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Maturity Index of Industry 4.0 – Bosch Brazil Case

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Abstract

The contemporary world shows substantial changes in environment, social and economics. Much of these changes and impacts are from the "4th Industrial Revolution" movement, also known as "Industry 4.0" (I4.0), which has been disrupting the business models, creating new markets, and destabilizing traditional forms. The I4.0 is a strategic approach in the integration of advanced control systems with internet technology, allowing communication among people, machines, products, and complex systems, thus, this paper aims to show ACATECH's evaluation of the I4.0 Maturity Index to the Brazilian Robert Bosch GmbH Operation, called "Industrie 4.0 Maturity Scan" and its performance level throughout the assessment by using a case study. The main contribution of this paper is identifying the elements and actions the company has been applying, and to inspire and to motivate other companies into I4.0 implementation, meeting the new market expectation.

Keywords: *Industry 4.0, Fourth Industrial Revolution, Maturity level, Acatech*

1. Introduction

The Industrial Revolution is a movement of humanity's natural evolutionary process (Gerlitz, 2015), therefore, happening as a natural society development movement and not previously defined by specific strategies or rules.

The name "Industry 4.0" for the 4th Industrial Revolution was coined in 2011 in Germany (originally *Industrie* 4.0), as part of the Government strategy with industrial and academic societies to recover the world technological leadership, and it is based on the complete interconnection of information in real time, using concepts throughout the value chain of Internet of Things (IoT), Internet of Services (IoS), Big Data, Smart Factory, Cyber-Physical Systems (CPS) etc. (Kagermann *et al*., 2013).

The I4.0 theme is not a school scientific subject, so it lacks definite answers, having different approaches that will be validated by the time, since we are talking about the 4th Industrial Revolution. The *Industrie* 4.0 German Strategic Plan was in development when they noticed the whole world was in the beginning of the 4th Industrial Revolution, and both were based almost on the same concepts, since then, Industry 4.0 (I4.0) has been used as synonyms of Fourth Industrial Revolution.

The I4.0, as an industrial revolution with disruptive character, more than impacting the economy and society, also brings challenges and opportunities in the scientific, technological, economic, social, and political dimensions (Zhou *et al*., 2015).

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This paper aims to show ACATECH's (National Academy of Science and Engineering) evaluation of the I4.0 Maturity Index of the Brazilian Robert Bosch GmbH's Operation plant, and its performance level throughout the assessment, by using a case study, having as main contribution the identification of the elements and actions the company has been applying to inspire and motivate other companies into I4.0 implementation, trying to show some steps and practical actions, attending the new market expectation.

2. Methodology

This paper is a case study, based on the methodology used by ACATECH (Schuh *et al*., 2017) in the study "*Industrie* 4.0 Maturity Index - Managing the Digital Transformation of Companies" applied at the Brazilian Robert Bosch GmbH's Operation plant. It was made an exploratory study based on literature review of the I4.0 technological tools, after cross checking the concepts, seeking to identify citations in the original papers from ACATECH (Kagermann *et al.*, 2013) that could corroborate the main technological tools and approaches from I4.0 that have been used in Bosch implementation, shown by the case study.

According to Schuh *et al*. (2017), the close cooperation with the project partners and the practice-oriented methodological approach were based on a combination of case studies and workshops. Case studies investigate a contemporary phenomenon within its real-life context and are used when the boundaries between phenomenon and context are not evident.

From an academic perspective, the I4.0 field is a recent phenomenon that lacks clear boundaries since it is yet insufficiently standardized and widespread, so this ACATECH methodology was chosen to represent one of the first models in the market. The model shows that workshops were employed to pool and make use of the different consortium members' experience whilst encouraging interdisciplinary dialogue and cooperation. This resulted in new cooperation ventures among the participants and allowed planning and implementing projects in a short time.

In this case, the self-evaluation has directly involved 16 Bosch's employees responsible for different areas like supply chain, logistic inbound and outbound, engineering, manufacturing, and information and communication technology. The evaluation was a self-assessment comprising 77 questions defined by ACATECH applied to the manufacturing area and mostly focused on the ABS[1] / ESP[2] business unit, not on the whole of the organization.

