A PROJECT SELECTION BASED APPROACH FOR ESTABLISHING A ROADMAP FOR DIGITAL TRANSFORMATION: CASE OF AN ELECTRONICS MANUFACTURER

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ABSTRACT

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GÜLDEMİR, DİLEK

M.Sc. in Industrial Engineering

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Digital transformation has become inevitable for companies to achieve success and competitive advantage in their sector. However, most companies have not been able to achieve the desired result in the digital transformation process and have failed. The companies could not solve their problems in every aspect and the requirements of the customers could not be met. We analyzed the concept and methodology of digital transformation through literature review, training, interviews, and company practices to better understand why they failed. In the Conventional Method, practitioners apply the maturity level measurement to the senior leaders of the company's organization. This study depends on a questionnaire and the practitioner's experience in the industry and is subjective. We examined the measurement patterns and found that they are all very similar. In the rest of the process, there are similar methods that vary depending on the practitioners' perspective. Depending on the results of the maturity level measurement, the practitioners discuss the needs of the business with the senior leaders. We found that the lack of methodology was due to limited time and staff interviews. The company's Corrective and Preventive Actions (CAPAs) involve all employees' participation and a large period of time. We have used CAPAs as input to a model we developed, the "PathWay Method" to propose a digital transformation roadmap.

We implemented our approach to an electronics manufacturer and obtained successful outcomes. We offered both practitioners a more efficient methodology and companies a roadmap.

Keywords: Digital Transformation, Compatitive Advantage, Maturity Level Measurement, CAPA, Roadmap, Project, Technology

ÖZ

A PROJECT SELECTION BASED APPROACH FOR ESTABLISHING A ROADMAP FOR DIGITAL TRANSFORMATION: CASE OF AN ELECTRONICS MANUFACTURER

GÜLDEMİR, DİLEK
Endüstri Mühendisliği Yüksek Lisans

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Firmaların sektörde başarı ve rekabet üstünlüğünü sağlayabilmeleri için dijital dönüşüm kaçınılmaz bir duruma geldi. Fakat firmaların çoğu, dijital dönüşüm sürecinde istedikleri sonucu alamamış ve başarısız olmuşlardır. Firmalar her yönü ile sorunlarını çözümleyememiş ve müşteri talepleri karşılanamamıştır. Neden başarısız olduklarını daha iyi anlamak için dijital dönüşüm kavramını ve yöntemini kaynak taraması, eğitimler, röportajlar ve firma uygulamalarıyla analiz ettik. Uygulayıcılar, firmanın üst düzey çalışanlarına geleneksel method olan olgunluk seviyesi ölçümü uygulamaktadır. Bu çalışma, bir anket ve uygulayıcının sektördeki deneyimine bağlıdır ve sübjektiftir Ölçüm modellerini inceledik ve hepsinin birbirine çok benzer olduğunu belirledik. Geriye kalan süreçler, uygulayıcıların perspektifine bağlı olarak değişkenlik gösteren benzer yöntemlerdir. Uygulayıcılar, firmanın ihtiyaçlarını üst düzey çalışanlarla olgunluk seviyesi ölçümü sonucuna bağlı olarak görüşmekteler. Bu aşamada yöntem eksikliği üzerine çalışmalara devam ettik. Eksikliğin kısıtlı zaman ve çalışan görüşmelerinden kaynaklı olduğunu saptadık. Tüm çalışanların dâhil olduğu ve geniş zaman dilimi içerisinde bir çalışma gerekmektedir. Firma Düzenleyici Önleyici Faaliyetlerin (DÖF) bunu sağlayabileceğini saptadık. DÖF'leri geliştridiğimiz "PathWay Method"e girdi olarak ullanarak bir dijital dönüşüm yol haritası önerdik.

Yöntemimizin uygulamasını bir elektronik üreticisinde yaptık ve başarılı sonuçlar aldık. Bu tezle hem uygulayıcılara daha verimli bir yöntem sunmakta hemde firmalara bir yol haritası rehberliği etmekteyiz.

Anahtar Kelimeler: Dijital Dönüşüm, Rekabet Avantajı, Olgunluk Seviyesi Ölçümü, DÖF, Yol Haritası, Proje, Teknoloji

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LIST OF ABBREVIATIONS

CAPA	: Corrective Action and Preventive Action
CM	: Conventional Method
DT	: Digital Transformation
IoT	: Internet of Things
IT	: Information Technology
ML	: Maturity Level
MLM	: Maturity Level Measurement
MMP^n	: Mathematical Model for n^{th} Iterating Phase
MMS	: Mathematical Model for Starting Phase (MMP^0)
PM	: PathWay Method
T	: Target
QDMS	: Quality Document Management System

CHAPTER I
INTRODUCTION

In developing countries, there is endless growth and technologization. While there was no end to development, the term Industry 4.0, or in other words, digital transformation (DT), appeared at the Hannover Messe in Germany in 2011. The terms Industrie 4.0 or DT can be found in the literature to this day. As technology continued to advance, these terms were used and added as a new step. They spread throughout the global industry and started to make everyone curious and excited.

Companies that are open to development and have sufficient resources have begun to take this step with new technologies. Accordingly, the competitive advantage between sectors grew. The remaining companies were doomed to shrink. Either they tried to maintain the current situation or their name was removed from the sector. In the end, they could not survive.

Due to competition between companies and sectors that were struggling to survive, companies began to seek consultants. This time, a movement began in the field of consultants and consulting companies, universities and academic staff began to research and work on creating models in this field.

The first DT model published by Rockwell Automation (2014) is called "The Connected Enterprise Maturity Model" and includes 4 dimensions and 5 maturity levels. Even though "The Connected Enterprise Maturity Model" by The Rockwell Automation is considered the first DT model, as shown in the table of Industry 4.0-Digital Transformation Maturity Models by Şener et al. (2021), the research area is for information technologies.

The first DT model that covers all areas is the IMPULS - Industrie 4.0 Readiness' model. It is a model created across 6 dimensions and 6 maturity levels.This "Industrie 4.0 Readiness" study was commissioned by the IMPULS Foundation of the German Engineering Federation (VDMA) and conducted by the Institute for Industrial Management (FIR) at RWTH Aachen University and IW Consult, a department of the Cologne Institute for Economic Research. Experts from the VDMA and some company representatives provided advice on the development of the study (Lichtblau et al. 2015).

Consulting companies or experts who want to advice in this area have begun to take their place in the industry, looking for consultants and research in this area. While working on the companies with the created models, collaboration with technology companies has been established and started to support the technology needs of the companies in this area.Currently, companies are trying to transform, technologize, and evolve their business models by seeking services from both large consultancy companies and expert consultants around the world.

Although these processes are not simple, they need to be very well integrated. With horizontal, vertical and end-to-end integration, digital transformation offers three different integrations. Without integrations, no transformation can take place and no better business models can be achieved. Consulting companies align the integration processes according to their needs for resources, technology and software.For a successful integration, the current situation must be analyzed in detail. The right people should be working in the right areas, for the right problems and needs. In this way, the most efficient transformation can be achieved.

We have studied articles, models, opinions of experts in the field and current practices. It has been shown that the methods of DT are always carried out by consulting companies using the same technique. In conventional method, the maturity level measurement is applied to companies by using existing models or creating a similar model specifically for them. Together with the resulting level from the model, a DT roadmap is presented. The necessary resources, technologies and software are applied along with financial resources to transform the business.

The objective of our thesis; the conventional studies do not fully reflect reality and do not cover a wide customer base (internal customers-external customers), and the basic or detailed points that need to be transformed are not communicated by certain people in top management in a short time.

The result of the studies is that the difference between the current level and the target level in the company does not reflect reality. We argue that this is an incomplete method and should not be supported.

The method recommended against this problem is to introduce another method in parallel with the conventional transformation process. With this method, detailed problems, examples of problems, and analysis of resources can be made available to a wider audience, rather than just the main problems. In other words, existing problems and their analysis can be amplified, and by collecting the problems of each customer (internal customer, external customer), the efficiency of transformation can be significantly improved.

There is no end to transformation and it is pointless to count the industrial revolution one by one for something that has no end. If you number it, you should use it as a step in the digitization process. But DT is endless and cannot be limited by numbers. From the 1st revolution to the 4th revolution and other revolutions that will emerge from now on, they can all be found at DT. Transformations aim to influence business models and make them better and ensure their continuity.

By performing this study, in parallel with the existing method, the efficiency of the transformation greatly increases. The CAPAs specify the content of the work to be done in parallel. The company should report on the CAPAs it has conducted over the years. This is because CAPAs are used to record the needs and problems of the company. In addition, this CAPA includes all departments, workplaces, staff (employees and workers), and customers. It is the data that the company keeps to improve its systems and processes.

CAPAs are analyzed and evaluated according to their domains and, more importantly, their impacts. With the results of the MLM and the results of the analysis of CAPA, realistic studies are created. In addition, a realistic roadmap is provided to the company.

In our thesis, we worked on the DT processes of an electronics manufacturer where CM was applied. Arguing that CM was not sufficient, we analyzed what would be the result if our own methodology had been applied. We concluded what kind of improvement we could have achieved if a DT study was carried out with our methodology.

CHAPTER II

FRAMEWORK AND LITERATURE REVIEW

2.1 TERMINOLOGY

2.1.1 Digitization vs Digitalization

Most people know digitization and digitalization as the same terms. They even add the term DT to them. In fact, these three terms are interrelated, and influence each other, but have different meanings.

Digitization is the conversion of data into a digital format. The data are not changed. It is converted into a digital format. If we go into detail, documents, processes or data are analog and are converted into a digital format, such as scanning a piece of paper, converting paper into a PDF document (a digital format) and recording the audio of a presentation into a digital file. According to Gartner's IT Glossary (2016) , digitization, commonly referred to as "digital enablement," is the conversion of analog data into digital form. Or, to put it another way, digitization converts an analog process into a digital one without making any further changes to the process itself.

It is also the transition of a process from manual to digital and avoids manual errors, so the culmination of digitization is the often mentioned but elusive "paperless office" (Gobble 2018). Ross (2017) points out from a more business perspective that "digitization involves standardizing business processes and is associated with cost cutting and operational excellence."

Digitalization is about the business model. It's about evaluating, revising and redesigning the way you do business. DT. Business processes, technologies and business models are being transformed by digitalization. For example, sensor technology and IoT allow companies to collect and analyze data (processes, workflows, etc.) in databases (clients, etc.).

According to Gartner's glossary (2016), digitalization is the use of digital technology to change a business model, generate new revenue, and increase the value of production capabilities. In Ritter and Pedersen's (2020), definition, the use of digital technology that leads to changes in business-to-business companies and commercial marketplaces is called "digitalization." "In digitalization, digitized data is the basis for knowledge that can be used to take action and bring about change," according to the article by Gobble (2018). Consequently, digitalization presupposes digitization.

If we look at all these definitions, we can easily see the difference between the two. Digitization is the transfer of information to the digital world, while digitalization is a corresponding change in the business model. One aspect of the distinction is well elaborated in the article by i- SCOOP (2016): "While digitization is more about systems of record and, increasingly systems of engagement, digitalization is about systems of engagement and systems of insight, leveraging digitized data and processes."

2.1.2 Digital Transformation

DT makes business processes and data faster, more efficient and more profitable. Nowadays this term is becoming more and more popular, but for whom and what does the term mean? For whom should DT be applied? Where should it be applied? And most importantly, how is the continuity of DT ensured?

When it comes to DT, one thinks of a wide field and ambiguity. Is there an end to DT? Can DT end when the world is constantly changing? What we want to explain is that DT has always existed in previous processes and will always be in our lives after this term. The reason is that DT stands for continuous improvement, customer satisfaction, efficiency, profitability, competition and superiority. In short, it is a business model that will prove its competitive advantage and superiority.

DT is a business model that we implement using available appropriate technologies based on internal and external customer needs and industry requirements. Even though we see different definitions as a result of the literature review, the main purpose is this definition.

Fitzgerald et al. (2013) gave a nice definition that is very close to our definition, "Use of new digital technologies, such as social media, mobile, analytics or embedded devices, in order to enable major business improvements like enhancing customer experience, streamlining operations or creating new business models". Solis and Littleton (2017) emphasized the importance of DT with customers with the definition of realigning or reinvesting in technology and business processes to better engage digital customers at every touchpoint in the customer experience lifecycle, known as DT. McDonald and Rowsell-Jones (2012) also successfully identified: "The DT goes beyond merely digitizing resources and results in value and revenues being created from digital assets." (Reis et al. 2018).

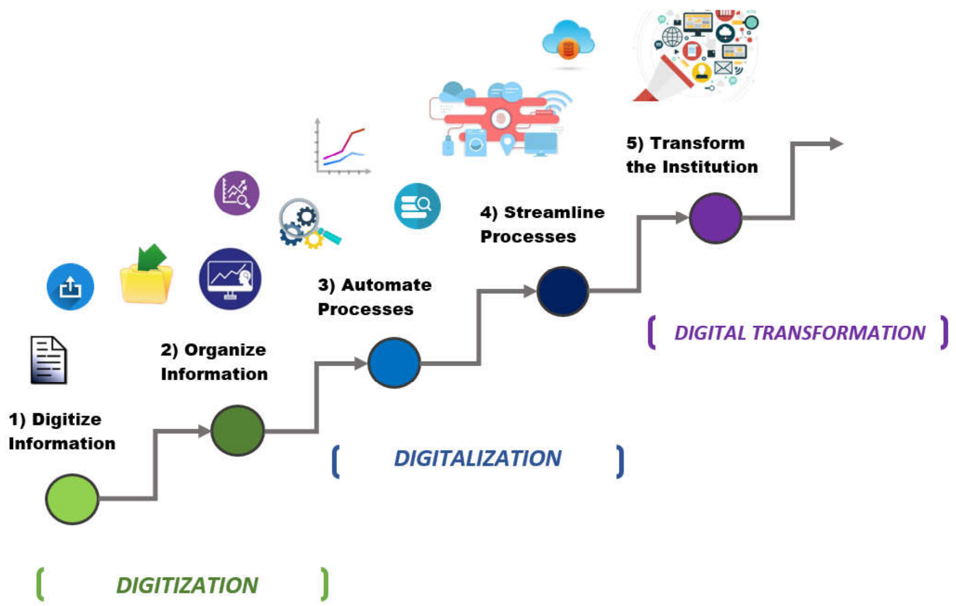

Figure 1: Stages' processes of digitization, digitalization and digital transformation

In Figure 1, we have illustrated the gradual transitions of digitization, digitalization, and DT. We have highlighted which processes come to the fore and in which phase's transformation takes place.

Digitization involves the digitization of information and organized information processes, and in this process information is only digitally transformed. In the next process, digitalization, processes are automated and streamlined. In this transition, a business model begins to emerge with the information that has become digital. Finally, at DT, the institution is transformed with the new business model and the corresponding technologies.

2.1.3 Integration Types of Digital Transformation

There are basic types of integrations that the company must provide in the DT process. DT requires the establishment of value networks, so the company must ensure the integration of production facilities, supply chains, and service systems (Üstündağ and Çevikcan 2017). These integrations are necessary to ensure the flow of information between the company's systems, employees, and customers. It is not enough to just ensure the flow of information, but this flow of information must be real-time and immediately accessible by the system.

The first step in achieving an Industry 4.0 vision and its goals is system integration (Schlechtendahl et al. 2015) (Pérez-Lara et al. 2020). At DT, there are three different integrations that enable communication with the internal and external entities with which the company is connected. These are defined as vertical, horizontal and end-to-end integration. The main purpose is to ensure the flow of data by establishing the correct interaction between processes. In this way, traceability of processes, operations, work orders, maintenance, equipment and other details within the company is ensured, reducing the production of more or less than planned, erroneous production, waste of inventory, human error and inefficiency.

In Figure 2, we have illustrated both vertical and horizontal integration. We have shown from the figures that vertical integration refers to the internal enterprise and horizontal integration refers to the external enterprise.

2.1.3.1 Vertical Integration

Vertical integration or internal integration (Pérez-Lara et al. 2020) is the integration of all departments, systems, computers, machines, work terminals, equipment and tools within the company. Vertical integration, which is one of the important concepts for Industry 4.0, provides efficiency and accurate production by using sensors, motors, valves, barcode readers, and alerts in addition to these structures to enable data flow and tracking.

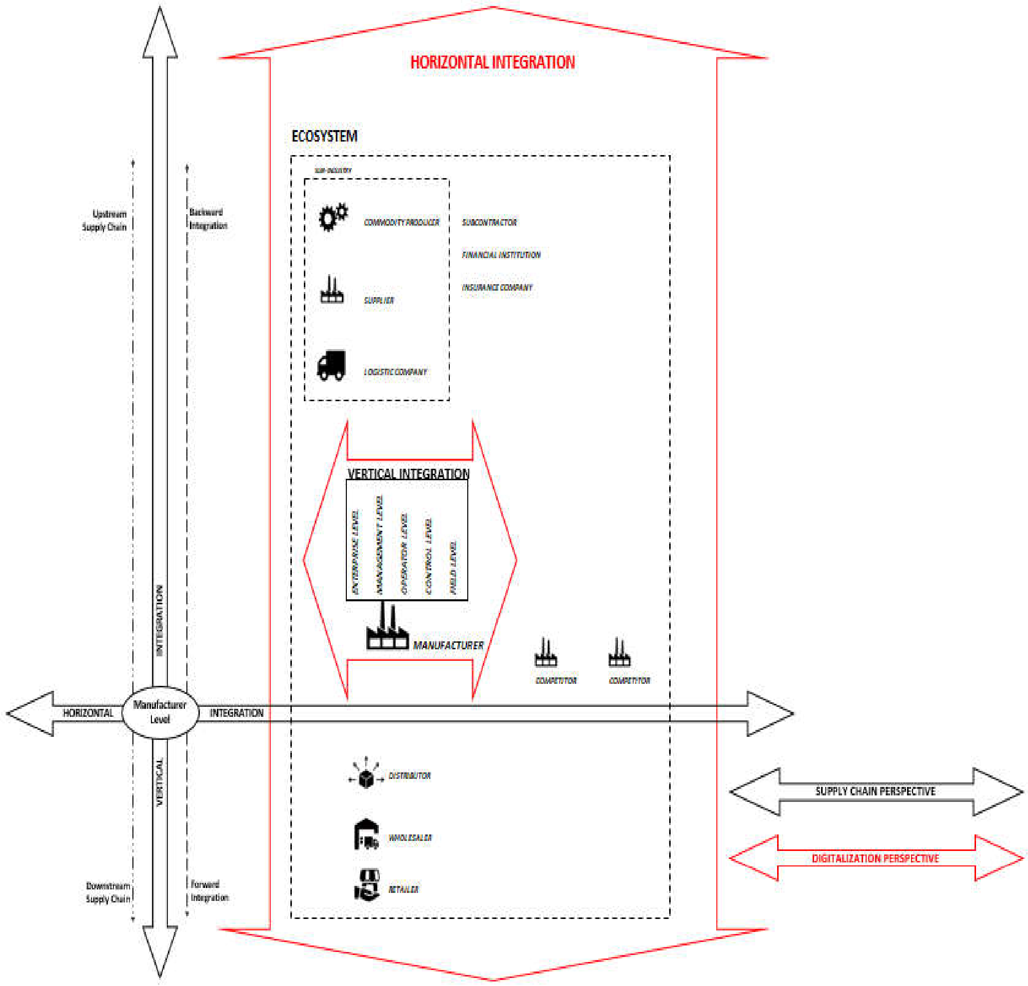

Figure 2: Integrations in digital transformation

This data is separated and transferred to the ERP system, creating a system that controls production. This is possible with the MES system, the Manufacturing Execution System. The data collected with appropriate hardware technologies for the company must be integrated into the MES system and then into the ERP system (Tamas and Murar 2019) (Apilioğulları 2022). The levels of company, management, operator, control, field in Figure 2 are the details of MES system (Üstündağ and Çevikcan 2017). Vertical integration is certainly done with successful MES integration.

2.1.3.2 Horizontal Integration

Horizontal integration is external integration (Pérez-Lara et al., 2020), which is the integration of data collected in a company with systems outside the company. Sub-industries, suppliers, customers, logistics companies, financial institutions, insurance companies, retailers, manufacturers, etc. It is the access of the necessary traceability data to the system of the companies with which it collaborates (Üstündağ and Çevikcan 2017). It demonstrates strong integrity, development, digitalization, and efficiency for companies in the same value chain.

Vertical integration includes basic elements such as organizational structure, human factor, interdepartmental relations, technological and management levels, while horizontal integration includes the integration of supplier and customer networks, information and management systems (Pérez-Lara et al. 2020).

2.1.3.3 End-to-End Integration

End-to-end integration is a product-oriented type of integration and the processes are determined depending on the customer. The processes are initiated based on the customer's problems and requirements. The value chain, which extends from customer needs to production, was static in the past and still is today. With Industry 4.0, however, the static processes are being replaced by dynamic and customer-oriented processes. All processes from the customer to the supplier are interconnected in Industry 4.0. In end-to-end integration, they are brought together and integrated at a single point so that they can respond flexibly to needs and processes.

To achieve end-to-end integration, two mandatory basic structures are required. These are vertical integration and horizontal integration. Priority should be given to providing vertical and horizontal integrations and mastering their processes. An end-to-end chain is created by providing a network of external processes with horizontal integration and a network of internal production processes with vertical integration (Smartpln 2020).

2.1.4 Big Data

Nowadays, data is growing enormously day by day. When we talk about Big Data, we are talking about real-time unprocessed data collected from various sources. The integration of this data collected in real time, the data flow of the source it is connected to, and the integrity of the system with each other is a very important process for Big Data. According to Manyika et al. (2011) of McKinsey Global Institute, “Big data refers to datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze Big Data is increasingly becoming a major organizational force to be reckoned with in companies of all sizes in this global era (Addo-Ttenkorang and Helo 2016).

In this context, it is not enough to just collect data. Big Data, which has a diverse and heterogeneous structure, should become valuable through its analysis (Oussous et al. 2018). Applications can be created by analyzing them with different data mining techniques and algorithms. Artificial neural networks, decision trees, genetic algorithms, nearest neighbor method, rule induction, regression, and cluster analysis are some of the data mining techniques. The areas used in Industry 4.0 are generally manufacturing, maintenance, R&D. Examples of applications: Collecting and integrating data from an RFID system is the first step. By storing and processing this data, some structure is created. Finally, Big Data becomes available through data mining techniques and analytics.

As customer-centric production and service strategies emerge in the new world, Big Data makes it easier to plan applications to be created in response to customer needs. Companies achieve competitive advantage, superiority, and profit as a result of improvements.

2.1.5 Cybersecurity

Cybersecurity is the process of preventing digital attacks on computer systems, information security, operations, networks, data and applications. Cybersecurity and information security have some overlap, with the resulting damage falling under cybersecurity, but they are not the same thing. Cybersecurity is not information security (Solms and Solms 2018).

In terms of cyber damage, Ignatuschtschenko, et al (2016) make the following assertions: Cyber damage is the negative impact of cyber events; it can affect people, businesses, infrastructure, or national interests. Cyber damage can have physical, psychological, economic, reputational, or social impacts (Solms and Solms 2018). In other words, it is essential for organizations to protect their assets, continuity, information, and data. To reduce the risk of information security breaches in the information security environment, various security measures must be taken (Solms and Niekert 2013).

2.1.6 IoT

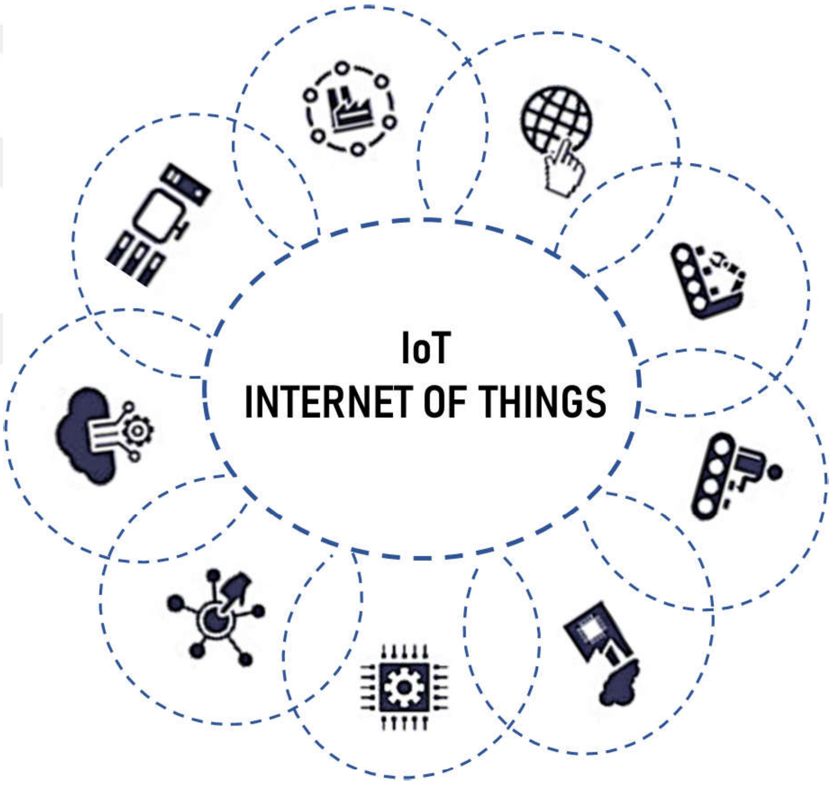

Figure 3: Internet of things (IoT) and its depends example elements

This technology, which stands for "Internet of Things," allows objects to communicate. It allows multiple objects to transfer data among themselves so that the operations of the devices can be performed correctly and synchronously.

