incidents to happen
SHE	Employee sense of safety	Because of safety instructions and safety checklist being shared to operators phones, he will be more aware about safety in his environment	• Encourage and enable safety audits • Audit results can be processed (support more training)	If employee feel safer at workplace = it will be an indication of better work culture
SHE	Employee Happiness/Satisfaction	Because of digitalization, many task/communication activities can be done more quickly and easily by the operators phone. This should make work easier and reduce stress compared to before	• Digitalization caters more to the younger workforce • Easy to see all your task on the mobile app • Easy to communicate and get information through the mobile app	If more employees are happy/satisfied = it will be an indication of better work culture
CI	Number of Improvement ideas submitted	The modules of 4Industry allow everyone on the shop floor to share their ideas through the app	• Easy to register idea through operator phone	If more ideas are submitted = more improvements possible
CI	No of improvement ideas shared from across facilities	The modules of 4Industry allow quick sharing of ideas across facilities	• Easy to share ideas globally with a single click of a button	If more ideas are shared = more ideas to implement = indication of a better CI program

Table 17: 4Industry sub-KPIs improvement justification

Industry KPIs

From Table 18, it can be clearly understood why will 4Industry improve the mentioned Industry KPIs through contributions from the underlying sub-KPIs or through conditions in which the digital manufacturing platform has to be used to achieve that improvement.

Loss and/or impact area	KPI	Sub KPIs or Conditions	Logic	Impact
OEE(Planned Stop)	Changeover time	Conditions • All CO instructions to be saved as Jobs	Because of all instructions being stored in the operators phone, they can quickly lookup and start the process	If less time is spent on changeover = the planned stop will be less
OEE (Planned Stop)	Time Taken for Planned Maintenance	Time taken to perform CIL	If a CIL can be done quicker, then the assigned planned maintenance can be finished quicker	If less time is spent on planned maintenance = the planned stop will be less
		Number of times Operators perform maintenance activities	If operators can do the planned maintenance themselves, then no time has to be spent waiting for the maintenance team	
OEE (Unplanned Stop)	Planned maintenance percentage	Number of times Operators perform maintenance activities	If operators are able to perform corrective maintenance task by themselves, then it doesn't have to be scheduled with the maintenance team, hence the corrective maintenance task should reduce	If planned maintenance percentage is higher = corrective maintenance decreases = less unplanned stop

		Number of CILs conducted	If more CIL are conducted, probability of equipment breakdowns should reduce, hence the number of corrective maintenance task should reduce	
OEE (Unplanned Stop)	Mean Time To Repair (MTTR)	Number of Maintenance instructions saved	If more maintenance instructions are saved, there will be a greater pool of solutions for reoccurring or similar problems. Hence time will be saved as you directly start implementing the solution	If MTTR improves = breakdowns and equipment failure are resolved quicker = less unplanned stop
		Time Taken for Maintenance team to react	If maintenance team can react faster, they will more quickly start solving the issue	
		Time Taken to register deviation	If deviation can be registered quicker, the process to resolve it can be started quicker	
		Time Taken to resolve deviation	If an equipment related deviation can be resolved quicker, the line can start running again quicker	

OEE(Unplanned Stop, Small Stop)	Number of Knowledge articles created	Condition • Store lessons learned as knowledge articles • Link knowledge article with equipment / failure mode	The interface of 4Industry encourages Knowledge articles creation and storage in the database linked to deviation	The more knowledge you have = the less time it takes to discover solutions for deviation = unplanned stop can be resolved quicker
OEE(Unplanned Stop, Small Stop)	Quality of Knowledge Articles	Condition • Set up knowledge creation from lessons learned and/or proposed solutions • Set up knowledge article quality rating process	Because of a article usefulness functionality in 4Industry, we can evaluate quality and sort the better quality articles	If knowledge articles are of higher quality = more useful in solving deviation quickly = less unplanned stop
OEE (Small Stops, Slow Cycles)	Operator Efficiency	Average Time Taken to access knowledge articles	If Knowledge articles can be accessed quicker, operator will have to spend less time searching for it	If operators are more efficient = they will do more value added task with the time available to them
		Time Taken to Resolve Deviation	If a deviation is solved faster, the Operator can get back to working faster	
		Time Taken to Register Deviation	Functionality of 4Industry allows quick registration of deviations through operators phone	
		Time Taken to complete routine task	If operator can complete a task or routine more	

			quickly, he can do more value-added activities in the same amount of time	
		Time Taken to conduct root-cause analysis	If an operator spends less time on root-causes analysis, they can resume value-added activities more quickly	
		Number of root-cause analysis required	Less root-cause analysis need to be conducted, less time spent by operators on it	
		Number of task required to resolve deviation	Less task required to resolve deviation, less time spent on non-value-added activity	
OEE (Startup Rejects)	Setup Time	Condition • All Setup instructions to be saved as Jobs	Because of better quality of changeovers, the Setup time should reduce	If Setup time can be reduced = the production line can start quicker = less startup Rejects
SHE	Health and Safety Incidence Rate	No of Preventive actions taken	If more preventive actions are taken, then the chances of an incident happening should reduce	If Health and safety incident rate decreases = indication of a safer workplace
SHE	Lost Time Incident	No of Preventive actions taken	If more preventive actions are	If Lost Time Incident Frequency

	Frequency (Rate)		taken, then the chances of an incident happening should reduce	decreases = indication of a safer workplace
SHE	Results of Audits	No of Preventive actions taken	If more preventive actions are taken, the manufacturing environment should be safer, so results of audits should improve	If results of audits improve = indication of better SHE culture
SHE	Employee Turnover	Employee sense of safety	If employees feel safer, they are less likely to leave, so turnover should reduce	If employee turnover reduces = Indication of better workplace
		Employee happiness/satisfactio n	If employees feel happier/ more satisfied, they are less likely, so turnover should reduce	
SHE	Time taken to resolve incident	Conditions-	Because of quicker communication , incidents can be raised quicker and resolved quicker	If time taken to resolve incident is quicker = work environment can be free from hazards quicker & injured personnel's can get help quicker = production operations can resume quicker

CI	Number of improvement ideas implemented	Number of improvement ideas submitted	If more ideas are submitted, more of them can be implemented after assessment	If more improvement ideas are implemented = indication of a better CI program
		Number of implemented ideas shared across facilities	If more ideas are shared across facilities, more of them will be implemented	

Table 18: Industry KPIs improvement justification

Appendix E – 4Industry Value Stream map

4Industry Value Stream

Discover where and how 4Industry will improve your production environment