The study methodology was divided into four constructive stages. Three of these stages built on each other, while the fourth provides a constant thread throughout the study's duration (Schuh *et al*., 2017).

The I4.0 Maturity Index provides manufacturing companies with guidance both on how to forge their own individual path towards becoming a learning, agile company and on which measures will deliver concrete benefits.

The Bosch's self-evaluation was done in the third quarter of 2020 and this study was conducted in the third quarter of 2021, meaning the environment probably is different since some improvements were probably made and a lot was certainly learned.

3. Framework

3.1. Industry 4.0

The 4th Industrial Revolution or Industry 4.0, first called "*Industrie* 4.0", was identified in the year 2011 in Germany, during the development of the German Strategic Planning to the year 2020. The several definitions of I4.0 are evolving every day, and here we are using as reference the work from ACATECH (Schuh *et al*., 2017), which defines I4.0 as "real-time, high data volume, multilateral communication and interconnectedness between cyber-physical systems and people."

At that time, the Strategic Planning had recognized the world was starting a new industrial revolution, due to the technology disruptive character impacting in the economy and society.

For this study, a literature review was conducted to identify the main factors necessary for implementing the concepts of I4.0, according to ACATECH's approach in the publication "*Industrie* 4.0 Maturity Index - Managing the Digital Transformation of Companies" (Schuh *et al.*, 2017). The main technological elements cited are: real-time capability, systems integration, decision support systems (visualization), automated decision making, vertical and horizontal process and systems integration, and Cyber-Physical Systems (CPS).

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[1] Anti-Lock Brake System

[2] Electronic Stability Program

Also, some concepts and approaches cited are: decentralized decision making, self-learning, agile methods, big-data, adaptability, interconnectivity, tailor made attendances, augment reality, digital shadow (digital twin), data acquisition, Radio-Frequency Identification (RFID), auto-ID solution, Information Technology (IT) security, dynamic collaboration within the value network and application computer programs (App).

3.2. The ACATECH Industrie 4.0 Maturity Index

According to the ACATECH study, the I4.0 Maturity Index helps companies to identify their current level of transformation into an agile and learning company both characteristics of I4.0 companies from a technological, organizational, and cultural perspective, focusing on the business processes of manufacturing companies.

ACATECH's approach considers that each company can have a unique way of implementation, mainly considering their current condition capability condition, strategic goals, operational business model, and transformation capability.

The ACATECH model is based on the Production and Management Framework that is divided in three aspects, corporate structure, corporate processes and corporate development, where structure refers to the indispensable aspects of the company to produce its goods and services, processes refers to the process chains in all areas, and development refers to the strategic and operational development (Schuh *et al*., 2017).

The model also considers that the success of transformation roadmap comes from four Structural Areas (resources, information systems, culture and organizational structure) and five Functional Areas (development, production, logistics, services and marketing and sales), and can be assessed in six Stages of Capability (computerization, connectivity, visibility, transparency, predictive capacity and adaptability), where the company should define priorities to achieve benefits, since investments are always a risk (Schuh *et al*., 2017).

Coming together, these concepts create a matrix of interconnection among functional areas, structural areas and I4.0 Stages (Figure 1), where each functional area is analyzed by all the structural area and measured according to the I4.0 stages.

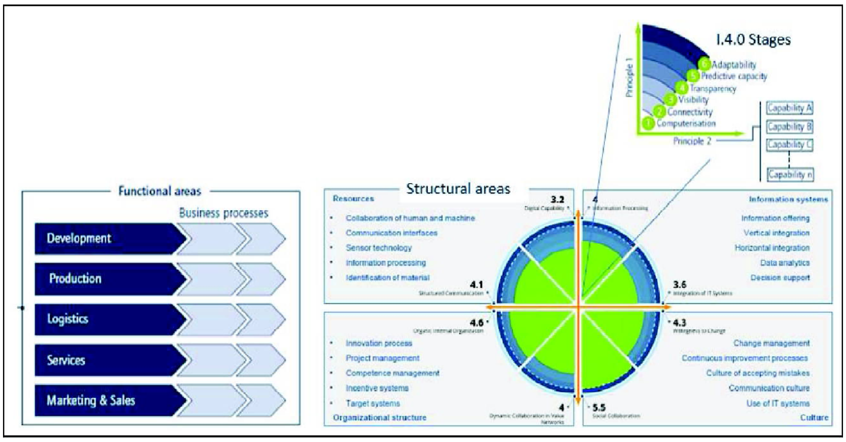

Figure 1: Concepts Interconnection Matrix

Source: The authors - Adapted from Schuh et al., 2017 and ACATECH report, 2020 (Appendix 1, page 14)

3.3. Industry 4.0 Capabilities for Businesses

The I4.0 capabilities allow companies to transform into agile and learning companies considering the four structural areas of: resources, information systems, culture, and organizational structure.