As in Figure 3 (IoT), we express that all devices are connected in the same network. They are web-based intelligent devices that collect, process, and transmit data. It allows human intervention, manual operation, and the elimination of errors that may occur as a result. Thanks to this intelligent device, the devices can communicate with each other and respond to the data they receive from each other without human intervention.

In aggrement with Gokhale et al., (2018): To more directly link the physical world with computational systems and increase efficiency and accuracy, the Internet of Things allows objects to be sensed and controlled remotely through existing network infrastructure. Kopetz and Steiner (2022) stated that the building block of the IoT for IoT devices is the smart object, such as RFID, and that the IoT will spread smart object technology.

2.1.7 Dashboard

Figure 4: Example of dashboard figure in Graphana application

Dashboard is the representation of information flow as summary information that is updated with an application at certain time periods or when certain alarms occur. Summary information can be presented in the form of indicators, charts and reports. It is important to summarize the data flow and present it with the correct indicator. The person tracking the flow of information should easily and clearly understand the situation when looking at these indicators. Colors should come to the forefront to make the indicators easier to see. In an important case, the color change should be noticed immediately and action should be taken by changing to the alert state.

The KPIs are determined by analyzing this information. The data is processed according to the KPIs and lower or upper limits are set. Accordingly, an alarm system is created with the corresponding dashboard.

In the above example, there is a dashboard screen, Figure 4 (Komaromi 2022), where the KPIs that are important to the business are displayed on a single screen with different graphs and different colors. When certain values change, this is indicated on the screen by colors or a warning is generated by the alert system at the edge of the graph. Different KPIs can be clearly presented to the user in different cases and at the right time through dashboards and data.

2.2 DIGITAL TRANSFORMATION IN THE BUSINESS PERSPECTIVE

2.2.1 Digital Transformation and Competitive Advantage

A competitive advantage is a situation that allows a company to outperform its competitors. It can achieve this by attracting more customers and increasing its market share. Various social changes often lead to economic progress. One of the most recent examples of such change is DT. To determine its effects, advantages, disadvantages and consequences on social behavior and work, scientists and specialists have carefully studied this new phenomenon. The main goal was and is to initiate an effective DT (Zaoui and Souissi 2020) .

Digital transformation is done by applying appropriate existing technologies to attract more customers with customer needs. At this point, the success of the company DT reveals the competitive advantage of the company. Rumelt's statement (2003): Statements about competitive advantage abound, but a precise definition is hard to find. Looking at the use of the term competitive advantage in the strategy literature, the common theme is value creation. However, there is not much agreement on who creates what value and when (Leao and Miguel Mira 2021).

The professor of economics and management at Harvard Business School is Michael E. Porter, who was born in 1947. He leads the Institute for Strategy and Competitiveness as its president. In the field of strategic management, he is one of the best researchers in the world.

The five forces model is one of Porter's most important contributions, and he has made many contributions. The five components of this model examine both a company's ability to serve customers and its ability to make a profit. Porter's five forces study is an effective tool for developing business strategies.

Although the five forces model was developed more than forty years ago, it is still valid despite the changing world. With the DT, competition is getting stronger and tougher. Porter's five forces model can bring important steps in this field. For this reason, we based our thesis and methodology on the five forces model. Thus, innovations in the process of DT are not a luxury, but a must for survival (Martinez 2020).

If we briefly discuss the five forces model in Figure 5, it emphasizes the balance of the five forces within the industry. Model includes bargaining power of buyers, bargaining power of suppliers, threat of substitute products or services, threat of new entrants, and rivalry between existing competitors (Porter 1979).

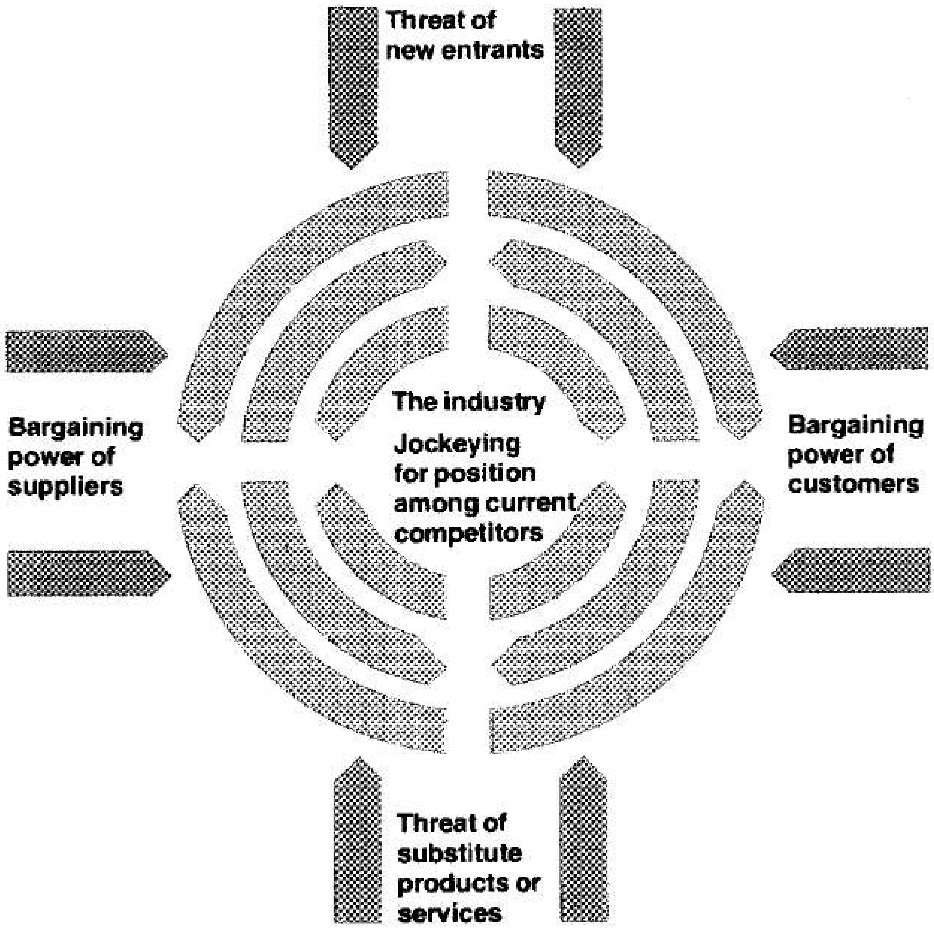

Figure 5: Porter's the Five Forces Model

This model, based on industry competition, emphasizes the importance of the five different forces. The five forces must be in balance on the part of both the supplier and the buyer. The goal is to increase the attractiveness of the different or standard product to the customer at the customer's request. In short, the greater the company's flexibility in the industry, the more cost-effectively it can meet customer demand. According to Porter and Heppelmann (2014), “the manufacturer may own the product, but product usage data potentially belongs to the customer.” This shows that the company becomes stronger in the industry when it carries out the DT process with customer requirements.

2.3 THE TECHNOLOGIST PERSPECTIVE

In general, from the perspective of digital technologies, DT is a successful and powerful technology. Digital technologists act with the customer in mind and adapt the most powerful technology available to the business. They are also looking to improve and optimize existing technology. When an additional software or hardware request comes from the customer, they work to improve it. However, improving with good/excellent technology is not enough. Thus, they have started to align their strategies with customer requirements to create the value chain (Zaki 2019).

Today, digital technologies are at a different peak, such as IoT, digital twin, virtual reality, artificial intelligence, M2M. The impact of these digital technologies is now manifesting with "full force" and enabling "unprecedented things" as we approach a tipping point (Brynjolfsson and Mcafee 2014) (Zaki 2019). It also provides a broader audience regardless of location (Schwab 2017) (Lanzolla and Anderson 2008) (Lanzolla and Giudici 2017) (Zaki 2019).

2.4 DIGITAL TRANSFORMATION FROM THE PRACTITIONERS' AND CONSULTANTS' PERSPECTIVE

All over the world there are practitioners and consultants working with different perspectives and different methodologies. There are large management consulting firms as well as successful practitioners working with a small team. Priyanka Malik (2022) in her article named the 15 best DT consulting companies and almost all of them are large global firms that we all know. So much so that the clients they work with are companies that have a large market like themselves. Priyanka Malik (2022) briefly summarizes what the consulting companies do: First, they study the companies' processes. Then they offer the DT transition by proposing new applications to replace old tools and processes.

Among these companies, the customer-focused employee is CapGemini, and the situation of understanding the customer's requirements is not in the forefront of other consulting companies (Cozmiuc and Pettinger 2021). Nissen (2018) notes that traditional face-to-face methods are still often used in the consulting process, even though consulting firms help their clients become more competitive through creative solutions and are actively involved in the development of new concepts and the use of digitalization.

2.4.1 Ali Rıza Ersoy

After working for Siemens Turkey for 32 years, Ali Rıza Ersoy founded his own consulting company, DT, and continues his DT processes here (TEİD 2017).

We had the opportunity to meet Ali Rıza Ersoy as part of the 5-training "Towards Industry 4.0" that he facilitated and that was conducted by the Rotary Club (2020). The contents of these trainings are respectively "Introduction to Industry 4.0", "Industry 4.0 Technologies and Application Example one (Cyber Physical Systems, Vertical-Horizontal Integrations, Internet of Things)", "Industry 4.0 Technologies and Application Example two (Autonomous Robots, Big Data and Analytics, Cloud Technologies)", "Industry 4.0 Technologies and Best Practices 3 (Augmented Reality, Additive Manufacturing, Cyber Security)", "How to Start and How to Proceed?" (Rotary 2020).

In Ali Rıza Ersoy's education, the journey of Industry 4.0 transformation began with the desire to make production more flexible through the use of technology. For example, it was observed that Western companies moved their factories to their own countries when the production of factories moved to China due to cheap labor could not achieve sufficient flexibility. This relocation is done by Western companies that can integrate technology well. The aim of this integration was to speed up production and production processes according to customer demand. In this way, the flexibility and the speed of production have become more efficient. Adidas is one of the companies that decided to move its factory from China to Germany to follow this change. The Adidas factory built in Germany is called "Speed Factory" and is designed for production with robots.

According to Ali Rıza Ersoy, three themes are the key concepts for Industry 4.0. The first of them, "*Time to Market*", emphasizes the importance of speed of production and service. It is an important goal to shorten the processes even more. The second key concept he highlighted is "*flexibility*." When we combine it with speed, it means the ability to produce on demand in the fastest way possible. This convenience is achieved through the integration of technology, which is the most important thing. The last theme is "*efficiency*" and follows the perspective of "doing more with less." (Ersoy 2020).

2.4.2 İnan Acılıoğlu

İnan Acılıoğlu, who consults with his own company DT, implements DT with his own methodology as a result of his studies. Inan Acılıoğlu, an industrial engineer, creates the DT roadmap of companies by identifying the problems of the company, departments and employees to achieve DT.

İnan Acılıoğlu mentions that in DT we cannot only talk about a technological change and that the technological change will not be efficient without the mentality and competence change of the employees (Acılıoğlu 2020).

According to İnan Acılıoğlu, there are three questions that companies need to answer and then implement. First, what are the automation possibilities in the company? A study should be conducted to see what tasks can be automated by the company's employees. Second, in which decision-making processes can we use data analytics more effectively? In other words, it should be examined how the quality of work can be increased. And finally, what are the business development opportunities? In other words, after the first two questions are resolved, we should look at what areas we can improve in the remaining time (Acılıoğlu 2022).

2.4.3 Saip Eren Yilmaz

Saip Eren Yılmaz has been involved in digitalization for many years and currently works as Director of Industry 4.0 Innovation at Stanley Black & Decker in the USA. Saip Eren Yılmaz argues that digitalization is not just about investing in machines and software. In other words, the concepts of digitalization and Industry 4.0 should not be lumped together. The real digitalization is the ability of technology to achieve the current system and the desired purpose, and Industry 4.0 with "proper integration" (Yılmaz 2020).

2.5 DIGITAL TRANSFORMATION IN OUR PERSPECTIVE

While writing this paper, we have studied researches, applications, practitioners and different perspectives. From our perspective, the foundation of DT is Porter's five forces model. In reality, DT is about surviving in the industry and growing the market. In doing so, we must be able to do so at the lowest cost.

The practitioner who comes closest to the mentality of our thesis is Saip Eren Yılmaz, one of the experts at DT. We argue that perfect technology is not required for DT. In his article, Saip Eren Yılmaz (2020) explains the term "technology myopia" as “popular I4.0 literature seems to have lost sight of the business necessities and is solely focusing on technology”.

2.5.1 Why Digital Transformation Fails

Many companies have launched DT but have not been successful. In fact, this has resulted in many losses and loss of prestige. World-renowned companies such as GE, Lego, Nike, Procter & Gamble, and Burberry experienced performance issues in the midst of a huge DT effort, resulting in executives leaving their jobs earlier than expected (Davenport and Westerman 2018:15). Companies either transform or fail to survive, and about 70 percent of companies fail DT (Saldanha 2019).

We have enumerated why companies fail in their DT efforts;

- Tony Saldanha (2019) likens to the lightning-fast takeoff and forward movement of an airplane. Jump into the DT process and stop the process immediately
- Integrating technologies without transforming people (Acılıoğlu 2020)
- Ignoring customers' needs and expectations (Davenport and Westerman 2018: 15) (Yılmaz 2020).
- Lack of technical skills among employees required for DT (Mielli and Bulanda 2019)
- Unpredictability in creating long-term plans (Gobble 2018).
- No prioritization of strategy and lack of a defined strategy (Acılıoğlu 2020)
- Budget worries and constraints that have not been properly planned (Saldanha 2019)
- Starting without thinking about inefficient business processes (Davenport and Westerman 2018: 15).

CHAPTER III
METHODOLOGY

We have developed our own methodology with the studies conducted in the conventional DT applications and the analysis of the needs of the company. As we mentioned earlier, these studies are designed to support existing DT studies and practices. This allows us to achieve more accurate and realistic results.

In our methodology, we use two different methods along with the existing methodology. In other words, we support the conventional application by conducting another study in parallel. When we study two different methods, it is in line with international business terms.

The first of them is the method that consulting companies use for DT, which is "***benchmarking***". This term is actually a study applied in DT with a comparison on the best practices in the industry. The CM method is used in the benchmarking method in the DT process.

As a result of the necessary literature review and research, benchmarking alone is not sufficient. In this process, consultants compare themselves to the industry average they have calculated. How many companies it can reach, whether the measurements there are healthy, how many companies affect this average, etc. affect the industry average in every way. Questions and assessments about the variability of these situations may not give exactly the right result. The dimensions and related questions are also different for each model.

The term that supports the CM in our methodology is "***baselining***." This is the comparison we made with the requirements and the solutions that should be within the company itself. Baselining in our methodology allows the use of CAPA data.

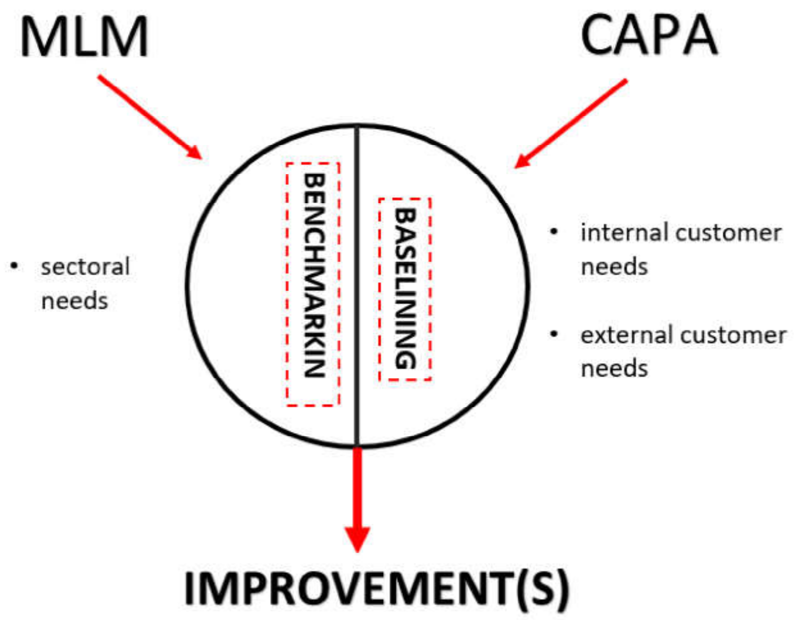

Figure 6: Combination of benchmarking and baselining

The goal is to create an accurate roadmap by supporting the external comparison performed in the conventional application with an internal comparison, as we show in Figure 6. So, for a successful DT it is necessary to act together with benchmarking and baselining. In this way, we can match the internal need with the external need and solve the business requirements together with the current technologies.

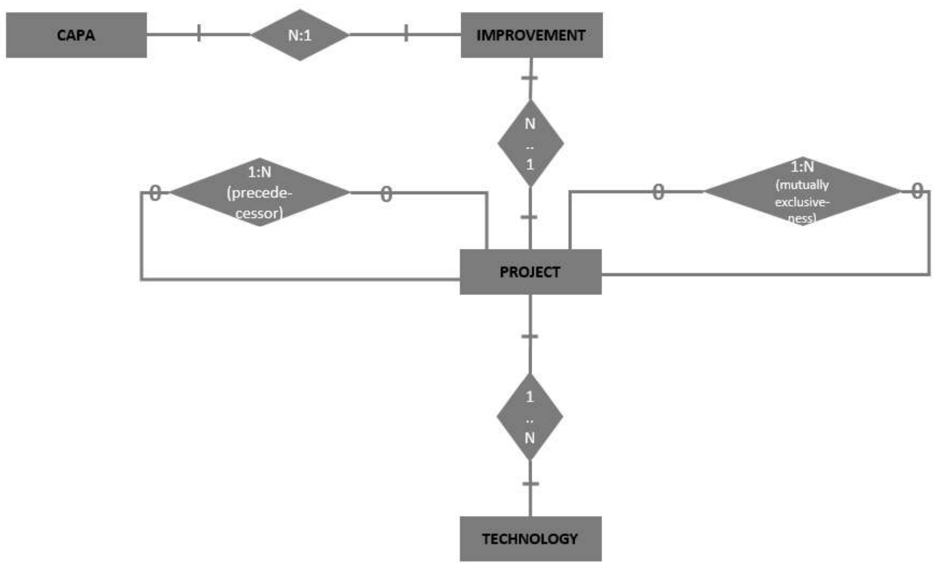

Figure 7: ER Diagram of Our Metodology

Our methodology consists of four key elements. These are included Figure 7 in the ER diagram we created for the CAPAs page. Our work on CAPA, improvement, project, and technology begins with CAPA data. For each CAPA data, an improvement is assigned. An improvement may provide a solution to more than one CAPA.

Each improvement reveals a project. A project can support multiple improvements. Multiple technologies are listed for each project. In order for the necessary projects to be implemented, the technology that is appropriate for the organisation must be selected from among those listed. There are also predecessor or exclusive connections between projects.

As we mentioned in the title of Digital Transformation, the term DT has emerged with industry 4.0, but it has always existed under other names. Perhaps its name will change in the next industrial revolutions with future periods and studies, but the purpose will always remain the same.

3.1 CONVENTIONAL METHOD-BENCHMARKING

We use benchmarking in the conventional DT process within the industry. A successful company in the same industry is used as a reference for comparison. To increase the development and competitive advantage of the existing company, we draw comparisons with the most successful company. We usually make these comparisons on processes, strategy and performance. The notes differ in each method in certain dimensions. CM includes MLM that we currently use.

What we mean by different methods is an instrument created by different or the same sources that we can apply through certain dimensions, question patterns and a likert system. Even if the logic of all methods is the same, there can be different question patterns and different dimensions.

The CM used in the DT process are also reported on a sectoral basis and according to certain industry standards. The MLM allow us to measure minimum and maximum values using specific scoring and scaling methods. In this way, we can measure the company's level of development in the industry with limited company information. The most famous among MLMs are IMPULS model and Acatech model. In studies in Turkey, there are own models implemented by consulting companies. Likewise, many academic studies can arrive at models similar to the ones we mentioned.

Expert consultants or the departments set up in the company DT conduct studies DT. Although studies are conducted in each area, these studies, which are usually conducted in production facilities, proceed in many phases. We can see the detailed process in Figure 8.

The company takes the initiative DT in the ***initiative phase***. In this phase, the company embarks on a search for the start of the transformation and goes through processes such as information gathering and consultant meetings. As a result of the negotiations, the company agrees with the appropriate consulting firm associated with the financial resource and they begin the preparation process for DT.

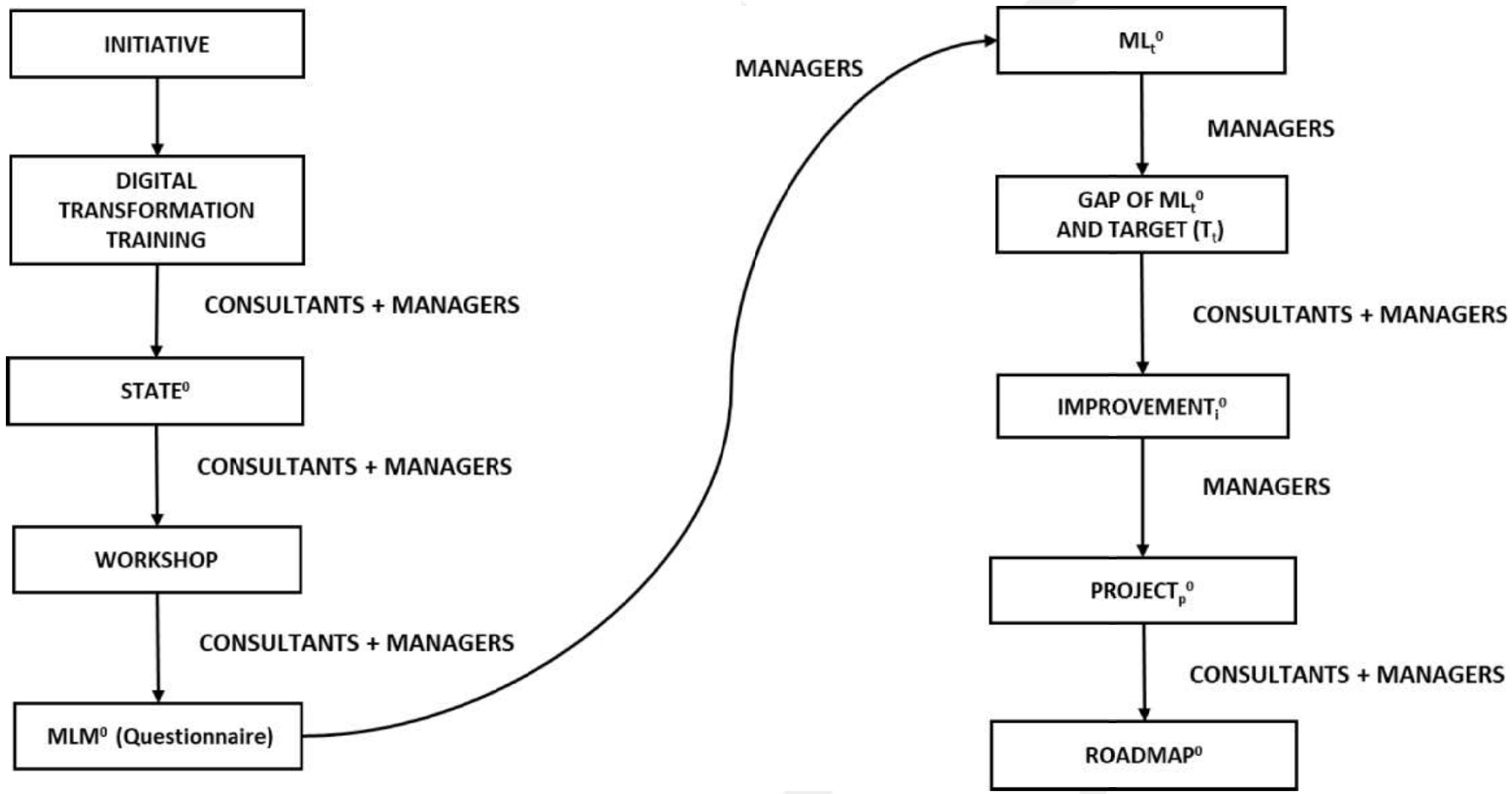

Figure 8: Conventional Method (Benchmarking) of Metodology

The preparation process includes the processes of culture, recognition, vision-mission, informationand data collection. Expert consultants and staff begin the initial conversations for the DT process. They discuss the current situation, goal, culture, visionand mission of the company. In addition, the first action is intensive training in the ***DT training phase*** to ensure that the company culture is suitable for DT. The trainings enable the company to adapt to DT as a way of thinking. These trainings include more than one training, both with all competent staff and on a departmental basis. Board members and senior executives receive their training first. In this way, the culture of the company begins to change from the highest level. They explain in detail the basic infrastructure such as the meaning of DT, terms, phases, roadmap and integration.