These areas are connected by the six stages of capability and each structural area has two 2 of the 8 principles (digital capability, structured communication, information processing, integration of IT systems, willingness to change, social collaboration, organic internal organization, dynamic collaboration within the value network - Figure 1) that guides continuous development, and each one comprises capabilities that must be successively developed for each value-based development stage. The level of the implemented capabilities defines the maturity stage of the principle and both principles combined provide an overall assessment of the four structural area analyzed.

The ACATECH Industry 4.0 Maturity Index investigates the capabilities separately for each of a company's functional areas. The specific maturity stage of each capability may be different for different functional areas and the business processes contained in them (Schuh *et al*., 2017).

4. Outcomes

The Bosch Group is a worldwide company and a leading global supplier of technology and services. Its operations are divided into four business sectors: mobility solutions, industrial technology, consumer goods, and energy and building technology. As a leading IoT provider, Bosch offers innovative solutions for smart homes, Industry 4.0, and connected mobility. It uses its expertise in sensor technology, software, and services, and its own IoT cloud, to offer its customers connected, cross-domain solutions all from a single source.

The Robert Bosch GmbH Brazilian plant was submitted to this self-evaluation in September 2020, with ACATECH presenting the results in the report "*Industrie* 4.0 Maturity Scan Results from Robert Bosch GmbH - i4.0MC - *Industrie* 4.0 Maturity Center GmbH" (Schmitz, 2020), reaching the overall Maturity Level of 4.2 (Page 44 of the Appendix 1 URL), which was among the best of the companies analyzed until that time.

The evaluation in manufacturing area mostly focused on the Braking Systems ABS[3] and ESP[4] business unit and not on the whole of the organization.

The self-evaluation has directly involved 16 employees responsible for different areas like supply chain, logistic inbound and outbound, engineering, manufacturing, and ICT. For this case study interviews were carried out with people involved in the evaluation, linked to the manufacturing department of braking systems, ABS and ESP. They were: Industrial Director—Technical Responsibility of Manufacturing Technologies, Sales I4.0 of Manufacturing Technologies, Manufacturing Manager, Specialist Engineer in Control, and IT Systems.

The evaluation is a self-assessment comprising 77 questions (Pages 22 to 25, 28 to 31 and 34 to 39 of the Appendix 1 URL). The overall Maturity Level can be broken down into various forms and, in this report, was split on two forms, addressing the 77 questions:

4.1. First Form

It approaches the evaluation of the questions in three scenarios of operational challenges necessary for I4.0 capabilities, which are:

4.1.1. Digital Shopfloor

With average score of 2.9 in 22 of the questions, this operational challenge addresses all tasks and difficulties associated with the shop floor. Operators should receive precise information, work instructions, and machine production, since issues often faced by cooperating with departments directly impact the shopfloor (e.g., material supply, quality and testing etc.).

4.1.2. Agile Organization

With average score of 4.5 in 22 of the questions, this challenge addresses the structures and guidelines of a company, which are partly outdated and cause difficulties.

4.1.3. Integrated Business Processes

With average score of 4.5 in 33 of the questions, this challenge addresses the communication and information exchange between all involved departments. This exchange can only proceed in an organized fashion if connectivity and a single source of truth is established. The same applies to the structured integration of suppliers and customers.

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[3] Anti-Lock Brake System

[4] Electronic Stability Program

4.2. Second Form

Another way of break down is to approach the questions average scores in the Individual Processes, where some processes are addressed in the questionnaire to give an assessment of the individual processes in the digital transformation. Those are:

4.2.1. Overall Process (Cross Divisional)

With average score of 4.3 in 22 of the questions, the overall process applies to all areas of the company. Relevant questions are asked to all departments, usually referring to the structuring forces culture and organizational structures.

4.2.2. Production

With average score of 3.2 in 17 of the questions, this process covers all areas around the shop floor. The employees and their competences, skills, and abilities are examined, also the operators and inter machines connectivity and their interfaces to other systems, such as MES (Manufacturing Execution System).

4.2.3. Production Planning

With average score of 4.7 in 9 of the questions, this process covers the interface between the shop floor and the planning. It refers to the IT support and data quality in the planning process, the exchange of information for production scheduling and material handling.

4.2.4. Quality

With average score of 4.7 in 10 of the questions, this process covers many aspects of the product testing. It focuses on how the quality department obtains all the necessary information and how the processes are supported by information systems.

4.2.5. Maintenance

With average score of 3.4 in 8 of the questions, this process covers the provision of information from the machines to the employees or system. It evaluates the level of information and how the employees are notified to contribute to the predictive maintenance.

4.2.6. Logistics

With average score of 4.4 in 11 of the questions, this process covers the issues of how employees receive their orders and how they can process them in the best possible way, and how they are supported by technical aids and information systems.

5. Discussion

Since this paper aims to show ACATECH’s evaluation of the I4.0 Maturity Index of the Brazilian Robert Bosch’s Operation plant and its performance level throughout the assessment, identifying the elements and actions the company has been applying, the company needed to show evidence related to the main topics of the I4.0 theme and/ or for the highest scores, and/or those relevant to comprehending the environment. Due to the high complexity behind the evaluation of the 77 questions, this paper was conceptualized with information from two basic sources: from the ACATECH’s report itself and from interviews with people, one in a digital meeting and another in a presential plant visit.

Some evidence was intentionally hidden or presented in different ways in this paper, since they are considered strategical and confidential to the company.

According to the ACATECH’s methodology, scores equal or below 2.0 are considered as fulfilling I3.0 (Industry 3.0 or Third Industrial Revolution) concepts and above 2.0 are starting to use I4.0 concepts.

For better comprehension of the demonstration, we correlated the discussion and the specific question of the ACATECH’s report with numbers from 1 to 18 (Figure 2).

We used four different approaches for the analysis: digital shopfloor, agile organization, integrated business processes, plus the current capabilities by using status quo:

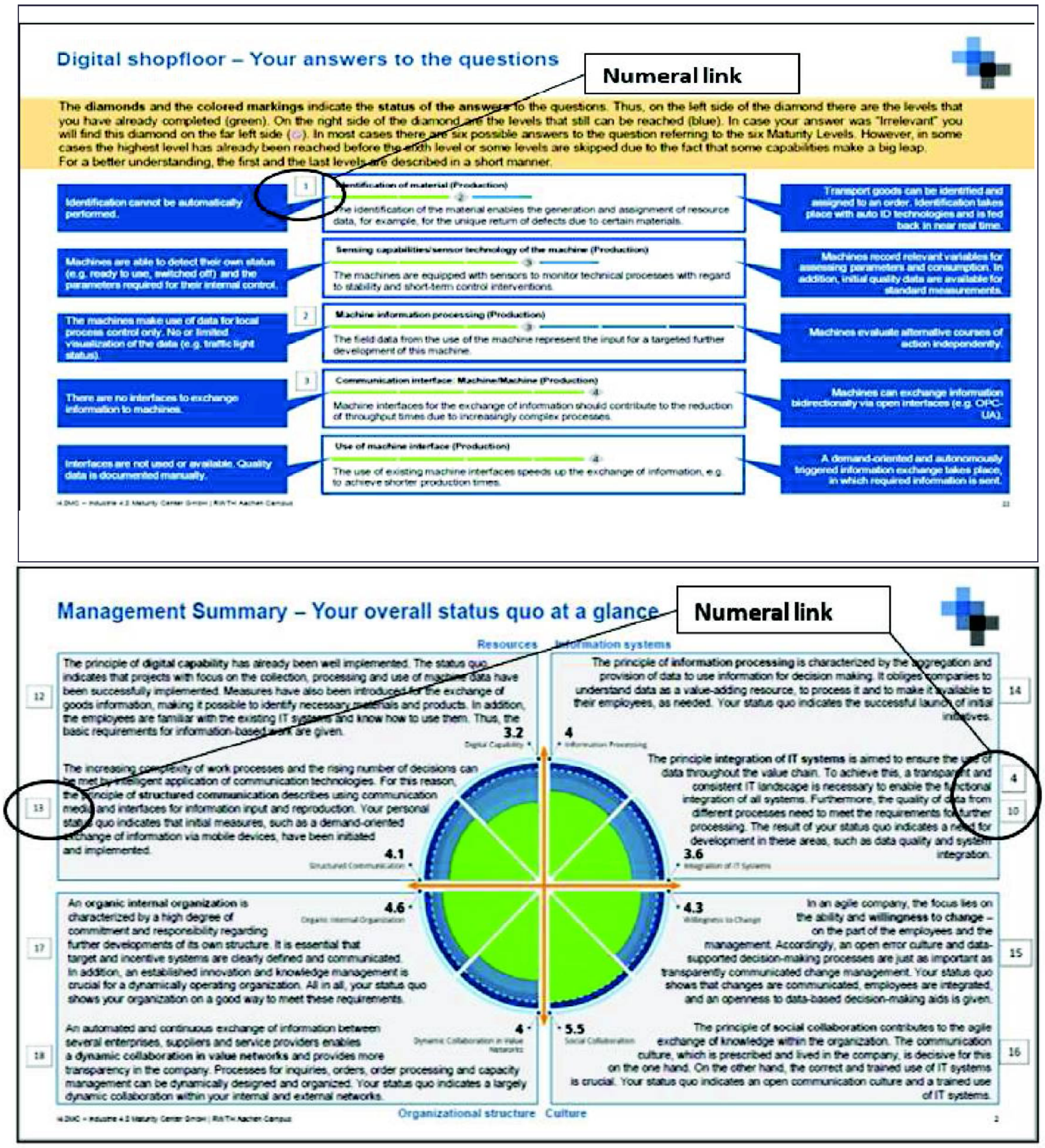

Figure 2: (Page 1 to 2) - Examples of Numeral Link in the ACATECH's Report

Source: The Authors - Adapted from ACATECH Report (Schmitz, 2020)

5.1. Digital Shopfloor

5.1.1. Identification of Material (Production)

It is done in two ways.

The first way is the DMC[5] with a QR Code[6] system for individual rough product identification, applied for the main suppliers and connected to the Bosch system, flowing to the internal manufacturing process to be complemented. Then

[5] Direct Machine Control (Laser marking)

[6] Quick Response Code (Matrix code)