When the company is done with the training, competent employees share information about the current situation of the company with the consultants in ***state 0 phase***. When they share the information about the current situation again after the necessary applications in the future processes, this becomes a ***state stage***. Topics such as the size of the company, its scope, processes, resources, systems used, infrastructure and equipment of the responsible people are discussed in detail. After this process, they move to the ***workshop stage*** to discuss existing problems. They conduct analysis and root cause analysis on problems. Consultants and competent staff constantly hold meetings in this area with the necessary discussions. In this process, the company's employees further clarify processes and problems in workshops that they give to the consultants on site. They ensure accurate and holistic transfer of technical and practical information to the consultants.

The next step should be to determine the maturity level of the company with a ***maturity level measurement*** in the ***maturity level model phase***. The consultants apply MLM with a questionnaire to the responsible employees of the company. In this way, the ML of the company is determined. The MLM can be a model that the consulting company uses privately or that was created by another institution/person. With the ML as a result of the model they use, certain dimension levels appear that show the current state of the company. These dimension levels in the preparation process tell us where the company is in the DT process.

What stage does the company want to reach? What is the point it wants to reach in the industry? For what purpose does the company want to reach that level? How much will productivity increase when that level is reached? The most important point is: what does the company want to achieve? With these questions, the company's goals and the point to be reached become clear.

Consultants perform a gap analysis to determine the difference between the result and the desired point at ***ML and the target level***. Target is the top level in the industry for consultants. They determine the dimension levels of the best company in digital transformation in the sector as the target level of the company and this is subjective.

After these processes, the task is to determine the necessary solutions and launch the applications. Up to this point, a passive study has taken place. After that, an active process begins, which reveals the durability of the company in reality.

Continuing their work, the solution search and planning phase begins in the ***improvement phase***. They take actions to achieve the target values. The consulting company brings together the technology companies they work with that offer digital solutions with the company's competent staff. As a result of the problems and analysis, technology companies are brought in for field solutions, systems and integrations. Necessary and appropriate technologies are determined with collaborative solutions and guidance from consultants. A DT project is proposed with appropriate technologies for the company in the ***project phase***. These projects are planned by the consultants in the ***roadmap phase*** depending on the financial resources of the company. As a result of the DT roadmap, which has been created with the scheduling, the company buys technologies and to be put into practice.

In this way, the methodology and detailed processes of DT are applied today. The process after the company has started the implementation work is very critical and important. It requires constant monitoring and improvement. The reason is: in order for the company to continue its work, it needs budget, effort and most importantly patience. The consultants must adjust each work period with special care.

3.1.1 Maturity Level Measurement

The consultants apply the MLM with the questionnaire prepared by the responsible people from the management for the analysis of the current situation. It is a subjective study as MLM is based on a questionnaire and the knowledge of the consultant applying CM in the industry. This model must be successful, published and scientific. Some examples are the IMPULS model, the ACATECH model and the project portfolio optimization model. This questionnaire is filled out by the managers in the company and the average is calculated from the results.

After applying the MLM, the ML of the company is determined in DT. Each model has its own scale and the model is interpreted based on the result. For example, the IMPULS model has levels from 0 to 5 according to the competence of DT. A level of 0 means that there is no awareness of DT, and a level of 5 means that there is sufficient awareness of DT and necessary actions.

3.1.1.1 Impuls - Industry 4.0 Readiness Model

The IMPULS model is the first MLM that covers all areas for Industry 4.0 and DT. As we mentioned in CHAPTER I, the Institute for Industrial Management (FIR) at RWTH Aachen University and IW Consult, part of the Cologne Institute for Economic Research, conducted this study on "Industrie 4.0 Readiness" on behalf of the IMPULS Foundation of the German Engineering Federation (VDMA).

In their study on a survey, there are six different dimensions and six different MLs from 0 to 5 that influence it. The six different dimensions are Strategy and Organization, Smart Factory, Smart Operations, Smart Products, Data¬driven Services and Employees. The questions and detailed steps are different for each dimension. If users tick answers in the survey that represent an improvement, detailed questions will be asked to the user. Depending on the dimension levels, the ML of the company DT results in a range from 0 to 5 in direct relation to success.

If, in addition to this information, we give the values for the level of maturity;

- **Level 0 :** Outsider
- **Level 1 :** Begginer
- **Level 2 :** Intermediate
- **Level 3 :** Experienced
- **Level 4 :** Expert
- **Level 5 :** Top Performer

If we briefly look at the dimensions (Lichblau et al. 2015);

- **Strategy and organization:** to what extent has your company's strategy for Industrie 4.0 been defined and applied?
- **Smart factory:** to what extent is your company's manufacturing automated and digitally integrated through cyber-physical systems?
- **Smart operations:** How many of your company's operations and products are digitally mapped and can be managed by ICT systems and algorithms in a virtual world?
- **Smart products:** How many of your products can be managed by IT so that they can communicate and collaborate with higher-level systems along the value chain?
- **Datadriven services:** Data-driven services: How many of your services are data-driven and can only be realized through the integration of production, consumers and products?
- **Employees:** Does your company have the know-how and attitude to put the principles of Industrie 4.0 into practice?

All detailed information can be found in the book "IMPULS INDUSTRIE 4.0 READINESS" by Lichtblau, et al. (2015). Lichtblau, et al. (2015) write about DT "The special potential lies above all in highly flexible, highly productive, resource-saving production."

3.1.1.2 Acatech Model

One of the successful models, the Acatech model, was created by Günther Schuh, Reiner Anderl, Roman Dumitrescu, Antonio Krüger, Michael ten Hompel (eds.) with the collaboration of Aachen University in 2018 and was also updated in 2020 (Schuh et al. 2020a).

Utku LEMBET (2021), who was a division manager for factory automation at SICK Sensor, one of the major German companies, suggested that the Acatech model is a successful model in both academic and application domains and should be investigated in this study.

Model has six-stage MLs between 1 and 6. At the same time, these six stages are divided into two different groups. The first group is Digitalization and includes stage 1 and stage 2. Group 2 is Industry 4.0 and includes stage 3, stage 4, stage 5 and stage 6. If we consider the ML (Schuh et al. 2020a) (Schuh et al. 2020b);

- **Stage 1 :** Computerisation
- **Stage 2 :** Connectivity
- **Stage 3 :** Visibility
- **Stage 4 :** Transparency
- **Stage 5 :** Predictive capacity
- **Stage 6 :** Adaptability

In addition to the IMPULS model, the Acatech model has a functional area. It works in five different functional areas. These are ***development, production, logistics, services, marketing and sales.*** In addition, there are four different dimensions: Resources, Information Systems, Organizational Structure and Culture.

3.1.1.3 Maturity and Readiness Model for Industry 4.0 Strategy

Alp ÜSTÜNDAĞ and Emre ÇEVİKCAN have published the book "Industry 4.0: Managing the Digital Transformation" (Üstündağ and Çevikcan, 2017). It is one of the rare and productive resources that reflect the truth published in Turkey about the DT process. It contains rich and diverse literature knowledge. They have explained these sources in detail and written concisely. They explain DT terms and processes step by step.

However, this source is not much different from the others about methodology. The authors have gathered MLM questions from various sources. They have developed a new MLM and tested in companies using a case study (Akdil et al. 2017) (Işıklı et al. 2017).

3.2 BASELINING

Baselining is a comparison method like benchmarking. The difference is that benchmarking is a comparison with the best example in the industry, while baselining is a comparison between the company's own goals (Chartterjee 2018). In other words, benchmarking is an externally based comparison method, while baselining is an internally based comparison method.

To increase its competitive advantage, a company should ensure that the problems are solved by considering both its competitors in the industry and its own internal presence. In the baselining method, the company that wants to get to the top starts a comparison process based on its target. In baselining, the first step is to take a snapshot of the company. The snapshot is used to determine an actual state. This establishes a starting point for comparison. The company compares the difference between the starting point and the target point with a gap analysis. In baselining, the target is the target point that the company wants to reach. The company determines the sufficient point for itself with its resources and target success level. Then, the necessary improvements and solutions are determined to achieve the goal. Finally, the project is formed by planning the solutions identified to achieve the objectives.

When we examine the CM, Consultants act with the benchmarking method. Although it is desired to reach a point determined by the company, the main problems cannot be solved. In other words, the real problems in the internal cannot be resolved radically when making an external comparison and an analysis based on this comparison. Consultants always examine current problems on the basis of limited, superficial and excellent technology. The real problems that need to be resolved and transformed become invisible. For this reason, the company can go to a certain point in the DT process instead of developing more efficiently.

For baselining, thanks to certain data, the company can clearly identify the problems inside it and the solutions to these problems. What kind of data it is, comes from the data that the company keeps inside itself. This is not a group of data that can be collected in a short period of time, nor can it be from a single source. However, it can be done over a long period of time and with the group of data that can include all employees of the company. The basis for baselining is such data collected in general and over the long term.

The source of this valuable data, regardless of workers or employees, is the company's CAPAs. CAPAs are valuable data created over time by each department and employee. With CAPA, we can identify the problem and root causes.

If we include CAPAs in parallel in the DT process, we can identify the main problems emanating from all employees of the company. In other words: We are dealing with the main needs of the company and the situations that need to be solved in a comprehensive perspective. When we include CAPAs in the DT process, we argue that the goal points can be improved with appropriate technology solutions for the basic needs of the company.

3.2.1 The Corrective Action and Preventive Action (CAPA)

The name CAPA is composed of the terms "*corrective action*" and "*preventive action*". Corrective actions are actions taken to identify and eliminate the causes of ***existing*** defective products and other quality problems. Preventive actions are used to identify and eliminate the causes of ***potential*** nonconforming products and other quality problems. There is a department for auditing and controlling CAPAs. CAPA has to be created for the nonconformity in the audits or processes in the company. Once a nonconformity occurs, the employee or customer who identifies the nonconformity, from which department the nonconformity originated, creates a CAPA to the responsible person.

In short, CAPA captures the problems in the company, the wrong operations, the problems that occurred, and the situations that need improvement. We can think of this as an action that runs in parallel with the FMEA. These are the actions taken to ***correct*** the problems that have occurred, ***improve*** the current situation, and ***prevent*** potential problems.

3.3 THE PATHWAY METHOD

We have stated that MLM and CAPA are included in our methodology. We argue that we can achieve more efficient results with these studies applied in parallel. After defining our methodology, we created our mathematical model to achieve the optimal result with the data. The main purpose of the mathematical model is to find the way to the needs so that a company can create a roadmap. For this reason we named our mathematical model "***PATHWAY METHOD***".

Based on the methodology we used, we created two different MIP models. The first of these models is the starting point of DT and a model that should be used in the initial studies. We named this model "***MATHEMATICAL MODEL FOR STARTING PHASE - MMS***".

Our second model, is the model that should be applied in the continuity, persistence and follow-up phases of the process after the first period. The name of this model is "***MATHEMATICAL MODEL FOR ITERATING PHASE - MMP***".

The reasons why we have created two different models;

- A CAPA in the current period cannot be resolved and will be included in the next period. For example, if the CAPA number 0080 created in 2019 cannot be resolved with the technologies selected in the 2019 period, it will be included in the 2020 period with the 2020 CAPAs.
- Even if a technology is selected with MMS/MMP, its application may not be completed in the current period. In this case, this technology will be included as a continuing technology in the next period with the next period's cost. For example, we selected technology number 18 with the 2019 period MMS. The time and effort required for technology 18 was not sufficient for one period. This technology was included as a continuing technology in the next period.

So, we separated both the initial period and the ongoing processes. However, we also changed the sets, parameters, and equations for MMP over MMS.

3.3.1 Mathematical Model for Starting Phase (MMS)

In this title, it consists of the MATHEMATICAL MODEL FOR STARTING PHASE - MMS, which we recommend as a starting point. This mathematical model that we apply in the first phase of DT requires the data from CAPA, which is owned by the company. After analyzing the CAPA data, we need to identify the improvements, projects and technologies associated with the projects we have created. Then we apply MMS.

3.3.1.1 Sets

The sets of MMS in the PathWay Method for DT are given as follows:

$S^J = \{j: 1,2, \dots, j, \dots, J\}$	*Set of CAPAs*
$S^I = \{i: 1,2, \dots, i, \dots, I\}$	*Set of improvements*
$S^P = \{p: 1,2, \dots, p, \dots, P\}$	*Set of projects*
$S^T = \{t: 1,2, \dots, t, \dots, T\}$	*Set of technologies*
$S_i^J = \{j': j' \in S^J\}$	*Set of CAPAs related to improvement* i
$S_p^I = \{i': i' \in S^I\}$	*Set of improvements related to project* p
$S_p^T = \{t': t' \in S^T\}$	*Set of technologies related to project* p
$S_p^{PD} = \{\tilde{p}: \tilde{p} \in S^P\}$	*Set of predecessors of project* p
$S_p^{ME} = \{\acute{p}: \acute{p} \in S^P\}$	*Set of mutually exclusiveness relation of unselected project* p *group*

After constructing the ER diagram given in Figure 7, we determined the sets related to our problem. We defined the sets based on the entities and their relationships. The sets include CAPAs, improvements, projects, technologies, and relationships between projects. Each improvement i is related with at least one CAPA, as seen in Figure 7. For improvement i, we define the related CAPA(s) using S_i^J. The sets are definitely not null sets for all improvements. Each project p is related with at least one improvement and technology. For project p, we define the related improvement(s) and technology(s) using S_p^I and S_p^T.

The sets are not null sets in our application. We define relations between projects about predecessors and mutually exclusiveness using S_p^{PD} and S_p^{ME}. Indeed, all projects are independent alternatives, and there are predecessors' relationships between those independent projects. We define the mutually exclusiveness relationships between projects to represent other constraints about the projects which we exclude in our mathematical programing models. For example, we do not have workforce constraint in our model, and two large-scale projects, say A and B, may have high levels of workforce requirement. Dealing with both A and B is practically not possible. Managers define those two projects as "not to be selected at the same time," and we represent this situation by defining mutually exclusiveness relation between A and B.

3.3.1.2 Parameters

The parameters of MMS in the PathWay Method for DT are given as follows:

α_j	*Impact of CAPA j*
β	*Total budget of current year (in USD)*
η_t	*Cost of technology t (in USD)*

MMS includes three parameters for impact, cost and budget values. When we made an assessment, we assign an impact value as $\boldsymbol{\alpha_j}$ in the range 1-5 for each CAPA. We defined parameter $\boldsymbol{\beta}$ for the financial resource allocated by the company based on the year for the DT process. The last parameter $\boldsymbol{\eta_t}$ represents the listed technology costs for the company's needs in the DT process.

3.3.1.3 Decision Variables

The decision variables of MMS in the PathWay Method for DT are given as follows:

$$v = Total\ impact\ of\ selected\ CAPAs$$

$$z_j = \begin{cases} 1 & if\ CAPA\ j\ is\ covered \\ 0 & otherwise \end{cases}$$

$$y_i = \begin{cases} 1 & if\ improvement\ i\ is\ fulfilled \\ 0 & otherwise \end{cases}$$

$$x_p = \begin{cases} 1 & if\ project\ p\ is\ selected \\ 0 & otherwise \end{cases}$$

$$w_t = \begin{cases} 1 & if\ technology\ t\ is\ selected \\ 0 & otherwise \end{cases}$$

$\boldsymbol{v}$ is the decision variable that occurs in the objective function and depends on impacts and CAPAs. Others are related to CAPAs coverage ($\boldsymbol{z_j}$), implementation of improvements for CAPAs ($\boldsymbol{y_i}$), selection of technologies ($\boldsymbol{w_t}$) and projects ($\boldsymbol{x_p}$) and are all binary variables.

3.3.1.4 Objective

The objective of MMS in the PathWay Method for DT are given as follows:

$$Max\ v = \sum_{j=1}^{J} \alpha_j z_j \tag{3.1}$$

In the DT process, we assigned impact values according to the importance of the data from CAPA. The impact values range from 1 to 5. Since improvement of CAPAs with high importance should be prioritized, MMS aims to maximize the impact. The target value of the model is the total maximization of impact, as we indicated in objective (3.1).

3.3.1.5 Constraints

The constraints of MMS in the PathWay Method for DT are given as follows:

$$y_i \le x_p \qquad \forall p, i \in S_p^I \tag{3.2}$$

$$\sum_{i \in S_i^J} y_i \ge z_j \qquad \forall j \tag{3.3}$$

$$\sum_{t=1}^{T} \eta_t w_t \le \beta \tag{3.4}$$

$$x_p + x_{\acute{p}} \le 1 \qquad \forall p,\ \acute{p} \in S_p^{ME} \tag{3.5}$$

$$x_{\tilde{p}} - x_p \ge 0 \qquad \forall p\ , \tilde{p}\ \in S_{\tilde{p}}^{PD} \tag{3.6}$$

$$\sum_{t \in S_p^T} w_t = x_p \qquad \forall p \tag{3.7}$$

$$z_j, y_i, x_p, w_t \in \{0,1\} \qquad \forall j, i, p, t \tag{3.8}$$

If the MMS constraints are explained in order, the improvements are satisfied if the linked project is chosen in the constraint set (3.2). According to constraint set (3.3), CAPA is covered if at least one of the associated improvements is accomplished. The overall cost of the technologies must not exceed the budget, according to constraint (3.4). For each mutually exclusive relation set, only one of the projects may be included in the DT process for constraint set (3.5).

The relationships between projects' priorities are constant (3.6). The interconnectedness of constraint set (3.7) means that if at least one of the linked technology is chosen, project is chosen. Constraint sets (3.8) include sign restrictions variables.

3.3.2 Mathematical Model for Iterating Phase (MMP)

In the process DT, we also created a model for the work after the first period. The purpose of MATHEMATICAL MODEL FOR ITERATING PHASE - MMP, which we created, is to develop and drive this process. It has the same logic and the same working method as MMS. We have changed some points of MMS in terms of sets, parameters and equations. We ensured the accuracy of the work and constantly made the necessary additions.

3.3.2.1 Additional Sets

The MMP sets contain remaining and new elements. Sets include previous step's, completed, continuing, and new technologies using S^{Tprev}, S^{TF}, S^{TC} and S^{Tnew} in the MMP. In addition, we created sets for one project and one technology that were not selected in the previous year. Previous step's technologies includes continuing and completed technologies using $S^{TF} \subset S^{Tprev}$ *and* $S^{TC} \subset S^{Tprev}$. The additional sets of the PathWay Method in MMP for DT are given as follows:

S^{Tprev}	*Set of previous step's technologies*
S^{TC}	*Set of continuing technologies*
S^{TF}	*Set of completed technologies*
S^{Tnew}	*Set of new technologies*

3.3.2.2 Additional Parameters

The MMP parameters include remaining and new items. We added the parameter in the MMP for completed, continuing and new technology. In addition, we expressed technologies continued since the previous year or completed in the most recent previous year as 1-0. We represented remaining cost of continuing technology $t \in S^{TC}$ or Cost of new technology $t \in S^{Tnew}$ (in USD) with η_t. For finished technologies $t \in S^{TF}$, cost of them is zero in USD as $\eta_t = 0$. The PathWay Method parameters in the MMP for DT are given as follows:

$$\delta_t = \begin{cases} 1 & \text{if technology } t \text{ is a continuing or completed technology} \\ 0 & \text{otherwise} \end{cases}$$

3.3.2.3 Additional Equation

MMP equation contain remaining and new element. The additional constraint of the PathWay Method in MMP for DT is given as follows. Constraint set (3.9) implies that technology t is selected in previous step's technology if technology t is a continuing technology.

$$w_t \geq \delta_t \qquad \forall t \qquad (3.9)$$

3.3.3 The Digital Transformation Roadmap

We have prepared our methodology for the DT roadmap for benchmarking and baselining. In our methodology, we mentioned that the two support each other and that they alone are not sufficient when applied. We periodically prepare a roadmap with the project that is the result of both benchmarking and baselining.

We do this together with consultants, management, customers and employees. In this way, we approach each area holistically and with a broad perspective. We free ourselves from the technological myopia described in the article by Saip Eren Yılmaz (2020). We are examining the entire field, including all impacts.

Our roadmap for MMS in Figure 9 is very similar to the CM roadmap, bechmarking. As we mentioned at the beginning, our goal is not to destroy what already exists, but to make it more efficient and support it. In addition to the existing roadmap, we have included baselining in the main part of the methodology. The beginning and end parts are the same as before. We have added working with CAPA data to the area we are actually studying.

Improvements are identified as a result of both CAPA and MLM studies. Consultants and managers hold meetings in order to combine these two parallel processes in a single point. Appropriate improvements are determined by joint decision. In other words, consultants and managers determine the final decision of improvements.

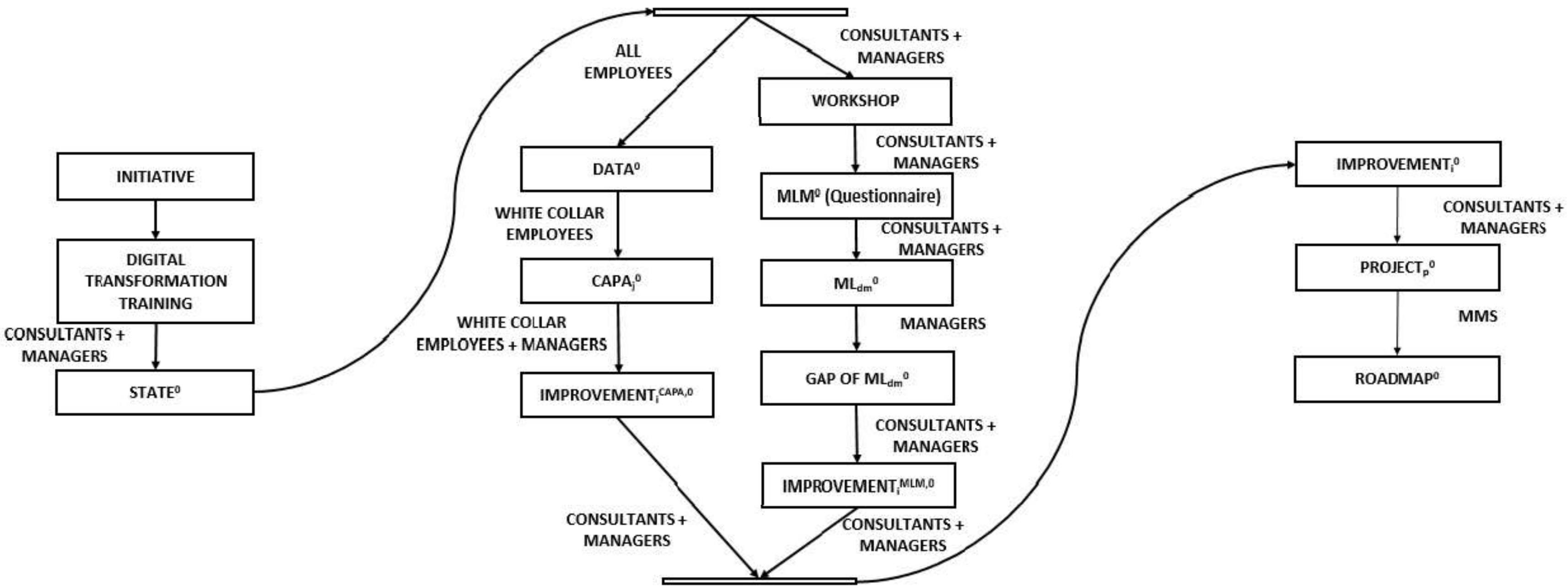

Figure 9: Starting Phase in PathWay Method

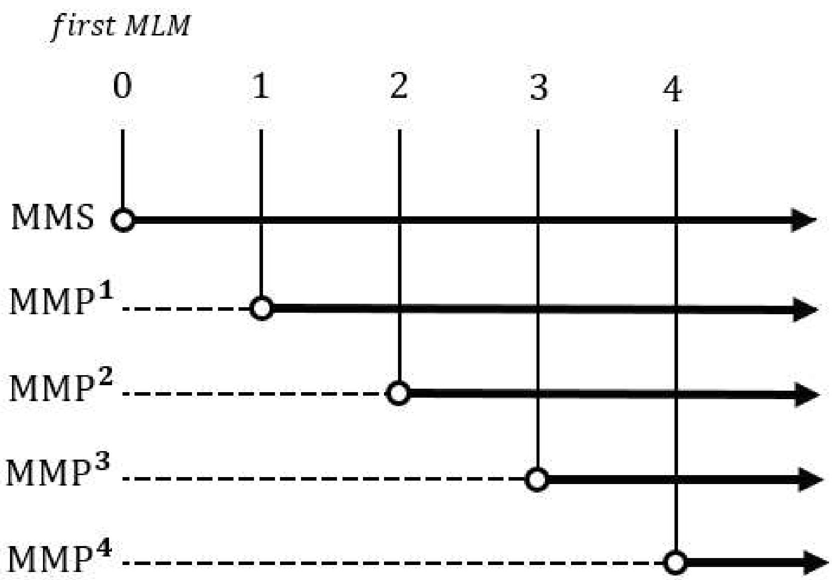

Figure 10: MMS and MMP chart depending on periods

After MMS, we continue with MMP and show the process regularly in Figure 10. The time zones of these periods could also be different. As an example, you can see a starting point followed by a graph of a four-period study. We show the MMP^n we applied to the ongoing process.