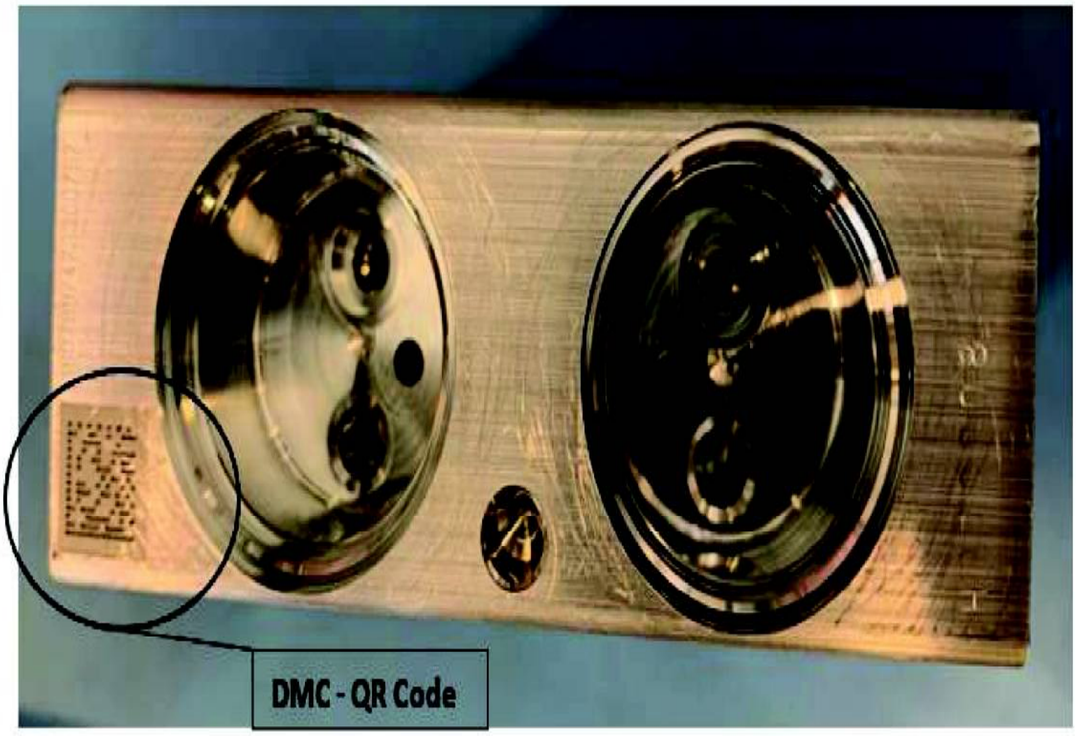

Figure 3: Pump Housing Machined

Source: Robert Bosch Brazil GmbH

the product starts in the workflow and is transformed in a machined pump housing (Figure 3), using the same QR Code, now including additional information about the current manufacture process.

The machines involved in the processes are connected to the system and can identify the component and, if approved in all previous processes, make their own decision to go ahead or stop the process flow.

A DMC reader recognizes it and informs the Bosch systems by VMDT[7], which is connected to the MES and to the SAP ERP[8] so the system can keep the traceability of the main information and status of the component and process flow.

The second way is the RFID tag, which mostly identifies a batch of components in boxes or racks, used by logistic combined with Autonomous Guided Vehicle (AGV) or Autonomous Mobile Robots (AMR)[9]. The RFID facilitates the milk run delivery and the transferring flow of components from incoming, to warehouse, to production, and then to expedition and customer.

Despite the use of smart and connected identification, the score of 2 correlates more to the lack of prediction data and automatic and autonomous quality assessment.

5.1.2. Machine Information Processing (Production)

Today, the Bosch plant machines have intelligence to decide whether to adjust manufacturing process deviations or not. The score 3 in this topic suggests a quick reaction - short term - for the stabilization of the process, which results from daily meetings using the Active Cockpit, a screen located into the production cleaning room given online access to all KPIs, often responding to some MES alarm suggesting intervention.

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[7] Virtual Machine Data Traceability – A specific App developed by Bosch

[8] Enterprise Resource Planning (SAP is the ERP supplier in this case)

[9] Evolution of AGV

5.1.3. Communication Interface - Machine/Machine (Production) and Human/Machine (Production)

Here we look for examples of information exchange between machines that impacted processes. In the online diagram of cycle time and process capacity presented, the bottleneck of the production flow is compared and identified, and the MES seeks to balance the parameters. Regarding human access to remote machines, we could not verify that the head office in Germany remotely interacts with machines at the Campinas plant, which is basically for maintenance.

5.1.4. Information Provision (Production / Maintenance / Production Planning / Logistics / Quality)

At the current level of information digitalization on the shop floor, the plant receives information inputs whit production control, productivity, and other key indicators available via the Active Cockpit, made automatically via MES, in this case ProMaster. Currently, at Bosch only scrap registers are made manually.

Despite the attention and care with the typical needs of the customers, which is defined at the beginning of the contract, the business model still lacks the place for mass customization initiatives. Mass production lines have control systems customized to the customer's product according to the contract. The processes have several automatic functional test stations, where failures are automatic segregated; however, the final inspection and packaging still needs human input.

5.2. Agile Organization

5.2.1. Change Management (Overall)

It is expected to find out projects with constant attention to the products and/or processes modifications, with examples of projects that were modified based on predictive views of future scenarios.

Bosch showed an example where, motivated by the transparency of process and manufacturing data, and knowing the future vision of demand volume, the company identified a certain lack of production capacity for a given product. After the team's analyzes, they identified that by reducing the cycle time (balance among the machines), optimizing some parameters of the machines and manpower was possible, which led to a 5% reduction in cycle time by 3 months, resulting in greater sales opportunity and a cost reduction of 5 MM BRL.