In Figure 11, we show the methodology of the MMP in the continuation of the MMS process. The preparatory processes (initiative, training) are not included in the MMP. We perform a gap analysis of the level and the target level that we have reached after the MMS. At this stage, we also take the dimensions as a basis. If we have not reached the target level, we continue the DT process.

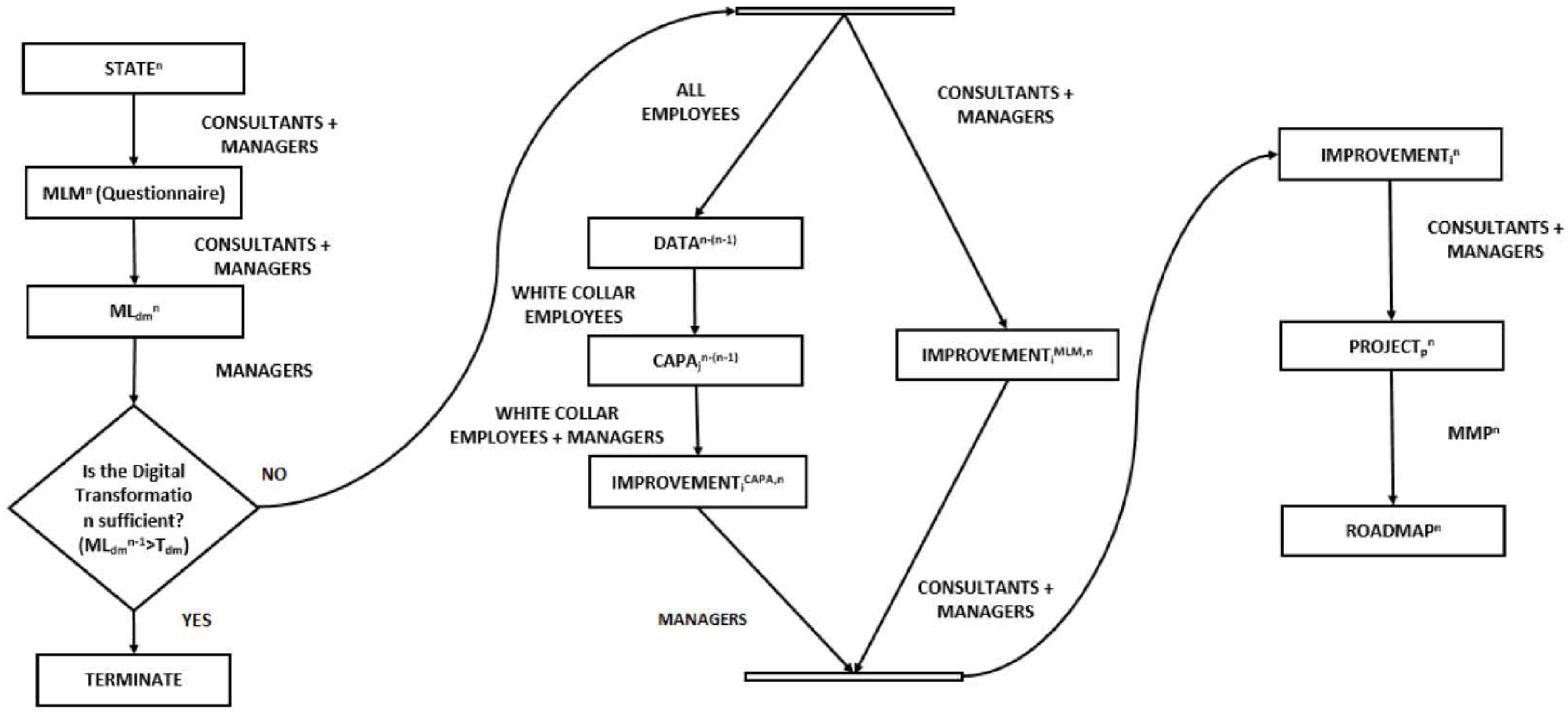

Figure 11: Iterating Phases in PathWay Method

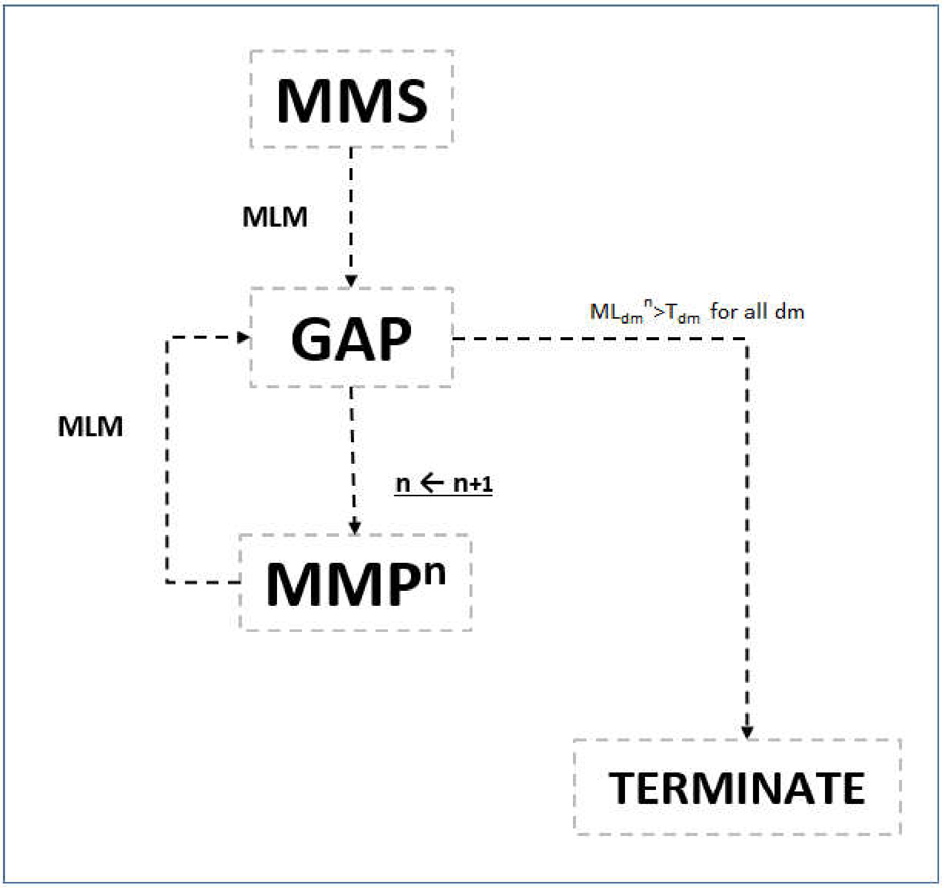

Figure 12: Flow chart of MMS and MMP

We can detail our DT roadmap in terms of MMS and MMP with the flowchart in Figure 12 about the CM. If there is a gap between the MMS result and target lavel, the process continues with MMP^1. If there is a gap again between the result after applying MMP^1 and target level, the cycle continues. Each future period (n+1) becomes the current period (n) by continuing the process, and we refer to each current period in the formula as n. Whenever, there is no difference between MMP^n and the target level, we can stop the process.

CHAPTER IV
APPLICATION

This thesis was implemented in an electronics manufacturer. In 2019, the company actually took the DT path. In this process, the company has applied the CM. In other words, they implemented this process step by step by moving forward with the consultants' standardized DT roadmap.

In the Figure 13, we have visualized what production looks like in a company in the electronics industry. When we briefly mention about the steps in the Figure 13, we have explained them by numbering them step by step. Surface mount technology (SMT) is a method of mounting electrical components directly on the surface of a printed circuit board (PCB). An electrical component mounted in this way is called a surface mount device (SMD).

Firstly, solder paste is applied to the PCB base so that the materials to be mounted on the PCB surface are fixed. Solder paste printing can be done either via a screen printing process using the stencil or via jetting or a combination of both.

1. Once the paste has been printed, the next step is solder paste inspection (SPI) to ensure that the solder paste has been printed correctly and is ready for component placement.
2. Pick & place is an important step in the assembly process where components are placed on the board. For surface mount devices (SMD), this is done with an automatic pick & place machine.
3. Once the components have been placed, it is important to check that no mistakes have been made and that all parts have been placed correctly before reflow soldering. This is done with an AOI machine.
4. During the reflow soldering process, a reliable connection is made. The solder paste melts during this process and cools again to create a good solder joint.
5. The final part of surface mount is to once again verify that no mistakes have been made by using an AOI machine to check the quality of the solder joint.

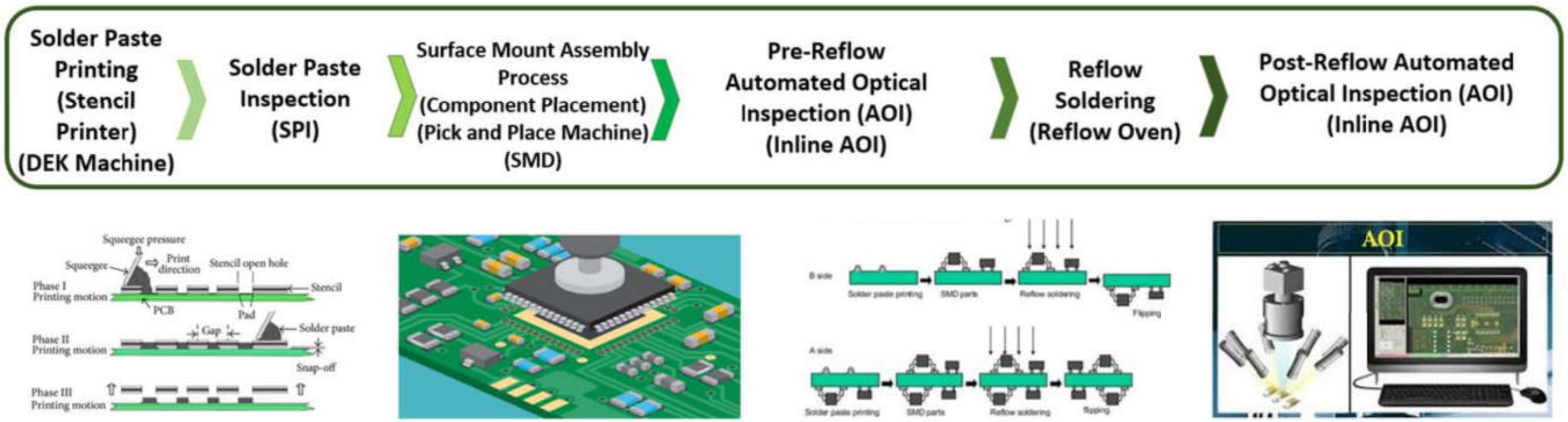

Figure 13: Processes of electronic manufacturing

As a result of the analysis, we reviewed the company development process at regular intervals based on one year. We continued the DT process by analyzing the situation in each period. In this process, our work began in 2019 and continued until 2022. We applied PM to the company for DT instead of CM using available data. We assumed that if a technology is selected in PM, it is accomplished with the initial cost and time estimates. Therefore, we neglected any practical cost and time increases in the implementation. Also, we performed the end-of-year measurements for ML as if the selected technologies were implemented. Since we do not have the option to roll back the clock to 2019 and apply PM in real life, we try to answer the question of, "What if we have applied PM in the company?" using the available data by this approach in this thesis study.

4.1 DATA

We started with the search for the necessary data and learned that the company had a QDMS (Quality Document Management System) system since 2018. The company started entering data from CAPA into the QDMS system in mid-2018.

Since we have worked on the digital transformation process over year-based periods, we retrieved CAPA data from the QDMS system in three periods as 2019, 2020 and 2021 CAPA data. There are 177 CAPA records for 2019, 159 CAPA records for 2020 and 214 CAPA record for 2021. The electronics manufacturer has a QDMS system, but other companies also have a system or file platform for the data stored. All data are recorded through internal-external customers' requirements to ensure the company's development. At the same time, every employee is able to write CAPA.

The collected CAPA data has many columns and data available. We analyzed the columns' meanings and necessities. We have listed the available columns in Appendix A. Some columns in the CAPA data are unfilled or redundant. Finally, we have 64 CAPA left for processing. Before starting the evaluation, we removed these unnecessary columns and filtered data according to their importance. Then, we assessed CAPAs and assigned the impact value that we previously defined in our methodology. We added several new columns to assign impact values correctly.

We used likert metric for impact values, i.e., a number between 1 and 5, where 5 means the highest impact. This stage should be applied before the assessment and is an important stage since the impact values are used as the objective function coefficients in our mathematical model that maximizes totaling impact.

4.1.1 Pre-Assessment of CAPAs

There are items that should be applied before the assessment, namely in the pre-assessment. We defined the pre-assessment applications of CAPAs in three stages. These are identification of Major CAPAs, separation of target customers and restriction of target customers, and consolidation of recurring CAPAs.

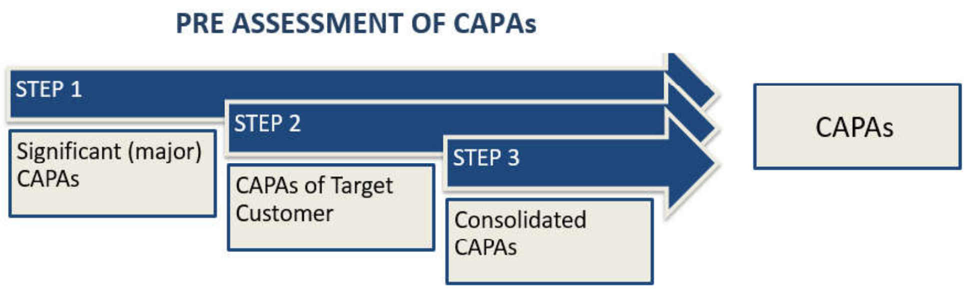

Figure 14: Pre assessment of CAPAs

The three steps we have illustrated in Figure 14 lead us to the desired CAPA data. If we look at the steps in detail, the following points emerge for the pre-assessment;

4.1.1.1 Step 1

1. Significant (major) CAPAs are filtered w.r.t.:
    a. Nonconformity Category
    b. Department of Nonconformity / Customer / Supplier
    c. CAPA Transaction Source
    d. Definition of Nonconformity
    e. Root cause
    f. CAPA Type
    g. CAPA Status
2. The column '*Impact*' is added
3. The column '*Product Group*' is added
4. The column '*Solution Area*' is added
5. The column '*Functional area*' is added
6. The column '*About digital transformation (Y/N)*' is added
7. The column '*Product*' is deleted
8. The column '*Management System*' is deleted
9. The column '*Management System Item No.*' is deleted

10. The column '*Workplace*' is deleted
11. The column '*Process*' is deleted
12. The column '*Team Leader*' is deleted
13. The column '*Planned Progress Report Date*' is deleted
14. The column '*Progress Report Writing Date*' is deleted
15. The column '*Author of the Progress Report*' is deleted
16. The column '*Progress Report*' is deleted
17. The column '*Planned Final Report Date*' is deleted
18. The column '*Writer of Final Report*' is deleted
19. The column '*Tracking Information*' is deleted

4.1.1.2 Step 2

1. CAPAs separated w.r.t target customer

4.1.1.3 Step 3

1. Repeated CAPAs consolidated

4.1.2 Assessment of CAPAs

Once the preparation phase is completed with the pre-assessment, the assessment should be performed and the data finalized from CAPA. For the impact value in the mathematical model, the fields of the added columns must be filled in. At this stage, the product groups that come to the forefront in importance and necessity for the company are important. We have given the final form of CAPA by filling in the fields of the columns and making the evaluation.

The elements to be used for the evaluation are as follows;

1. The column '***Impact***' is filled for each CAPA
2. The column '***Product Group***' is filled for each CAPA
3. The column '***Solution Area***' is filled for each CAPA
4. The column '***Functional area'*** is filled for each CAPA
5. The column '***About digital transformation (Y/N)***' is filled for each CAPA

An example of our work: CAPA The processing source of data numbered **00138** CAPA is a customer audit. During the customer audit, the customer determined that moisture sensitive materials were not suitable during production. Our functional area is warehouse and production, and our solution area is material tracking and control. We rated the impact value **4** out of 5 based on production, product quality, and customer importance.

We created the necessary data for our model through CAPA number **00138** with the ER diagram we created. We listed the improvement, the project we need to implement depending on the improvement, and the technological alternatives required for the project.

If we go through this CAPA example, the improvement is CAPA number **00138** "Material Control". The project we need to implement for this solution is WMS (Warehouse Management System). The technological alternatives for WMS are different brands and technologies with different costs. We need to solve the CAPA with the appropriate technology selection.

4.2 DIGITAL TRANSFORMATION MATURITY LEVEL MEASUREMENT

We mentioned that CM is used by consultants, companies and relevant people in the current system. Based on this situation, a roadmap is created and the journey of transformation begins. In this direction, we have conducted a process with the CM, which is currently applied in the electronics company where we wrote our thesis.

With the intensive studies we conducted in 2019 as well as in 2020 and 2021, we quantified the extent to which the efficiency of the transformation has increased. We applied the IMPULS Industrie 4.0 Readiness Model to the company as a tool to measure the ML.

Since the transformation process started in 2019, we chose 2019 as the starting point. First, we conducted an analysis using the CM for 2019. The IMPULS model, which we use as a tool, provided us with the key dimensions for 2019 based on certain key dimensions and the questions asked about them (managers).

4.2.1 Result of 2019 (Starting Point) Impuls Model

The result of this measurement for the starting point was not very good. Out of the 6 key dimensions, 3 were 0 out of 5, which clearly shows that the company has a very weak level.

Table 1: Level of key dimensions in 2019

KEY DIMENSIONS	LEVEL (2019)
Strategy and organization	0
Smart factory	0
Smart operations	2
Smart products	1
Datadriven services	0
Employees	1

If we look at the results of the MLM key dimensions for 2019 in Table 1, we can see that a foundation has already been laid for the Smart Operations, Smart Products and Datadriven Services dimensions. For the level of the other three key dimensions (Strategy and Organization, Smart Factory, Employees), we can easily say that there is no indication and no plan for transformation yet. The value 0 in the key dimension Employees can even give us an indication of the corporate culture and the competencies of the company's employees.

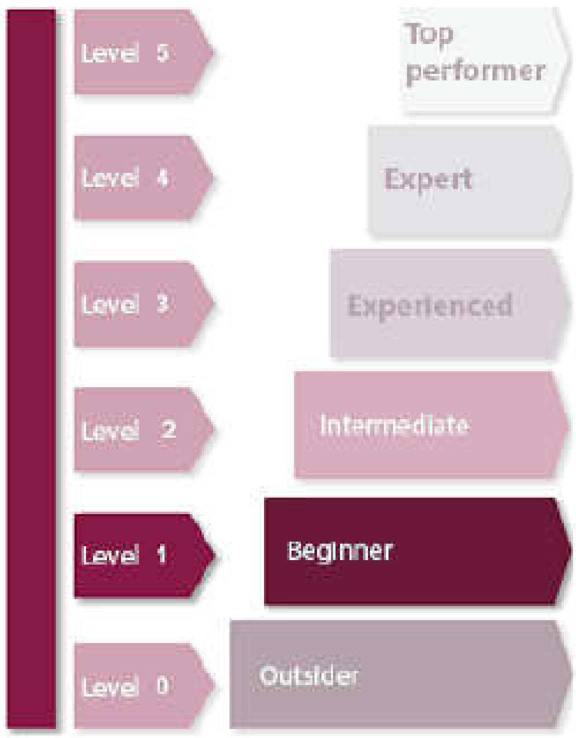

Figure 15: Maturity Level of 2019

Three dimensions lend themselves as entry levels for DT. The company's level in DT resulted in 1 out of 5, as shown in Figure 15. In addition, the industry comparison is effective to bring the result to level 1. Specifically, benchmarking with the Group (information about the company's business unit; "Manufacturing") and Number of Employees (the number of employees in the company; "500 or more employees") options affected the dimension level.

We show the MLs through the 2019 IMPULS model, depending on the key dimensions, in Figure 16 above. It is clear to see how much is at the base level in the results across 5 levels.

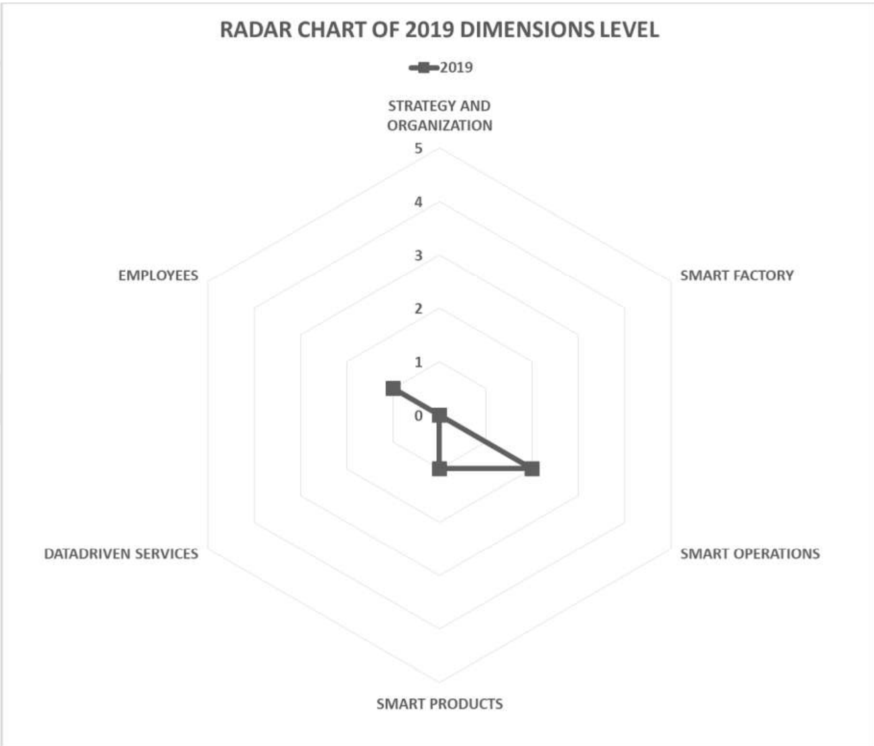

Figure 16: Radar chart of 2019 dimensions level

It should be examined in depth to see what the ML is and how to progress. In doing so, we analyzed the dimensions one by one. It is very important to go through the groups of questions in order to be able to analyze on a basic level.

A ***strategy and organization*** dimension of 0 means that the departments are not ready for DT. We can say that no indicator has been set in the company. The most important point is that a certain investment budget is set only at this stage. Setting the investment budget to be ready is a critical point. It means that we can start the journey DT. At the same time, we need to talk about an integrated technology and innovation management system for improvement of dimension.

Like the strategy and organization level, the ***smart factory*** dimension level is also 0. From this result, we can see that the adequacy of the existing systems for DT is not sufficient. The first thing to do here is to examine the existing system controls and capacities. It is necessary to look at the technical characteristics of the current system, to what extent it can be used and improved. At the same time, the compatibility of the existing system with the machines should be determined. The collection status of critical data with the existing system should be analyzed. Analysis, research, and/or a pilot study should be investigate the ability to capture critical data with the current system.

It should be determined where relevant process data can be captured and what technologies are required to do so. Interfaces need to be created to connect systems and machines. If the integration of the system is not suitable for the machines, there is a need for a system that enables integration. Separate research should be started for this.

The ***smart operations*** level, which was slightly higher than the other dimensions, resulted in level 2, indicating that information sharing across existing systems is limited. The sharing of information across departments is also limited in this way. First of all, the limitation of information sharing should be removed, and the workpieces should be connected to the relevant departments with correct and appropriate integrated systems. In addition, a cost-benefit analysis of the solution to be applied should be performed.

The workpieces also do not move on the autonomous system during the entire production. The question of where and how the autonomous controls will be when the autonomous systems are put into operation should be analyzed and reported. To obtain information on how the autonomous system processes will respond to changes, it is necessary to study the production processes in detail. IT Solutions and cloud solutions have reached a point where Smart Operations is 2. After this point, it is necessary to determine the areas that are needed in IT and cloud solutions.

The other dimension is the ***smart product*** of level 1. The limitation of the current system is that certain operations are at an introduction level, such as product storage, self-disclosure, integration, localization, assistance systems, monitoring, object information, or automatic identification. In order to achieve DT, these limitations need to be removed and the competence of the system needs to be increased.

At the beginning, the dimension of ***datadriven services*** was set as level 0. The first remark we will make should be related to data and we can see that at the starting point, the enterprise does not have data-based service competencies. We can clearly see that the link between the datadriven services dimension and the smart factory with 0 dimension.

With the increase of the level of the data-driven services dimension, it is necessary to provide data-oriented services. For this purpose, it should be determined in which areas data-driven services can be offered. This is to provide a better and more personalized service to the customer, who is the primary target.

To make DT successful, financial investments must be made and accurate data must be collected. Then, the integration of this data should be provided to the customer with correctly analyzed and personalized data.

The sixth and final dimension ***employees*** resulted in level 1. Although the level is 1, the corporate culture and the competence of the employees are not ready for it. For this, employees need to be equipped with the necessary training, seminars, studies and information. In this way, the culture change and the competencies of the company's employees for DT start to increase in a positive way. Basically, it is important to invest in employees' skills (training in areas such as IT infrastructure, automation technology, data analysis, data and communication security, development and application of assistance systems, collaboration software). In other words, increasing the culture and skills of company employees in conjunction with the DT process has a positive impact on every aspect.

4.2.2 Conventional Method Application with Impuls Model

4.2.2.1 Result of 2020 Impuls Model

As a starting point, we launched the DT process by applying the CM. We also did MLM reporting, which we plan to do in 1-year periods, at the beginning of the 2020 period. We were able to report on the progress of the methods used, the technologies selected and the developments by digitizing them through the IMPULS model. We must admit how difficult the process is DT. We can clearly see this from the results of the reports.

Table 2: Level of key dimensions in 2020

KEY DIMENSIONS	LEVEL (2020)
Strategy and organization	0
Smart factory	0
Smart operations	2
Smart products	1
Datadriven services	0
Employees	2

We can see the results we found by answering the questions in the IMPULS Model, which we implemented at the beginning of 2020, in the relevant Table 2. For this report, we can say the following; there is a difference between the report, which was determined at the beginning of 2019 and whose dimensions were determined with the IMPULS Model.

We can see the results of the IMPULS model in the beginning of 2020 in the corresponding Table 2. Only the employee dimension has changed compared to Table 2. This shows us that this basic dimension is emphasized, but not to the extent needed. In other words, although training, seminars and studies on certain topics have been organized for employees, this clearly shows that they are not conducted in a way that affects other dimensions and take action for the company's employees. If a sufficient path was taken with the employees, the values of the other dimensions would also change positively.

Figure 17: Maturity level of 2020

As can be seen in Figure 17, the company's level in DT has not been able to improve. Even when plans have been made and actions taken within the company, it has not been sufficient. In addition, the company is not fully ready for the DT process with its employees. This situation is also related to the competence of the company's employees. Employees must be specifically involved according to their responsibilities.

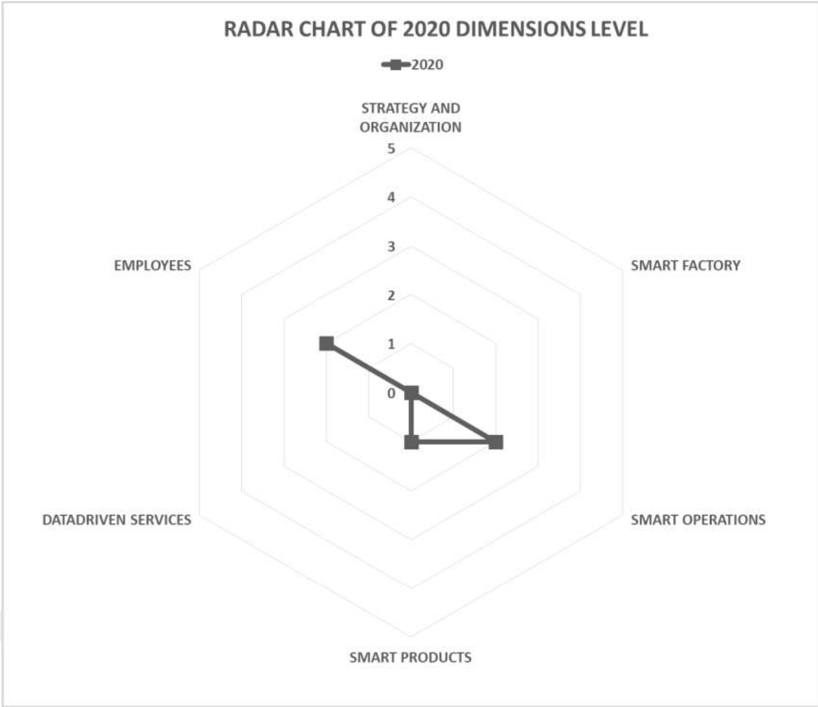

Figure 18: Radar chart of 2020 dimensions level

We have shown the radar chart of 2020 in Figure 18. The result of 2020 is very similar to the starting point. If we interpret this figure, we can clearly see to be a long way to go. There is still much to improve and that the situation is very much open to development.

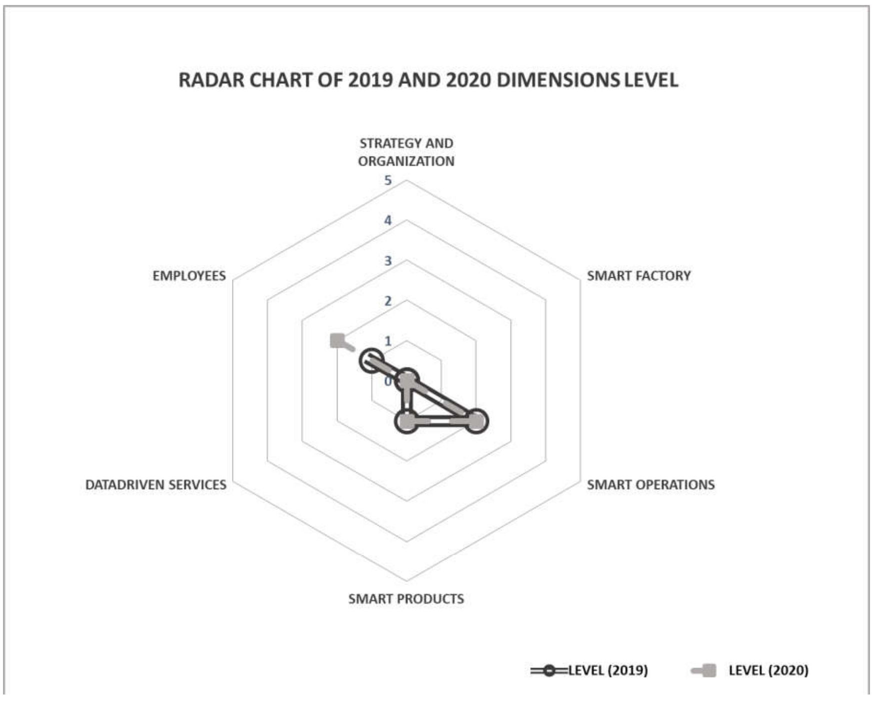

Figure 19: Radar chart of 2019 and 2020 dimensions level

If we compare the starting point in 2019 and 2020 with the radar map, we get the result in Figure 19. In fact, we can see in Figure 19 that there is not much difference between the two MLM results. We can easily interpret that there has not been sufficient progress in DT as there has been improvement in one dimension (employees).

4.2.2.2 Result of 2021 Impuls Model

We applied IMPULS Model at the beginning of 2021 in order to measure the ML 2021 of the company. We reflected the company's developments, applied technologies and changing structures by the beginning of 2021 in the survey responses of the IMPULS model. We have reported the results as in previous periods.

Table 3: Level of key dimensions in 2021

KEY DIMENSIONS	LEVEL (2021)
Strategy and organization	2
Smart factory	2
Smart operations	2
Smart products	5
Datadriven services	2
Employees	3

First, we can see the dimensional levels of the results from Table 3. There are significant positive changes compared to the results of the previous period. Taking a closer look, we can see that the dimensions are at the middle level of the DT process. The Smart Products dimension is at the highest level. From this we can see that the awareness of DT has increased in each dimension, that the importance of projects has increased, and that certain studies have begun to be carried out in earnest.

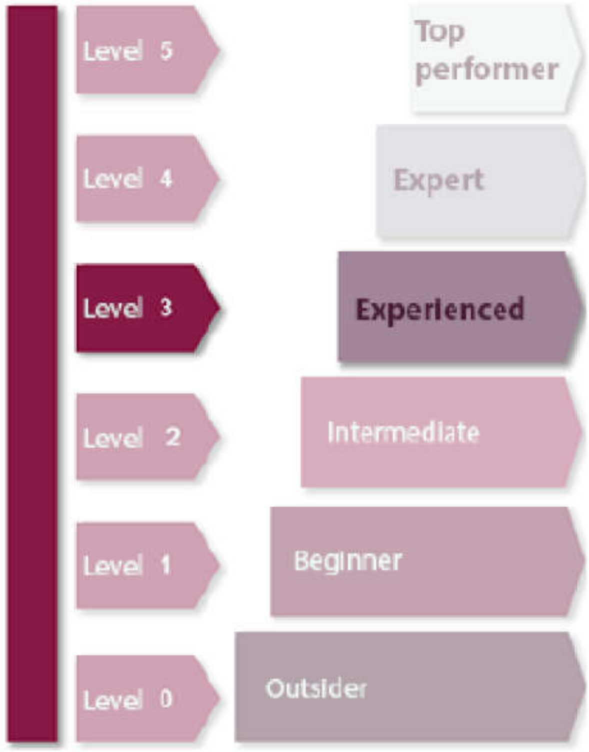

Figure 20: Maturity level of 2021

Projects have been started and are continuing with importance to the maturity of DT. As can be seen in Figure 20 , the ML was set at 3 as the dimensions increased. This ML indicates that some foundation has now been established and progress will be more stable from now on. The company's employees have been sensitized, a certain structure of IT has been built, system integrations with appropriate technologies have been achieved, data collection has been brought to a point, and work on the basics of automation has begun.

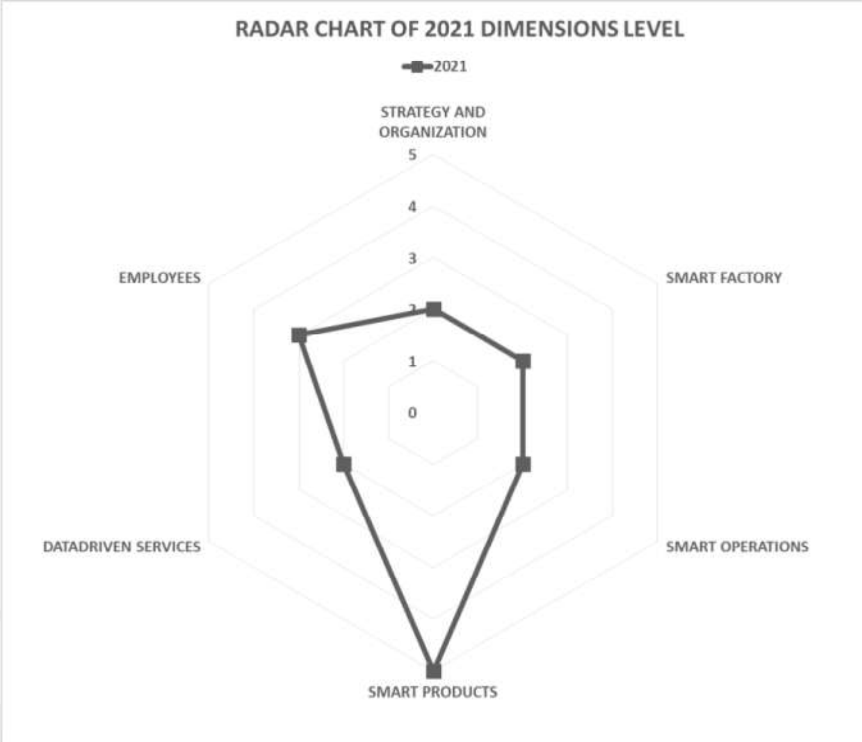

Figure 21: Radar chart of 2021 dimensions level

We have presented the results of the analysis using the radar chart in Figure 21. The development of the smart products dimension is significantly out of proportion to the others. What we expect; at the same pace it should have developed regularly, but only in this area there was a jump.

The ***strategy and organization*** dimension has made it to level 2, where pilot initiatives are being taken and studies are being conducted. This level can be further developed. For its development, it is necessary to supplement the deficiencies at the strategy level in this area. With the pilot studies, it became clear what the indicators would look like and the studies were started. Then we need to expand the indicators and integrate them into the strategy process. Now we can clearly say that the company is involved both financially and systemically in the DT process. The investment potential is at a maximum for requires. This shows that the ML can rise even further.

The next dimension, the ***smart factory***, was set at level 2. At this level, it should be examined whether the existing systems can be upgraded. The machines and systems should be evaluated about integration and the extent working in harmony. This will also determine if additional upgrades are needed. It should be analyzed how the data collected can be turned into a profit.

It should also be analyzed whether additional data needs to be collected.Subsequently, new technologies should be explored with the need. An automated method should be examined the extent usage in data collection. Existing interfaces should be reviewed and cross-system interfaces should be edited.

The ***smart operation*** resulted level 2 and we analyzed it in the previous MLM results. We can see that information sharing between departments is still limited and problems cannot be solved. The level of system integration should be reconsidered. There is an ongoing pilot study and a system that cannot be automated. It is not possible to be successful with the existing methods and resources.

The ***smart products*** level, which reaches the maximum value among the dimensions and pushes the level forward, has been determined as 5. Product memory, self-disclosure, integration, localization, assistance systems, monitoring, object information or automatic identification have reached a certain level. Knowledge and awareness of the company has increased.

The utilization status of the data collected by the company is not enough. Therefore, the dimension level of ***datadriven services*** is 2. More efficient data should be used ve the personalization of the data for the customer should be ensured. Services need to be improved to provide high quality and efficient data to customers. Providing a datadriven service is one of the key foundations of DT in the enterprise.

We assume that ***employees*** become more aware and have certain work competencies when the employee dimension reaches level 3. Level 3 shows awareness has emerged and the development process has continued. The employees were informed about data analytics, data and communications security, IT infrastructure, automation technology, development and application of assistance systems and collaboration software.

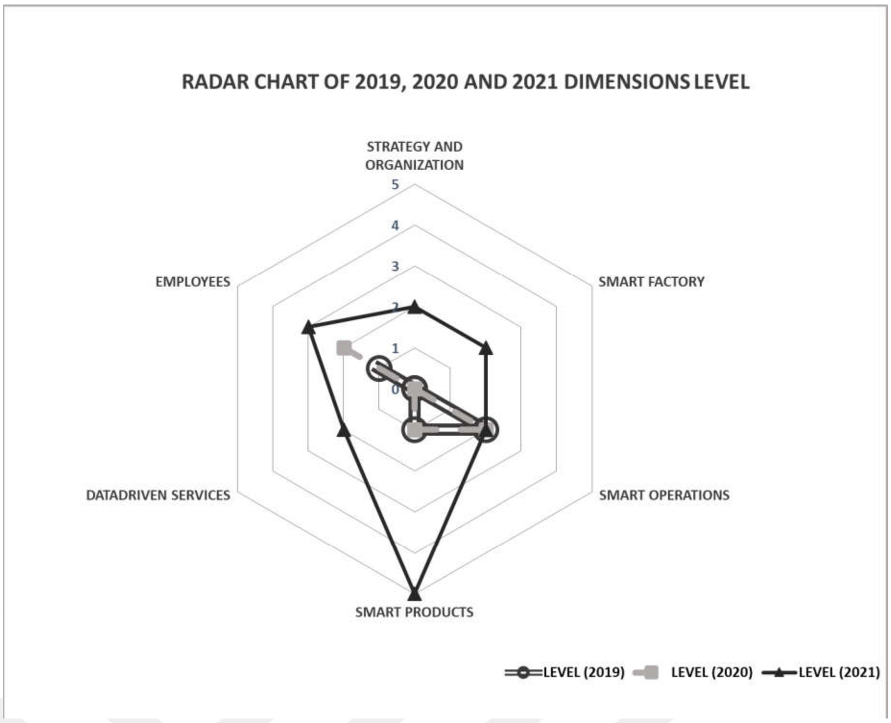

Figure 22: Radar chart of 2019, 2020 and 2021 dimensions level

Figure 22 has showed the change between the periods depending on the years 2019, 2020, and 2021. The seriousness and importance of the process have been realized late and smart products have suddenly leveled up disproportionately. Disproportionate development caused loss of control. This causes a negative impact on inefficiency and the DT process in solving problems for employees.

4.2.2.3 Result of 2022 Impuls Model

We have examined the beginning of 2022 using MLM and 2022 is the final period of the work process for company development in our work. DT began from the starting point of 2019 and continued for three periods with the maturity of 2022. The company's DT process continues even after our work is completed.

Table 4: Level of key dimensions in 2022

KEY DIMENSIONS	LEVEL (2022)
Strategy and organization	4
Smart factory	0
Smart operations	2
Smart products	5
Datadriven services	3
Employees	4

As a result of the IMPULS model applied depending on the 2022 period, we have the dimension values in Table 4. We can see that most of the dimensions are shifting to a higher point, while some of them are fixed or declining. The details of these values are different from the others.

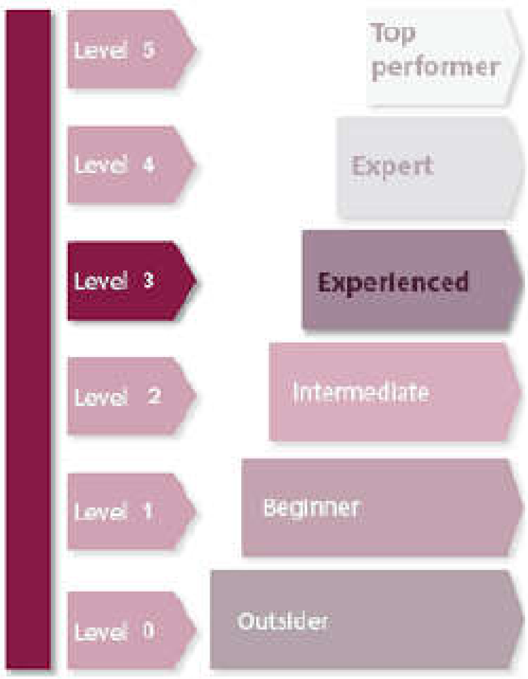

Figure 23: Maturity level of 2022

The ML of the company for the 2022 period is the same as for the previous period, as Figure 23. The company has determined its ML as "*Level 3 Experienced* "after the three-period work processes.

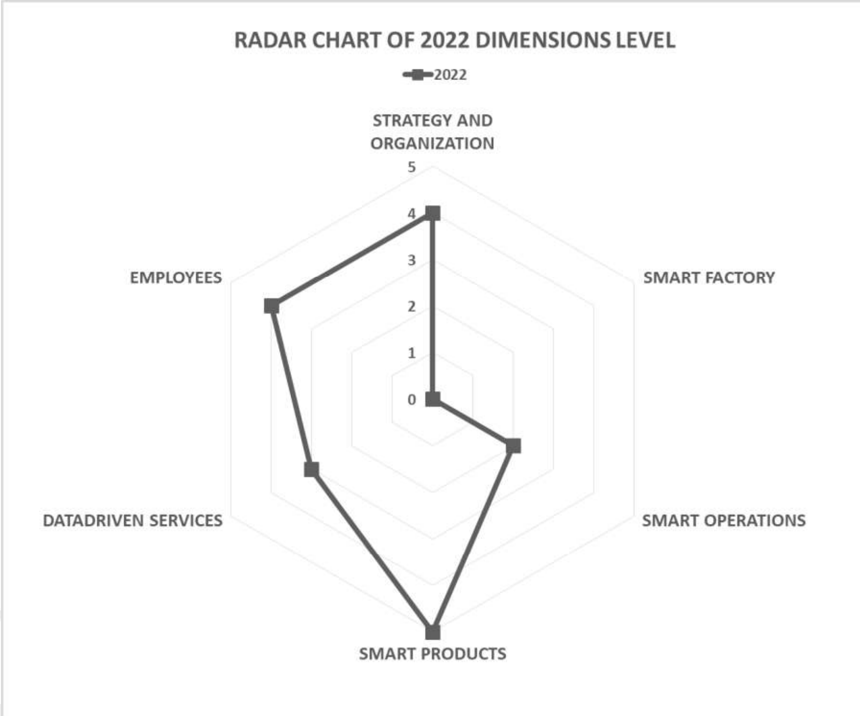

Figure 24: Radar chart of 2022 dimensions level

In Figure 24 , there is a difference abnormally in the level values of the dimensions in the radar chart. We performed a detailed analysis of the information obtained.

We see that the ***strategy and organization*** dimension has reached a certain level. Level 4 of the dimension shows us that the company is at an important point. We can interpret that the development base of the company has been established in this area. The final studies should be carried out. It is necessary to control the departments that have not yet implemented the strategies developed on DT. It determines the status of the current indicators and develops the missing points.

Valuable works has been done with considerable financial resources up to this level. The company has reached a successful point for the strategy and organization dimension and has proven its existence in the DT process.

If we look at the next dimension, ***smart factory,*** there is an abnormal level transition. While the level of this dimension was 2 in the previous period, it was 0 in the next period, despite the improvements. If we looked at the questions and the answers in the IMPULS model, the level should have increased. We contacted the people responsible for the IMPULS model about unbalanced. In their answers state, they cannot answer a question about the IMPULS model that they created in 2015, that we can always reach the IMPULS model, and they created an another model based on the IMPULS model in Appendix B. When we analyzed, we can say that this dimension level should be 3.

The ***Smart Operation*** dimension seems to be the same from the starting point, but improvements have been made in this area. This development, which is also reflected in the answers, is actually positive. Despite these results, the smart operation's inability to level up is the same as the previous dimension. However, this dimension must be at level 3.

In this process, pilot works were completed and dissemination works were started. Even if the autonomous system has not been put into use, we have reflected in the answers that data is retrieved from the machines where the studies are carried out. For this reason, we can easily say that it is not possible for the developments not to affect the levels.

It is necessary to keep control by continuing the existing applications for the ***smart product*** in the previous period. To maintain this level in recent times, continuous monitoring and tracking of developments are important.

We can say that data is becoming increasingly personalized and customer-centric. ***Datadriven services*** are beginning to improve within the plans, collecting high-level data and offering data-centric services. The company has laid the foundation for data-driven services. We understand with level 3 that a large part of it is used. The Company has demonstrated successful progress in the DT process for the Datadriven Services dimension.

If we look at the employees who form the basis of the company, the dimension of ***employees*** has evolved over the previous period. Based on the 4th level, company supported employees in their skills and competencies and brings them to a certain level of maturity. This is a sign that the DT process is progressing on a more solid basis.

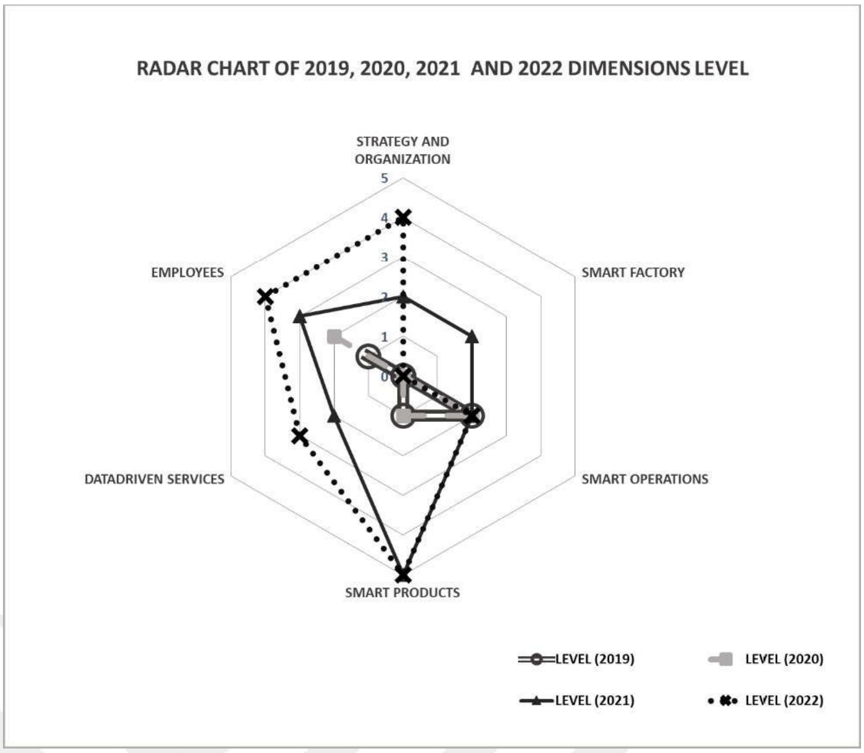

Figure 25: Radar chart of 2019, 2020, 2021 and 2022 dimensions level

If all periods are compared as in Figure 25, we can see that the DT process was severely delayed and in the first period (from 2019 to 2020) there was an unsuccessful process. The impact was minimal, which clearly to shows that the company was not given a good recommendation. The company could not decide what to do because there was no proper guidance. But in the last two periods, we see that there is a good development. Even though it is a late development, certain foundations were laid in the last period. Considering how much time and effort we lost in the first period, we have fallen behind our competitors, and it is very important to consider the impact of this development.