This example shows that action fits more into improving productivity and efficiency. However, an argument for the score of 5 is the adoption of the DMC identification (QR Code), which is the result of a past product change based on analysis of existing data about products failures in the field indicating different future needs.

5.2.2. Communication Interface Human/Human (Production Planning / Production / Quality / Maintenance / Logistic)

This topic relates to the communication and data sharing, via mobile devices or fast delivery systems.

For Production Planning and Control (PPC), for production and for logistic, the planning of the production is shared physically via the leveling board (*heijunka* board).

For production, the demand versus capacity control is made using the digital Andon with the systems Data Collector and Tooling Monitoring (not available during the audit) when applicable.

For maintenance, the Tooling Monitoring controls the technical downtime, and the equipment wear is controlled by comparing with produced parts instead of the available time (Asset Management).

For the operation as a whole, a 15-minute daily briefing meeting analyzes the KPI[10]s, discusses the main issues and decisions are taken based on them. Solving more critical issues uses the support of the digital A3 tool (Lean-Manufacturing).

5.2.3.Communication Culture (Overall)

We can evaluate the score of 6 in this item with examples of communication and data sharing that occur autonomously. We identified, in the manufacturing area, the Active Cockpit, the Data Collector via a dashboard, and the Tooling Monitoring systems that monitor and generate KPIs with precise information from each workstation and/or tooling, via connectivity with the machines PLC[11]s.

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[10] KPI - Key Performance Indicator

[11] Programmable Logic Controller

5.2.4. Collaboration within Value-Added Networks (Overall)

Spontaneous internal and external value-adding collaboration is verified with connection and interaction, where comparing processes and regularly sharing lessons learned and best practices to improve global efficiency is possible. Benchmarking worldwide workshops are often held to reduce cycle time and improve performance.

The main products or processes results are presented, shared, and discussed with the team to spread the best practices. An example of some projects presented in a workshop in 2020 (CIP[12]), where 10% increase of productivity worldwide was obtained.

Apparently, the most appropriate grade seems to be 5 instead of 6, since that was a predictive decision, and not an automation of decision and action.

Another example of collaboration within value-added networks is the analysis of the CaP[13] System CIP (Figure 4), in which some indicators were evaluated, and actions were defined to keep production on track.