4.2.3 Conventional Method Application with Impuls Model and PathWay Method

Under the chapter 4.2.2 Conventional Method Application with Impuls Model, we have analyzed the case that DT is applied only with the CM. We have presented the results of the applying method with a radar chart. Each dimension creates a workspace in its province and they have emerged dimensions at different levels in 2019, 2020, 2021 and 2022.

On the other hand, we have shown the gap values of levels between the periods. From the gap values, we can see the extent to which the dimensions have evolved, which dimensions are working more efficiently, and which dimensions should be worked on.

In this work, we argue for MLM and CAPA analyses with the PathWay Method are more efficient than MLM. We analyzed the CAPA as from 2019 CAPAs. Based on the results of the PathWay Method, we extracted the dimension levels and made comparisons at the start of years 2019, 2020, 2021, and 2022.

We obtained the impact values by analyzing the CAPA information of periods. We listed improvements, projects, and technologies and selected the optimal project using the path model we applied. In this way, we determined which development should be prioritized in which area. In the following, we assumed that the company selected the appropriate project and took action. As a result, we created a stronger and more accurate roadmap.

4.2.3.1 Result of 2020-PM Impuls Model

We conducted CM for the 2019 starting point in title 4.2.1 Result of 2019 (Starting Point) Impuls Model and measured the initial maturity of the company. As a result of analyzing the information for the 2019 CAPA and the PathWay Method, the appropriate projects were selected. We took action based on the analysis results of the 2019 CAPAs and used PathWay Method for the 2020-PM. We emerged the levels of dimensions with MLM.

Table 5: Level of key dimensions in 2020-PM

KEY DIMENSIONS	LEVEL (2020-PM)
Strategy and organization	2
Smart factory	2
Smart operations	2
Smart products	2
Datadriven services	3
Employees	3

We can examine the levels of dimensions as a result of the 2020-PM in Table 5. We can easily see that the dimensions' levels are close and proportional to each other. The results of dimensions' levels show us that the process of DT is planned, proportionate and with detailed consideration of each dimension area.

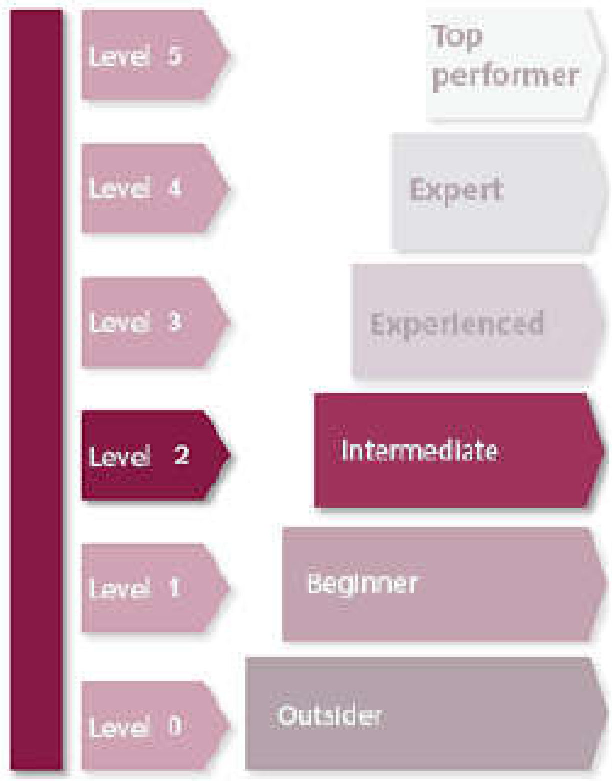

Figure 26: Maturity level of 2020-PM

While the ML of the company was 1 at the beginning, Figure 26 shows that the ML of the company is 2 at 2020-PM. We can interpret that work is synchronized and in partnership with each department owing to the dimensions' proportionality.

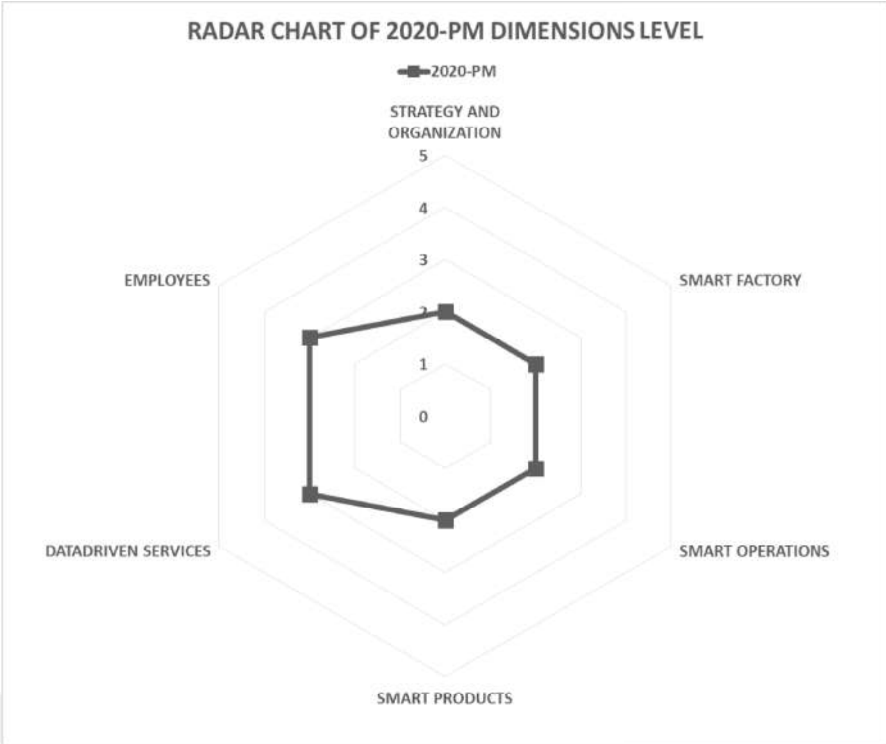

Figure 27: Radar chart of 2020-PM dimensions level

We detailed the dimension levels achieved by 2020-PM in the radar chart in Figure 27. The levels of the first period were close in Table 5 and the proportionality of the levels is reflected in the radar chart. At this period, we can say that the roadmap will be successful and the implementations will have an improving effect on the DT process.

We can start with the ***strategy and organization*** dimension, where the dimension level was set as 2. The pilot studies have started with appropriate technologies. However, there is a lack of strategy and the strategy still needs to be developed. In the first phase, the indicators were defined under the guidance of the CAPAs. The next step is to develop the indicators and integrate them into the strategy process. The company is ready for investment in financial terms and close to the maximum level for this development. As a result of this development, management is ready for DT in the process of technology and innovation integration.

The ***smart factory*** has dimension level 2 in the 2020 PM. At this level, we should assess the extent that existing systems can be upgraded and integrated. If additional improvements need, an analysis should be performed and new technologies explored. The compatibility and integration of the technology to be selected are equally critical. Following this, the necessary interfaces must be worked on.

The level of ***smart operations*** has increased to 2 since the first period. We have analyzed the interpretation of level 2 and the necessary actions in title number **0**. If we mention the most basic cases for this dimension, information exchange is crucial for ensuring autonomous processes. The process is about identifying the need for IT and cloud solutions.

The company can offer various functions with the ***smart products*** dimension 2, such as product memory, self-reporting, integration, localization, assistance systems, monitoring, object information, or automatic identification. The level is currently insufficient and needs to be developed gradually for DT.

We have explained the description of ***datadriven services*** at level 2 in the previous section in title number **0**. We emphasized that the data collected is insufficient and that more efficient data should be collected. Likewise, more efficient and personalized data should be offered to customers.

The ***employees dimension*** level has risen to 3. That means awareness is raised and being taken seriously in the period. This level reflects that employees' attitudes toward DT have improved.

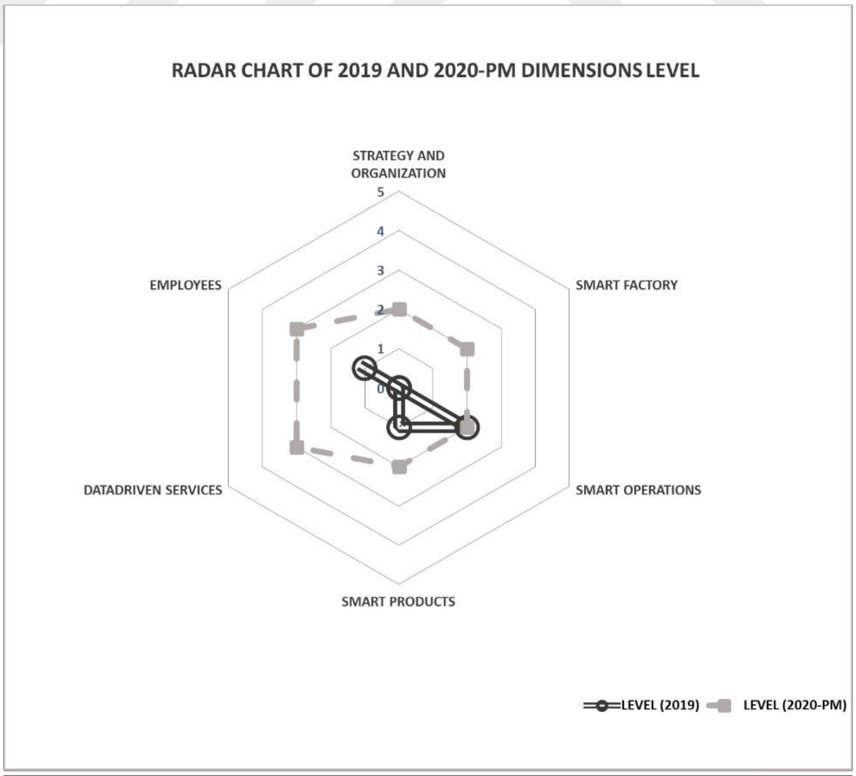

Figure 28: Radar chart of 2019 and 2020-PM dimensions level

As can be seen in Figure 28, there are regular, logical and accurate results between the starting point and the 2020 PM. Except for smart operation, we can see that all dimensions are equally positively affected. This shows us that the roadmap created with the analysis of CAPA and the PathWay Method will be a successful work.

4.2.3.2 Result of 2021-PM Impuls Model

We analyzed the 2020 CAPAs for the next period and applied a PathWay Method. After a period, we analyzed the 2020 CAPAs by their application times and impacts. We also presented the MLM results under the name 2021-PM.

Table 6: Level of key dimensions in 2021-PM

KEY DIMENSIONS	LEVEL (2021-PM)
Strategy and organization	4
Smart factory	4
Smart operations	2
Smart products	5
Datadriven services	3
Employees	4

If we look at the result for 2021-PM in Table 6, the data increases more regularly than in the previous period. In these results, we can see that the ML of the company will increase.

Figure 29: Maturity level of 2021-PM

The ML of the previous period was 2 and the ML of 2021-PM is level 3 with the result of the IMPULS model, as shown in Figure 29. The company will be at the "expert" level after two periods with the PathWay Method.

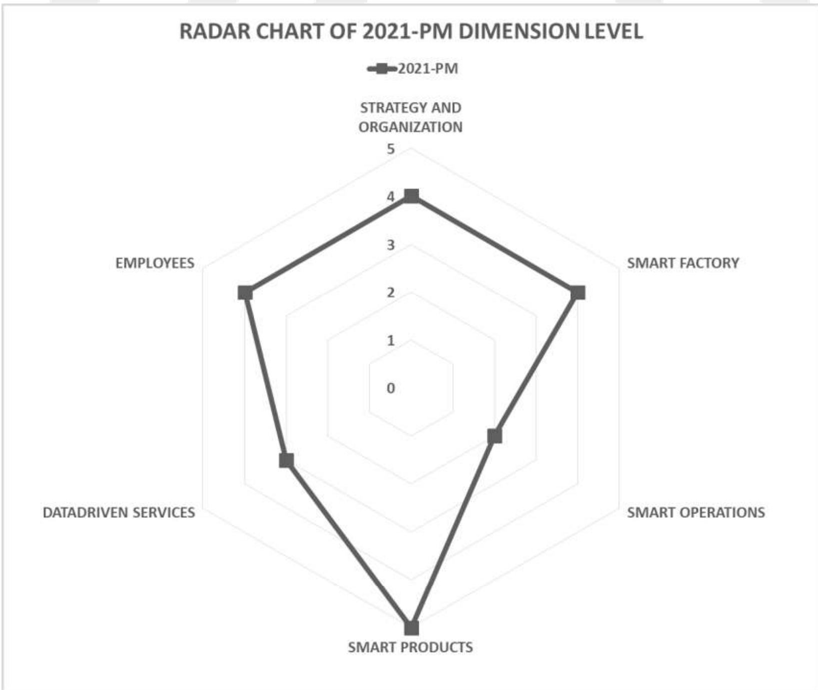

Figure 30: Radar chart of 2021-PM dimensions level

We show the result on the radar chart for 2021-PM in Figure 30. For this result, we can interpret that the foundations of DT are formed, the company's values and awareness are sufficient for transformation, and its power and influence in the industry.

The ***strategy and organization*** dimension has level 4. The company is close to the end of the transformation with the last works. We have listed the analysis of the current situation and the necessary actions for the 4 levels of this dimension. The company has proven its existence at this point for DT and should focus on the remaining minor requirements.

The value of the ***smart factory*****,** the next dimension, is also set to 4. We can say that effective data has been collected and indicators have been included. Indicators should be controlled about appropriate for the data. Continuous improvement is needed for gaps need to be filled. In addition, efforts should be made to provide new functionality for existing systems. Pilot studies should be conducted to optimize processes and workflows. Interfaces should be reviewed and new interface requirements clarified.

The dimension of ***smart products*** is the highest level. We have commented on the current situation in title number **0**. In short, it is very important to constantly control and monitor developments to maintain this level.

We commented in title number **0** on ***datadriven services*****,** which are at the same level as in the previous period. First of all, a proper correction is needed to personalize the data.

The ***employees*** have moved up from the 3rd to the 4th level. It is a successful development for the culture of the company. We can mention the positive DT process about the awareness of the employees and the match of their competencies with DT.

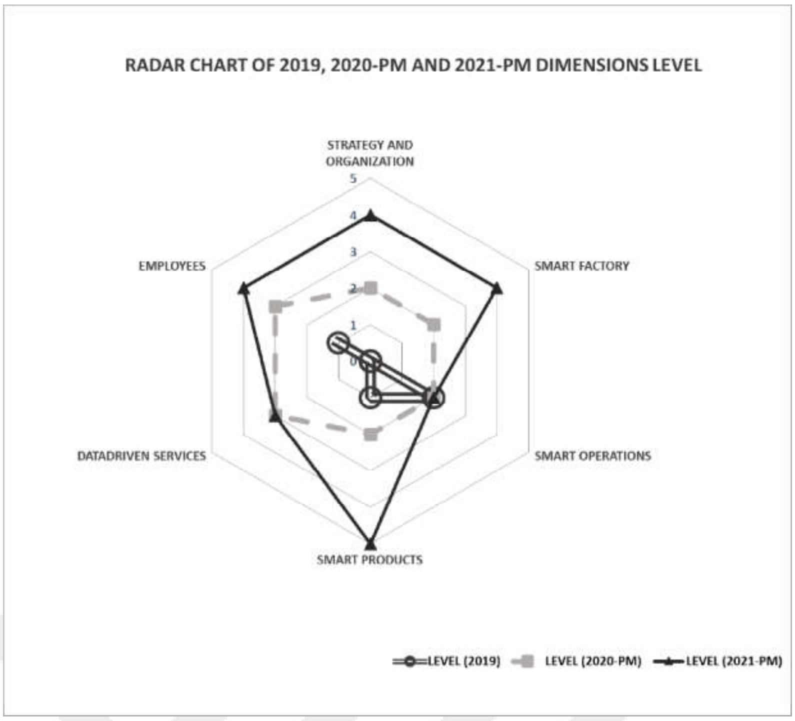

Figure 31: Radar chart of 2019, 2020-PM and 2021-PM dimensions level

When we examine the MLM results up to this period, there is no blockage in the periods. There has been a regular progression and positive level increases. We compared this with other dimensions in Figure 31. Only the dimension of intelligent operation has remained at the same level over the periods. In the other dimensions, the levels have developed.

4.2.3.3 Result of 2022-PM Impuls Model

We have improved the CAPAs of the last period with PM. We have designated the MLM at the beginning of 2022 as 2022-PM.

Table 7: Level of key dimensions in 2022-PM

KEY DIMENSIONS	LEVEL (2022-PM)
Strategy and organization	5
Smart factory	3
Smart operations	4
Smart products	5
Datadriven services	5
Employees	4

We have shown the dimensions' levels for 2022-PM in Table 7. As you can see from the results, some of the dimensions are at the best point and the rest dimensions are close to the best point.

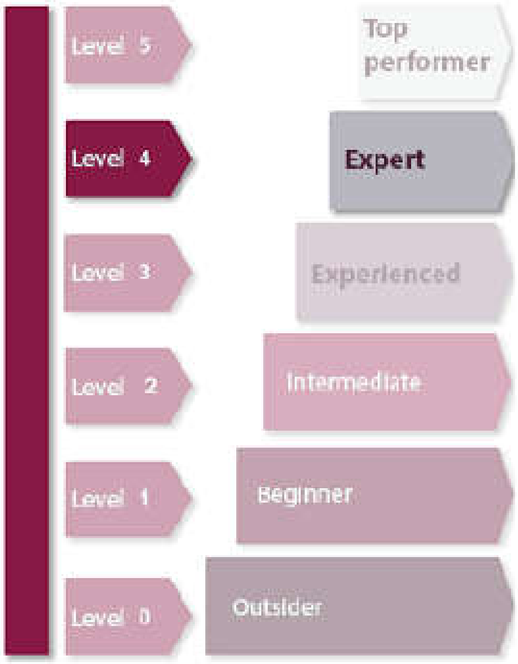

Figure 32: Maturity level of 2022-PM

We can see the result of the ML given by the IMPULS model in Figure 32 and the result is close to success. The ML is the level 4 "expert".This means that we are close to the success of the DT process.

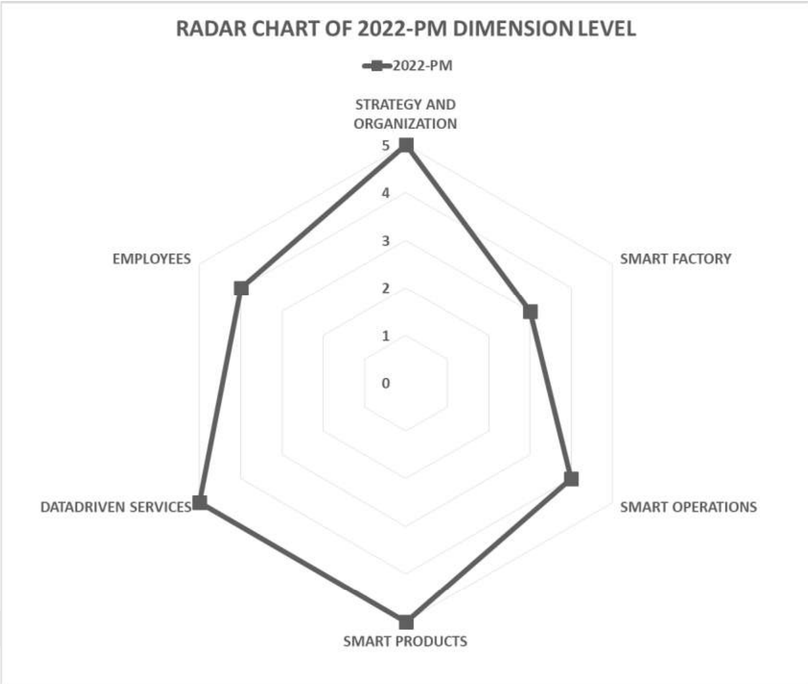

Figure 33: Radar chart of 2022-PM dimensions level

We have plotted all the dimensional levels with the radar chart in Figure 33. Compared to the previous radar charts, it provides a very broad overview. Three of the six dimensions show success with level 5 in the DT process.

For the ***strategy and organization*** dimension, an appropriate strategy has been implemented in the DT process and we have achieved successful results in all business areas. The potential is maximum and shows its presence in the industry by completing the DT process. The indicators created overlap with the system. Accordingly, significant financial resources are allocated.

The most critical point is that the dimension of ***smart factory*** has decreased compared to the previous period. This is not because the company has regressed through PM. The dimension level that should be 5 with the answers of the IMPULS model is 3. The reason for this is related to the situation that we mentioned under the title 4.2.2.3 Result of 2022 Impuls Model. We have reached the highest level of development with the answers and we can mention about automation for the company.

The ***smart operations*** dimension was at level 2 in the previous period and has risen to level 4 in 2022-PM. The integration of information into the systems is largely present. There are also examples of autonomous control within the enterprise. High-level security measures have been implemented for information technologies, and compliance should be verified with current requirements at regular intervals.

The ***smart products*** are at the same level as in the previous period. Although it is at the same level, its awareness and development continue with the development of the other dimensional levels.

The company provides a high level of ***datadriven services*.** The company also has the required competencies in services with the dimension of datadriven services at level 5. With this successful development, the company is at a level where it can be higher in the sector.

In the last dimension ***employees*,** the competencies of the employees are at the level required for DT. If they also are equipped with the necessary minor training, the company can easily take the lead in the sector as well.

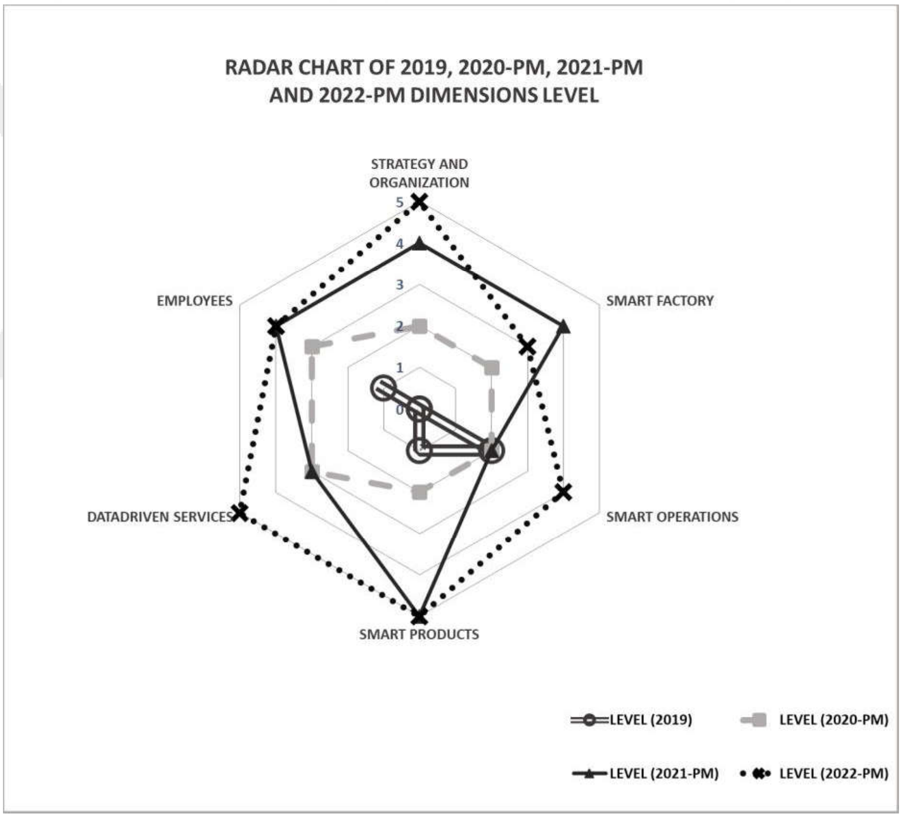

Figure 34: Radar chart of 2019, 2020-PM, 2021-PM and 2022-PM dimensions level

We have shown the MLM results of 2019 (starting point), 2020-PM, 2021-PM and 2022-PM in Figure 34 with a radar chart. The radar chart result reflects the proportional increase of dimension levels, development, and ML.

4.2.4 Comparisons of Periods

We have compared the results of the CM and PM applications. We separated these comparisons by period and plotted them on the radar chart. We have analyzed in detail the results of three different periods as 2020 and 2020-PM, 2021 and 2021-PM, and 2022 and 2022-PM.

4.2.4.1 Comparison of Radar Charts for 2020 and 2020-PM

We applied CM with the IMPULS model on the company. We labeled the result as 2020. On the other hand, if the company had applied a method to analyze its own CAPAs and use PM, we called the result 2020-PM.

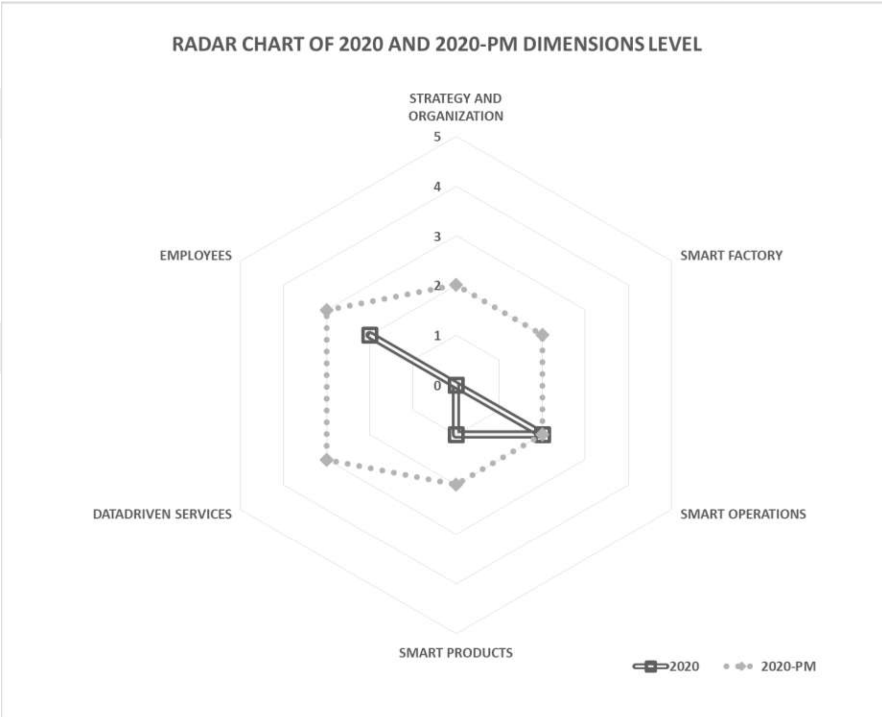

Figure 35: Radar chart of 2020 and 2020-PM dimensions level

The radar chart in Figure 35 includes a comparison of 2020 and 2020-PM. The dimension levels of 2020 are more basic and almost identical to the starting point. However, if we examine 2020-PM, we can see how the dimension levels have evolved and how the dimensions are in harmony and proportion with each other in this evolution.

Except for the Smart Operations dimension, all dimensions are at least one level higher in 2020-PM than they were in 2020. Only in Smart Operations was there no change. The reason for this is the lack of customer-specific personalized service. This is related to the completeness and credibility of the data. It is a very important point to be sure of the data and then provide it for the service to the customer. Since the data presented to the customer is crucial, it must be presented on a reliable basis. There is an improved outcome in the first period. Another important aspect of this result is that each dimension levels are close to the other.

4.2.4.2 Comparison of Radar Charts for 2021 and 2021-PM

We assumed that the necessary technologies were selected and implemented using PM with analyzing the CAPAs of 2019 and 2020. After two periods studied for solving the CAPAs with the same method, we called the result 2021-PM in title number **0**. We compared the levels of dimensions in the results for both 2021 and 2021-PM.

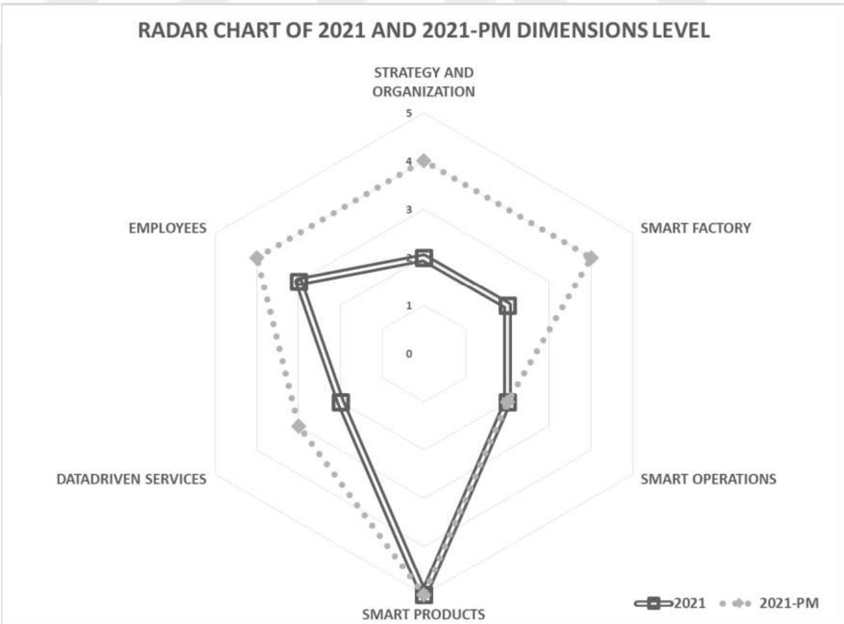

Figure 36: Radar chart of 2021 and 2021-PM dimensions level

We plotted the results of the parallel periods as 2021 and 2021-PM and compared them using the radar chart. If we look in detail at the comparison in Figure 36, we can interpret that 2021-PM develops with a jump, but lags behind 2021 by one step. The 2021 results are in a situation as if they were one period behind.

In this period, the situation is different for the smart products and smart operations dimensions. For the smart products dimension, the 2021 PM has synchronized with the 2021 progress and reached the upper point. This means that we can say that the company has made successful progress at certain points. What we really want at this point is gradual and proportional progress. Thus, other departments and systems can be more securely integrated in the DT process. The most important point at DT is to make the transition deliberately and safely. The reason smart operations is the same is that the situation we mentioned on page 88 persists in both 2021 and 2021-PM.

For this period, there is a different situation for the smart products and smart operations dimensions in the others. For the smart products dimension, 2021-PM has been synchronized with the progress of 2021 and they have reached the upper point. This means that we can say that the company's own progress is later, but at certain points, it has made a successful progress. What we really want at this point is a step-by-step and proportional progress. In this way, it can be more securely integrated with other departments and systems. The important point in DT is conscious and safe transformation.

4.2.4.3 Comparison of Radar Charts for 2022 and 2022-PM

We compared improvements by examining data from CAPA of the third time period and applying PM and incorporating them into the DT process. The greatest efficiency of this work is customer satisfaction (internal and external customers) and competitive advantage. We have stated in the previous chapters that DT is not only about advanced technology and that competitive advantage should be considered. We resulted from high efficiency with the transformation process 2022-PM.

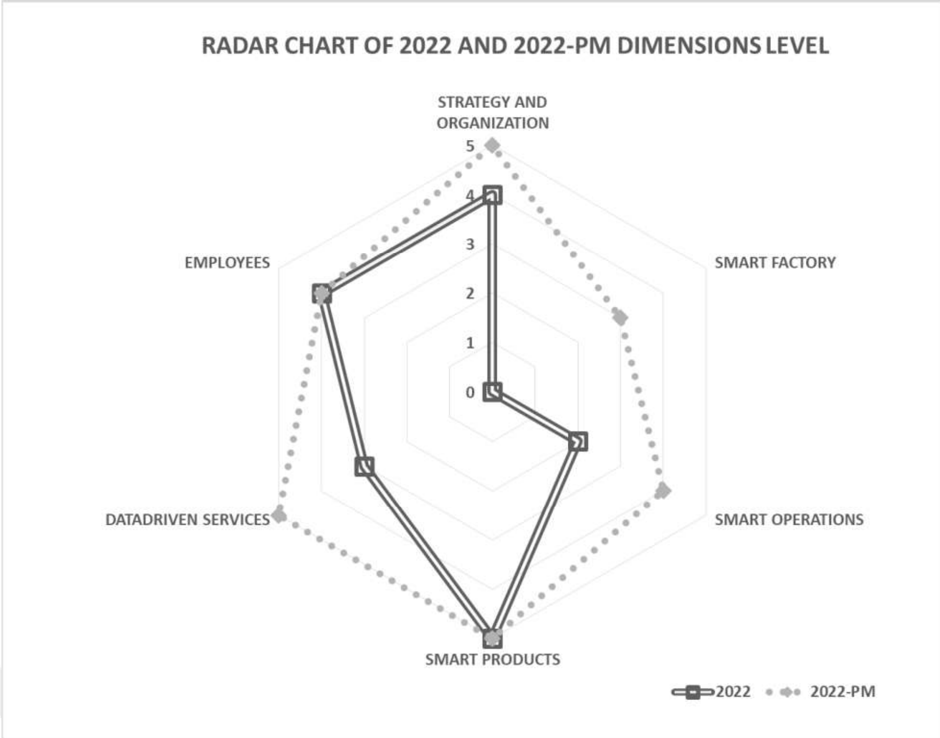

Figure 37: Radar chart of 2022 and 2022-PM dimensions level

We can explore the comparison of 2022 and 2022-PM with the radar chart in Figure 37. The dimensional levels of 2022-PM are close to each other. This shows us that the DT process is being considered in each area and that the work is being done with a common goal. In this way, we can detail the work done with the difference between 2022 and 2022-PM. There is a difference in every aspect of the results. We show the problems are solved with the technologies selected with PM. If we take into account the customers' requirements (internal customers-external customers), the process of DT becomes more efficient.

CHAPTER V
SOLUTION

We have finalized the year-based results of 2019, 2020 and 2021 CAPA data and the z_j (CAPA), y_i (IMPROVEMENT), x_p (PROJECT), w_t (TECHNOLOGY) and v (OBJECTIVE) values of the PM results. We have handled each follow-up year together with the development of the previous year. We worked on the financial resources allocated by the company for each year and solved PM on a yearly period basis. We compared and reported the objective results.

We find the optimal solution by using GAMS, runs are completed on an Intel® Core™ i5-8265U CPU, WEX-WEI x86 64bit/MS Windows and 8 GB RAM PC. The GAMS solution of the PM took 17 seconds in 15.1.0 version in Appendix C.

The Company has provided year-based financial resources for the DT process. These resources are reserved for technologies that meet the requirements. We restricted the financial resource determined every year with the Budget constraint in PM and it prevented us from going out of the company's resources.

The financial resource determined by the company for the years 2019, 2020, and 2021, namely the budget is $55,000, $65,000, and $65,000 respectively. We also acted on this budget constraint in PM for the CAPA, improvement, project and technology input values that we handled every year. We used the GAMS to solve it and got the output as an excel file.

Table 8: Available and usage budgets based on years

YEAR	2019	2020	2021
AVAILABLE ($)	55,000	65,000	65,000
USAGE($)	47,000	65,000	59,000

While trying to reach the maximizing impact result with a year-based budget constraint, we achieved the same maximum impact with less financial value than our budget. In Table 8, we showed the budget (available) allocated by the company and the amount (usage) required for the optimal value.

Although the company allocated up to $55,000 in financial resources for 2019, $47,000 of this could be achieved by procuring appropriate technologies and providing the optimal solution. It is necessary to use all of the $65,000 prepared for 2020. Finally, using $59,000 of the $65,000 budget allocated for 2021 solutions was sufficient for the necessary technologies.

Table 9: Impact solutions based on years

YEAR	TOTAL IMPACT	CUMULATIVE OF TOTAL IMPACT	TOTAL IMPACT IN OPTIMAL SOLUTION OF PM	CUMULATIVE TOTAL IMPACT IN OPTIMAL SOLUTION OF PM
2019	57	57	45	45
2020	104	161	102	147
2021	62	223	76	223

We showed objective values with maximizing impact in Table 9. We can examine the successful completion of existing CAPAs from the impact values with the technologies selected and applied every year. Table 9 includes the current impact values calculated on the collected data. “Total Impact” includes the total impact values of the CAPAs based on the year, and the impact values added based on the year are included in the “Cumulative of Total Impact”. When PM is applied with GAMS with the financial resources allocated by the company, we see the year-based results in “Total Impact in the optimal solution of PM” and “Cumulative Total Impact in Optimal Solution of PM”.

All CAPA data (in cumulative of total impact) were solved by the PM method. In this way, internal and external customer demands were solved by choosing appropriate technologies. We mentioned the listed technologies from the selected projects. Appropriate technologies are optimally selected by PM for CAPAs (indirectly). Multiple technologies are tied to a project. For this reason, We can select one technology from the technology list it is connected to in order to carry out the project.

Table 10: Selection technology based on years

YEAR	BUDGET($)/TECHNOLOGY(W)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2019	55,000	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
2020	65,000	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
2021	65,000	1	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	1

YEAR	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2021	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1

In Table 10, there is a year-based representation of the results after the solution. W is a binary variable and we see the selected technologies as 1 in the results in Table 10. Since we deal with the CAPAs of each year separately, we see the selected technologies at the used budget value on a yearly basis in Table 10.

For example, technologies that can improve 00138 CAPA for 2019 are any of 28, 29, 30, 31, 32, 33, and none of them could be selected in the 2019 period in Table 10. Thus, we could choose technology 29 in the 2020 period and start the improvement process of 00138 CAPA.

Depending on the budget, certain projects are taken over with appropriate technologies. These projects have more than one technology but choose one technology so that project can be taken over. This is related to which project (indirectly) the open CAPA (CAPA to be improved) should be improved. The projects implemented step by step over the years are selected depending on the CAPAs.

Table 11: Selection project based on years

YEAR	BUDGET($)/PROJECT(X)	1	2	3	4	5	6	7	8	9
2019	55,000	0	0	1	0	1	1	0	0	0
2020	65,000	0	0	1	0	1	1	0	1	0
2021	65,000	1	1	1	1	1	1	1	1	1

When we report the project selection with the financial resource allocated every year, Table 11 appears. All of the prepared projects have been put into practice when the 2021 CAPAs are also improved with the addition of previous processes (investments and studies).

If we give an example over 00138 CAPA, project number 8 is WMS. We should have selected any technologies numbered 28, 29, 30, 31, 32, and 33. We selected technology 29 in the 2020 period, and project number 8 was selected, which depends on it.

Each project affects more than one improvement. It improves CAPA by being selected improvements linked to selected projects. When we act on the year-based financial constraint values and the ER Diagram, we expect the PM result to be similar to X.

Table 12: Selection improvement based on years

YEAR	BUDGET($)/IMPROVEMENT(Y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
2019	55,000	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	1	0	0	0	0	0
2020	65,000	1	0	0	1	0	0	1	1	1	1	1	0	0	1	0	1	1	0	1	1	1	0
2021	65,000	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

We have shown the result of y, which is a binary variable, in Table 12 based on years on the optimal budget. When a project is selected, the improvements affected by that project are as 1. All projects were implemented in 2021 with selected technologies in each list group, so it has an impact on each improvement as 1. The connection of the w, x, and y selections that we see in the table comes from here.

For example, after we selected project 8, which is associated with technology 29, we could make the necessary improvements. The necessary improvements associated with project number 8 are 3 (warehouse management), 6 (inbound logistics), 13 (material control), 14 (material tracking), 15 (material tracking warehouse management), 20 (shipping and logistics).

It is a binary variable that directly affects the target value and connects to the impact value. In this work, more efficient results have been achieved by incorporating CAPAs into the DT process. We have reached this point and will examine which CAPAs have improved annually in the selected budget.

Table 13: Selection CAPA 2019 based on years

YEAR	BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211
2019	55,000	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1
2020	65,000	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
2021	65,000	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

For the 2019 target results, all impacts were not provided as per the PM result. While the total impact value was 57, the selected technologies were able to deliver 45 impacts considering the budget constraint. In Table 13, some of the 2019 CAPAs have not been improved. If CAPAs 00080, 00138, and 00168 could be improved, the maximum impact value for 2019 would be 57. In the next years, technology has been provided to improve previous years' CAPAs and this gap has been closed.

Table 14: Selection CAPA 2020 based on years

YEAR	BUDGET($)/CAPA(Z)	00268	00272	00274	00275	00277	00285	00287	00295	00297	00301	00325	00328	00340	00342	00357	00362	00368	00369	00376	00389	00411	00412	00416	00417	00424	00431
2019	55,000	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
2020	65,000	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1
2021	65,000	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

In Table 14, we see the results of the 2020 CAPAs on an annual basis. Since these CAPAs were not available in 2019, they could not be improved and were assigned a value of 0. At the same time, the 2020 CAPAs were impacted by the 2019 improvements and were assigned a value of 1.

Table 15: Selection CAPA 2021 based on years

YEAR	BUDGET($)/CAPA(Z)	00439	00450	00451	00452	00453	00454	00460	00531	00553	00554	00575	00587	00593	00604	00607	00620	00621	00622	00629	00634	00640
2019	55,000	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
2020	65,000	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
2021	65,000	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Looking at the CAPAs for 2021, we see that the 2019 and 2020 CAPA values could not be improved (because they were not in previous years), but the CAPA values for 2021 have been completed and improved with technology decisions made in previous years. Table 15 shows the improvements for 2021 CAPA on an annual basis.

For example, if we examine the 2019 CAPAs in Table 15, 00138 CAPA of 2019 resulted according to the available resources and constraints as "0" so we could not select it. When we get to the 2020 period, we could select 00138 CAPA.

5.1 SENSITIVITY ANALYSIS

We conducted a sensitivity analysis study on the budget for PM using GAMS. We did the sensitivity analysis that we extracted with Budget values based on technology costs. We have listed the suitable technologies for the selected projects from the necessary improvement. In the listed technologies, we have accepted the minimum cost of technology as *the lower value*, and the sum of the minimum cost of technologies that need to be done for that year as *the upper value*. We applied the sensitivity analysis between a value smaller and close to *the lower cost of technologies*, and a value greater and close to *the lower total cost of technologies*. While applying this, we paid attention to two important points;

- A project can last longer than a period. We calculate the cost of the technology we choose over the period in which it is continued. That is, if the application period of the technology continues in the next period, we include the cost in the current period. For example, the MES (Manufacturing Execution System) project is a comprehensive project and requires more effort and time. The most appropriate technology in the MES project required for the 2019 CAPAs is **18**. Assuming we apply technology 18 to improve 2019 CAPAs, it takes more than 1 period. We have to add cost value in both 2019 and 2020.
- In the current period, we may not implement a project. We may not choose an appropriate technology due to budget constraints or "mutually exclusive". We add the technology that we cannot select in the current period to the technology list for the next period. For example, CAPA number 00138 belongs to the year 2019. We could not implement the improvement in the 2019 period due to constraints. We included CAPA number 00138 in the list for the 2020 period and applied the necessary technology in this period.

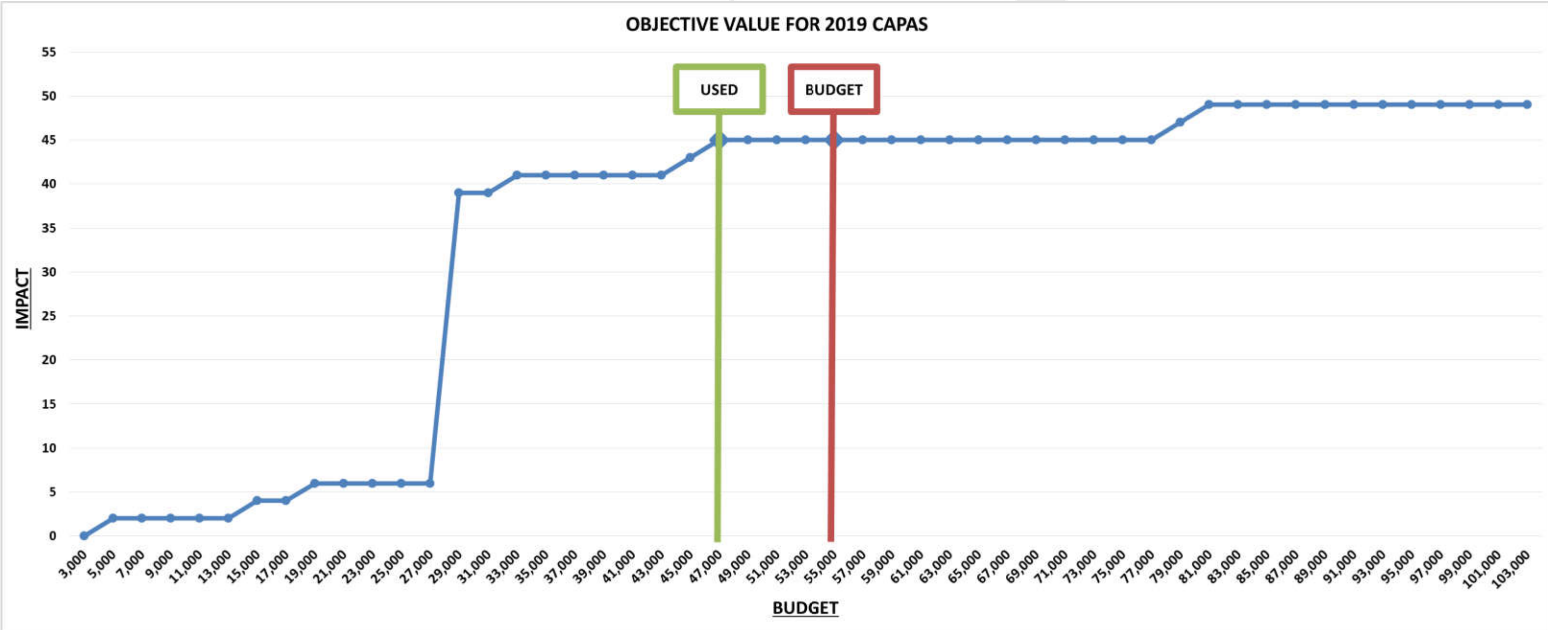

Figure 38: Graph of impact and budget with available and used budget in 2019

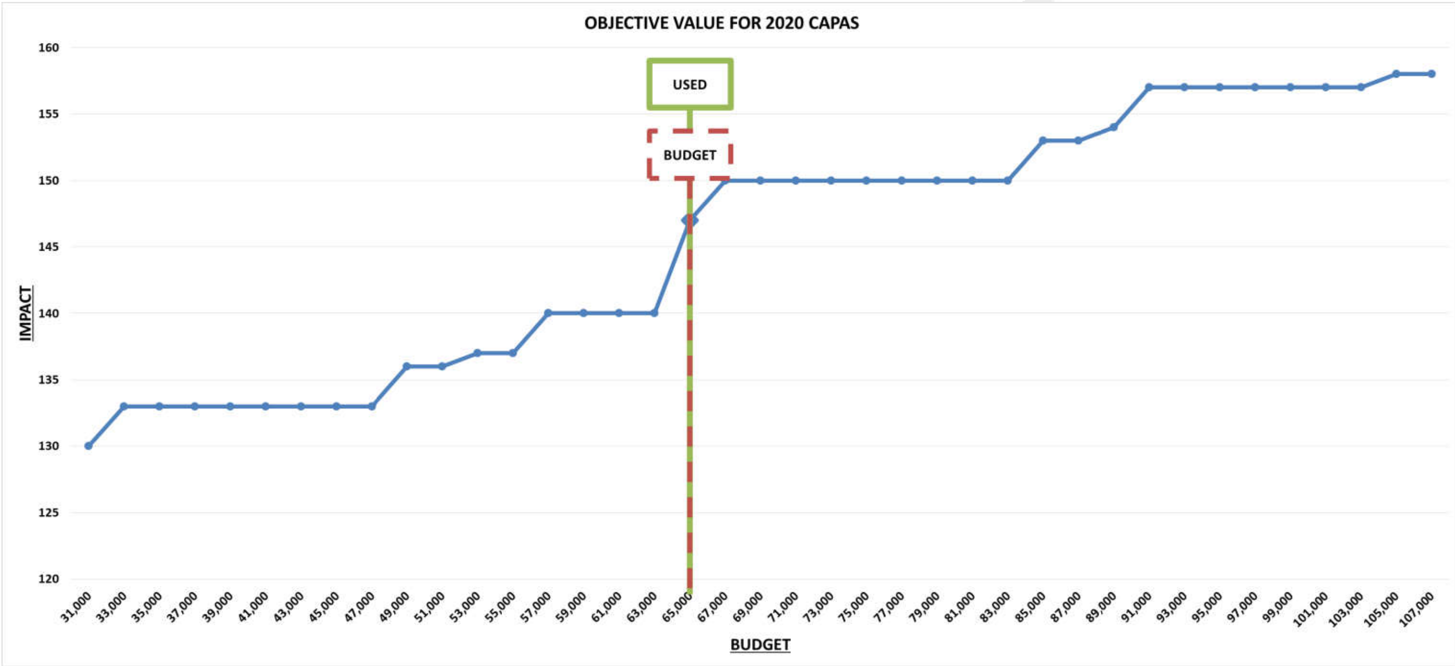

Figure 39: Graph of impact and budget with available and used budget in 2020

We made the resulting graph of the sensitivity analysis for 2019 CAPAs in Figure 38. Likewise, we marked both usage and available values in the graph. We analyzed the effect of the determined impact value and the budget on the impact values.

The sensitivity analysis of the next period is included in the graph in Figure 39. Both usage and available budget values were equal as a result of the PM applied for 2020 CAPAs. These values are shown in the sensitivity analysis' graph in Figure 39. In addition, the impact value corresponding to the lower budget value in sensitivity analysis can not 0. It starts from a certain value. This is the cause; selected technologies continue to be implemented with financial resource constraints for 2019 CAPAs. Implemented technologies also affect the CAPAs of 2020. The minimum impact value of 2020 starts from a certain impact value point due to the impact of the technologies applied in 2019 as well as a cumulative impact calculation.

The graph in Figure 40 shows the sensitivity analysis of 2021 CAPAs with PM. As in 2020, we see the impact values starting from a certain point in this sensitivity analysis. The impact value increases depending on the affected CAPAs. The marked usage and available budget status show us that appropriate technologies can be applied with less budget.

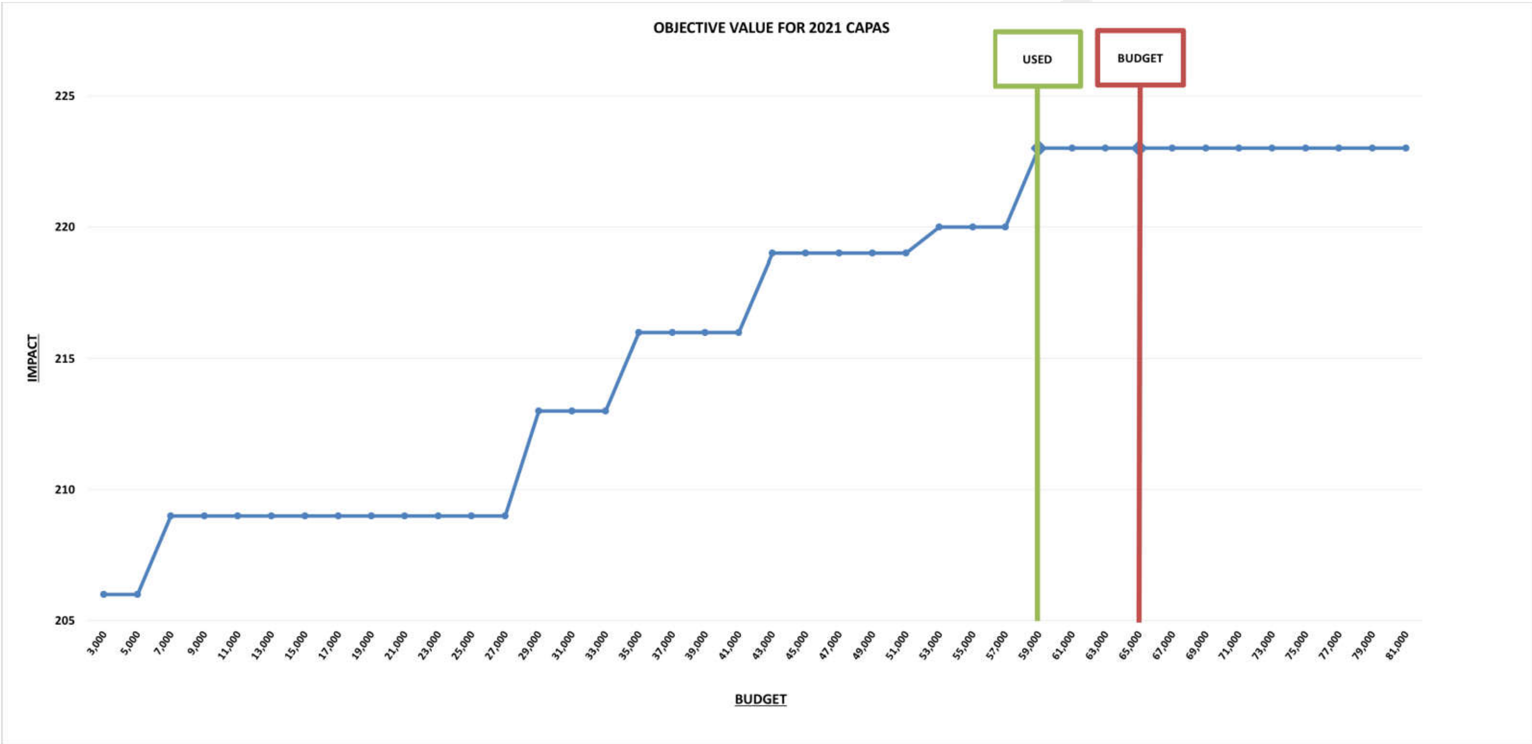

Figure 40: Graph of impact and budget with available and used budget in 2021

We performed a sensitivity analysis with GAMS on a budget basis for w. In the study conducted between the budgets between the lower cost of technology and the lower total cost of technologies, we made a sensitivity analysis of our variable values.

Table 16: Selection technology based on budget in 2019

BUDGET($)/TECHNOLOGY(W)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
3,000							0	0																													
5,000								0->1																													
7,000							0->1	1->0							0																						
9,000																																					
11,000							1																														
13,000								0																													
15,000							1->0								0->1			0																			
17,000																																					
19,000								0->1																													
21,000							0								1																						
23,000								1																													
25,000																																					
27,000							0->1	1->0																													
29,000							1->0	0							1->0			0->1																			
31,000																																					
33,000					0			0->1						0																							
35,000																																					
37,000															0																						
39,000								1																													
41,000																																					
43,000																																					
45,000								1->0							0->1																						
47,000								0->1																													
49,000																																					
51,000																																					
53,000	0	0	0	0		0			0	0	0	0	0			0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55,000															1																						
57,000																																					
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61,000																																					
63,000								1																													
65,000																																					
67,000					0->1		0							0->1	1->0			1																			
69,000																																					
71,000																																					
73,000															0																						
75,000																																					
77,000																																					
79,000								1->0							0->1																						
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85,000					1									1																							
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103,000																																					

In the sensitivity analysis, we see the selection and change status of the technologies in Table 16 for 2019. The state of technology is indicated by four different displays.

Two of them indicate the transition;

- "0->1" notation; while the technology was 0 (not appropriate) in the previous budget, it has been updated to 1 (appropriate) and is the transition field.
- "1->0" notation; while that technology was 1 (appropriate) in the previous budget, it has been updated to 0 (not appropriate) and it is a transition field.

The other two represent steady state.

- "1" notation; that technology is appropriate and selected within the specified budget.
- "0" notation; that technology is not appropriate for the specified budget

Table 17: Selection technology based on budget in 2020

BUDGET($)/TECHNOLOGY(W)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
31,000																																			0	0	
33,000																																		0		0->1	
35,000																																			0->1	1->0	
37,000																																		0->1	1->0		
39,000														0																							0
41,000																							0														
43,000																																		1			
45,000																																					
47,000																													0								
49,000														0->1																				1->0			0->1
51,000																																					1
53,000																							0->1														1->0
55,000																																					0
57,000														1																							0->1
59,000																							1														
61,000																																					1
63,000																																					
65,000					0									1->0									1->0						0->1								1->0
67,000																																					0->1
69,000	0	0	0	0		0	0	1	0	0	0	0	0		1	0	0	1	0	0	0	0		0	0	0	0	0		0	0	0	0				
71,000																																				0	
73,000																																			0		
75,000														0																							
77,000																							0														1
79,000																																		0			
81,000																																					
83,000																																					
85,000														0->1																							
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89,000																							0->1														1->0
91,000																																					0->1
93,000																																					
95,000																							1														
97,000														1																							1
99,000																																					
101,000					0->1																		1->0														
103,000																							0														
105,000					1																		0->1														1->0
107,000																							1														0

The w (technology) selection results and sensitivity analysis of PM applied with 2020 CAPAs are given in Table 17. Likewise, we can see four different situations (0->1, 1->0, 1, and 0) and the changes that occur on a budget basis.

Table 18: Selection technology based on budget in 2021

BUDGET($)/TECHNOLOGY(W)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
3,000																																			0		
5,000																																		0			
7,000																																			0->1		
9,000																																		0->1	1->0		
11,000																																					
13,000																																					
15,000														0									0														
17,000										0																											0
19,000	0																																	1			
21,000																																					
23,000																																					
25,000																																					
27,000					0																																
29,000														0->1									0->1											1->0			
31,000														1																							
33,000										0->1				1->0																							
35,000										1->0				0->1																							0->1
37,000	0->1																																				1->0
39,000	1->0																																				0->1
41,000	0	0	0	0		0	0	1	0		0	0	0		1	0	0	1	0	0	0	0		0	0	0	0	0	1	0	0	0	0		0	0	
43,000	0->1																																				
45,000																																					
47,000	1																																				1
49,000																																					
51,000																																					
53,000	1->0				0->1																													0			
55,000	0->1									0				1									1														1->0
57,000																																					0
59,000																																					0->1
61,000																																					
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65,000																																					
67,000					1																																1
69,000	1																																				
71,000																																					
73,000																																					
75,000										0->1				1->0																					0->1		1->0
77,000																																		0->1	1->0		
79,000										1				0																				1	0		0
81,000																																					

One technology was selected from each project group in the 2021 study. Technology results and changes selected depending on different budget values are available for 2021 in Table 18.

We mentioned the selection of appropriate technologies with sensitivity analysis in the previous topic. As a result, we analyzed the selection of projects that depend on the selected technologies. For the improvement of the CAPAs, the necessary improvement-related project is selected with the appropriate technology and the required budget.

Table 19: Selection project based on budget in 2019

BUDGET($)/PROJECT(X)	1	2	3	4	5	6	7	8	9
3,000			0						
5,000			0->1						
7,000					0				
9,000			1						
11,000									
13,000									
15,000			1->0		0->1	0			
17,000			0						
19,000			0->1						
21,000					1				
23,000			1						
25,000									
27,000									
29,000			1->0		1->0	0->1			
31,000			0						
33,000		0	0->1	0					
35,000									
37,000					0				
39,000			1						
41,000									
43,000									
45,000			1->0		0->1				
47,000			0->1						
49,000									
51,000									
53,000	0						0	0	0
55,000					1				
57,000									
59,000									
61,000									
63,000			1						
65,000									
67,000		0->1		0->1	1->0	1			
69,000									
71,000									
73,000					0				
75,000									
77,000									
79,000			1->0		0->1				
81,000			0->1						
83,000									
85,000		1		1					
87,000									
89,000									
91,000					1				
93,000			1						
95,000									
97,000									
99,000									
101,000									
103,000									

The sensitivity analysis result performed with the 2019 CAPAs is given in Table 19. Changed and selected projects are shown with notations. The three projects with the optimal were selected with the 2019 financial resources as projects 3, 5 and 6.

Table 20: Selection project based on budget in 2020

BUDGET($)/PROJECT(X)	1	2	3	4	5	6	7	8	9
31,000									0
33,000									0->1
35,000									
37,000									
39,000				0					
41,000							0		
43,000									1
45,000									
47,000								0	
49,000				0->1					
51,000									
53,000							0->1		1->0
55,000									0
57,000				1					0->1
59,000							1		
61,000									1
63,000									
65,000		0		1->0			1->0	0->1	1->0
67,000									0->1
69,000	0		1		1	1			
71,000									
73,000									
75,000				0					
77,000							0		
79,000									1
81,000									
83,000									
85,000				0->1					
87,000								1	
89,000							0->1		1->0
91,000									0->1
93,000									
95,000							1		
97,000				1					1
99,000									
101,000		0->1					1->0		
103,000							0		
105,000		1					0->1		1->0
107,000							1		0

We can examine the sensitivity analysis study for 2020 from Table 20. Changes in Optimal Budget are more than others. We can explain the reason with our objective of maximizing impact.

Table 21: Selection project based on budget in 2021

BUDGET($)/PROJECT(X)	1	2	3	4	5	6	7	8	9
3,000									0
5,000									
7,000									0->1
9,000									
11,000									
13,000									
15,000				1			1		
17,000									1
19,000	0								
21,000									
23,000									
25,000									
27,000		0							
29,000				0->1			0->1		1->0
31,000									0
33,000									
35,000									0->1
37,000	0->1								1->0
39,000	1->0								0->1
41,000	0		1		1	1		1	
43,000	0->1								
45,000									
47,000	1								1
49,000									
51,000									
53,000	1->0	0->1							
55,000	0->1			1			1		1->0
57,000									0
59,000									0->1
61,000									
63,000									
65,000									
67,000		1							
69,000	1								
71,000									1
73,000									
75,000									
77,000									
79,000									
81,000									

We reported that each CAPA was improved in 2021. We see this situation in the sensitivity analysis in Table 21. Already at the start of 2021, we started with the selection of six out of nine projects. Subsequently, the remaining projects were implemented with the necessary investments.

As with any variable, we performed a sensitivity analysis on this one. In the sensitivity analysis of Y, which we applied between certain budget values, we came very close to be improved of CAPA. The analysis report is annualized as for the other variables.

The changes values are included in Table 22, which we created using the CAPAs PM result for 2019. There has been a lot of change, especially in the 11th improvement. The reason is that the technology costs and the maximum impact of the CAPAs are lower than the other improvements. When the budget is increased and a higher maximum impact value can be selected, the solution automatically selects other projects and changes their improvements to move closer to the optimum.

Table 22: Selection improvement based on budget in 2019

BUDGET($)/IMPROVEMENT(Y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
3,000											0											
5,000											0->1											
7,000	0																					
9,000											1											
11,000																						
13,000																						
15,000	0->1							0		0	1->0					0	0					
17,000											0											
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Table 23: Selection improvement based on budget in 2020

BUDGET($)/IMPROVEMENT(Y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
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65,000					1->0							1->0		0->1				1->0		0->1		0
67,000												0->1										
69,000	1	0	0	1		0	1	1	1	1	1		0		0	1	1		1		1	
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Table 23 includes sensitivity analysis of improvements for 2020. In this analysis, where we see strong changes, most of the changes are in the financial resources allocated by the company and in the usage value. In Table 20, we see in the objective sensitivity analysis for the year 2020 that the value of the impact increases by $65,000. This is due to the change in variables.

Table 24: Selection improvement based on budget in 2021

BUDGET($)/IMPROVEMENT(Y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
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37,000		0->1										1->0										
39,000		1->0										0->1										
41,000	1	0	1	1		1	1	1	1	1	1		1	1	1	1	1		1	1	1	
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All of the improvements have been selected at a lower budget in 2021 in Table 24. The improvements requested have been achieved for the CAPAs thanks to the implemented projects. Even if we consider the changes in a result of the sensitivity analysis, all the improvements were successfully selected when the value of financial resources reaches $65,000. In this table, we can see that the total value of the impact has been completed.

We created a sensitivity analysis in Z (CAPA). We demonstrated the results of the current year's CAPAs and the previous year's CAPAs. However, in the 2019 PM, we only addressed the 2019 CAPAs since 2019 is the starting point. In 2020, we worked with both 2020 CAPAs and 2019 CAPAs that could not be improved. Similarly, in 2021, we made improvements over the 2021 CAPAs and the CAPAs in both 2019 and 2020.

Table 25: Selection CAPA based on budget in 2019

BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211
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29,000		0->1	0->1	0->1		0->1	0->1	1->0	0->1	0->1	0->1		1->0	0->1	0->1	0->1	0->1
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BUDGET($)/CAPA(Z)	00268	00272	00274	00275	00277	00285	00287	00295	00297	00301	00325	00328	00340	00342	00357	00362	00368	00369	00376	00389	00411	00412	00416	00417	00424	00431	00439	00450	00451	00452	00453	00454	00460	00531	00553	00554	00575	00587	00593	00604	00607	00620	00621	00622	00629	00634	00640
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Table 26: Selection CAPA based on budget in 2019-detail

BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211
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29,000		0->1	0->1	0->1		0->1	0->1	1->0	0->1	0->1	0->1		1->0	0->1	0->1	0->1	0->1
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We have shown all CAPAs in Table 25, and their details (2019 CAPAs only) in Table 26. The CAPAs marked with an "X" in Table 25 represent the 2020 and 2021 CAPAs and were not used. Table 26 has the impact of budget values on CAPA improvements.

Many CAPAs have been improved when the budget value was $29,000. Project 6 had an impact on the improvements that were needed to solve these CAPAs by selecting the 18th technology.The results of the sensitivity analysis performed for the 2020 CAPAs are shown in Table 27. In Table 28, we have included both the 2019 and 2020 CAPAs. We reviewed all the changes and analyses of the CAPAs selected in the $65,000 budget with optimal results. The changes of W, X, and Y were effective in the CAPA sensitivity analysis.

Table 27: Selection CAPA based on budget in 2020

BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211	00268	00272	00274	00275	00277	00285	00287	00295	00297	00301	00325	00328	00340	00342	00357	00362	00368	00369	00376	00389	00411	00412	00416	00417	00424	00431	00439	00450	00451	00452	00453	00454	00460	00531	00553	00554	00575	00587	00593	00604	00607	00620	00621	00622	00629	00634	00640
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Table 28: Selection CAPA based on budget in 2020-detail

BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211	00268	00272	00274	00275	00277	00285	00287	00295	00297	00301	00325	00328	00340	00342	00357	00362	00368	00369	00376	00389	00411	00412	00416	00417	00424	00431
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Table 29: Selection CAPA based on budget in 2021

BUDGET($)/CAPA(Z)	00080	00103	00104	00135	00138	00140	00142	00148	00150	00152	00158	00168	00183	00189	00253	00191	00211	00268	00272	00274	00275	00277	00285	00287	00295	00297	00301	00325	00328	00340	00342	00357	00362	00368	00369	00376	00389	00411	00412	00416	00417	00424	00431	00439	00450	00451	00452	00453	00454	00460	00531	00553	00554	00575	00587	00593	00604	00607	00620	00621	00622	00629	00634	00640
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We have presented the results in a single table, including both the 2019 and 2020 CAPAs in the sensitivity analysis of the 2021 CAPAs. By the beginning of 2021, the 2019 and 2020 technologies have already improved some of the 2021 CAPAs. At that point, the financial resource that the company has allocated to the CAPAs that need to be improved has been allocated to the technologies that need to be improved. We have detailed these changes in a budget-based Table 29.

CHAPTER VI
CONCLUSIONS

Before we began our work, we sought to understand the question of why 70% or even more of organizations fail at DT. Why does this failure happen in spite of the existence of a growing technology sector, R&D studies, software, and consultants in the field of DT? How can it be that the problems are not solved even if all the necessary investments are made?

When we started this work, we were in a pandemic and our advantage was that we could get more information from increasing online education, and seminars. We had the opportunity to attend online DT training and seminars. In this area, we were able to easily access resources such the consultant surveys, expert interviews, and conversations.

We found the answers to these questions with expert opinions. We have seen that the work we perceive today as DT, such as perfect technologies, Industry 4.0 applications, and automation does not reflect DT. These terms that companies and consultants focus on are not the real solution and studies are subjective. The real solution is to solve the company's problems with the appropriate technologies available and to do this work with data and all employees (board members, managers, employees, and workers).

There are also some experts and managers who have the same mindset as our methodology. But the methods they use are the same or similar to each other. They cannot involve all employees in the method they use, so they work a constricted method.

Also, they cannot fully capture all the problems/questions/answers/information with high employee turnover. In our method, the company's CAPAs support the existing method and make it more efficient. It is focused on all employees and has data on all problems from internal and external customers from the past to the present.

We encountered difficulties and problems in our study because we got involved in this work using real practice as systems, machines, technologies, and integrations. In modeling, we designed our model based on the model in the book by Üstündağ and Çevikcan (2017). In developing our model, we needed a lot of time to think in detail, design it, complete it and find the optimal solution for the real implementation of the project requirements.

If the company does not have CAPA records, our methodology can still be applied with the help of other existing data, but we suggest the company to start with the collection of CAPA data. It is necessary to find the cause of the company's problems and find out how to solve and prevent them. This is not only about DT, but also about the data and studies that are necessary for the survival of the company. After the CAPA data reaches a sufficient point to be processed, they can start the DT process. In the continuation, they should continue to collect CAPA data. Even though we have an application of our methodology to an electronics manufacturer, it can also be applied to any industry.

In our thesis work, we have achieved efficient results. According to the CM result that the company actually applied and the PM result that we applied and should be, we have presented an accurate, regular, sequential, and solution-oriented DT roadmap with 43% improvement in ML and 5.3% budget saving. This work of ours can guide for companies as a guidebook and they can implement it.

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APPENDIX

Appendix A

- CAPA Code
- CAPA Transaction Source
- Type of CAPA
- CAPA Status
- Opening CAPA
- Definition of Nonconformity
- Detail of Nonconformity
- Nonconformity Category
- Department of Nonconformity / Customer / Supplier
- Opening Date
- Product
- Management system
- Management System Item No.
- Workplace
- Process
- Team Leader
- Responsible Department
- Planned Progress Report Date
- Progress Report Writing Date
- Writer of the Progress Report
- Progress Report
- Root Cause
- Root Cause Explanation
- Action No.
- Action Description
- Action Opener
- Person to Perform the Action

• Responsible for the Action
• Date of Opening the Action
• Planned End Date
• Revised Planned Completion Date
• Action Realization Date
• Work Done
• Status of the Action
• Planned Final Report Date
• Final Report Writing Date
• Writer of Final Report
• Result Report
• Monitoring Start Date
• Monitoring End Date• Tracking Information
• CAPA Closing Date
• Qualification Information
• Closed CAPA

Appendix B

About Level of Smart Factory Dimension in Industry 4.0 Readiness Model Inbox ×

D [redacted]@gmail.com> Wed, Nov 30, 2022, 8:30 PM
to [redacted]info@fir.rwth-aachen.de, [redacted]

Hello Dear [redacted], Dear [redacted] and Dear [redacted]

First of all, thanks for a tool that helps to measure maturity level like IMPULS Model.
I am writing to ask you a question about one key dimension of IMPULS that is a "Smart Factory".
I did a few experiments on the Model. In this process, I noticed the reverse change in the Smart Factory dimension.
In my first attempt, I chose medium automation options in smart factory. Smart factory level 4th level is out.
In my second attempt, I chose everything as automated and selected options suitable for digital transformation. But the result of smart factory level is 3rd level.

I would expect the smart factory level to be 5 with the ones I chose in my 2nd trial.

In both of my attempts, I added the selected options and the results to the world files. World files are attached to the e-mail.

I would be very grateful if you could provide information on the subject.

Best regards

[redacted]@fir.rwth-aachen.de> Dec 1, 2022, 12:17 PM
to me

Dear Sir,

The Industrie 4.0 Readiness Check was created in 2015 in collaboration with IW Consult and the IMPULS Foundation of the VDMA. You can still find the Industrie 4.0 Readiness Check from 2015 here, and you are free to use it, please mind the correct citation. Further support from our side regarding this is not available.

A lot has happened in the meantime. In 2017, we participated in a study on the "Industrie 4.0 Maturity Index" on behalf of the Academy of Science and Engineering acatech. From this activity, we founded the Industrie 4.0 Maturity Center, which has since been working intensively on the maturity of companies and the associated digital transformation. On the homepage, you have the opportunity to execute a free Industrie 4.0 Maturity Scan. We are actively developing this tool further.

For any further information please feel free to contact the Industrie 40 Maturity Center.

Best regards,
[redacted]

[redacted]
Business Unit Manager Communication Management

FIR e.V. an der RWTH Aachen
Institute for Industrial Management at RWTH Aachen University
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Appendix C

```
GDXXRW          35.1.0 r82a9585 Released Apr 29, 2021 WEI x86 64bit/MS Window
Input file : C:\Users\dilek.parlatan\Documents\gamsdir\projdir\RESULT_MMS_2019_55000.gdx
Output file: C:\Users\dilek.parlatan\Documents\gamsdir\projdir\RESULT_MMS_2019_55000.xlsx
Adding new sheet: Y
Adding new sheet: X
Adding new sheet: Z
Adding new sheet: W
Total time = 1125 Ms
*** Status: Normal completion
--- Job MMS_2019_55000.gms Stop 12/27/22 10:15:46 elapsed 0:00:17.202

*** Ignoring settings from C:\Users\dilek.parlatan\Documents\GAMS\gamsconfig.yaml
*** Error: Empty or nil value field for name MINLP in section commandLineParameters
```

```
IBM ILOG CPLEX   35.1.0 r82a9585 Released Apr 29, 2021 WEI x86 64bit/MS Window

--- GAMS/Cplex Link licensed for continuous and discrete problems.
--- GMO memory 0.52 Mb (peak 0.52 Mb)
--- Dictionary memory 0.00 Mb
--- Cplex 20.1.0.1 link memory 0.00 Mb (peak 0.01 Mb)
--- Starting Cplex
```

```
Root node processing (before b&c):
  Real time             =    0.03 sec. (0.29 ticks)
Sequential b&c:
  Real time             =    0.00 sec. (0.00 ticks)
                          ------------
Total (root+branch&cut) =    0.03 sec. (0.29 ticks)

--- MIP status (101): integer optimal solution.
--- Cplex Time: 0.03sec (det. 0.29 ticks)

--- Fixing integer variables and solving final LP...
```