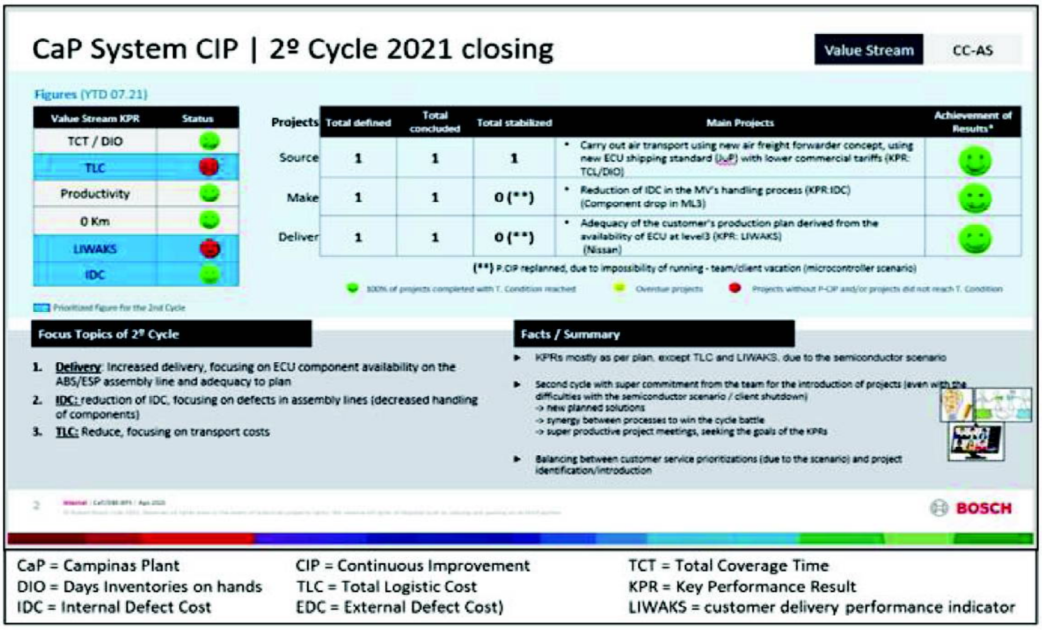

Figure 4: Campinas Plant Continuous Improvement

Source: Robert Bosch Brazil GmbH

5.2.5. Incentive Systems (Overall)

Here, the approach is to get evidence of agile team-members receiving incentives to achieve goals, which go beyond financial, for example, training, education, benefits, promotion, improvement in the career plan etc.

To strengthen employee participation, Bosch seeks to leverage these opportunities for financial gains and more, highlighting in training the importance of the global strategy for achieving corporate gains.

The Continuous Improvement Plan at Bosch Brazil, CLIC, is a program with the main goal of incentivizing the culture of continuous improvement, promoting creativity, and financially rewarding the employees by their implementation.

Figure 5 shows the main figures of employee's participation in 2021, where savings are increasing from 0,8 in March to 1.792,7 TBRL in July, employee participation is increasing from 2% by January to 12,6 in July, the average by employee increased from 0,03 to 0,51, and the total of implementation raised from 77 by January to 602 by July. Once the number of implemented projects increase exponentially, especially for the savings, the Quality Reward program, connected also with the CLIC program, also increased, but more focused on the departments results.

[12] Continuous Improvement workshop

[13] Campinas plant (Bosch)

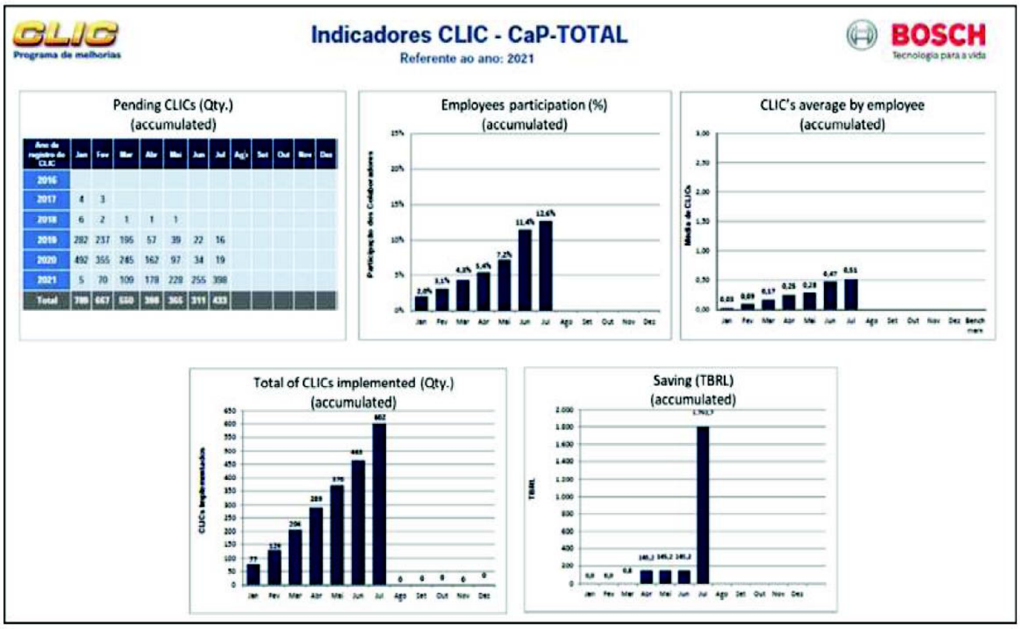

Figure 5: CLIC Program Indicators

Source: Robert Bosch Brazil GmbH

5.3. Integrated Business Processes

5.3.1. Decision Support (IT) (Production Planning / Logistics / Quality / Maintenance)

This topic seeks examples that prove IT support and integration in the decision-making process, via automatic response or intervention engines.

The PPC department has 24/7[14] IT support to ensure that the entire PPC process works and to guarantee the stability of the SAP, MES, and VMDT tools. The intensive support suggests personnel follow-up, which differs from a scores 5 and 6, in which automatic engines would replace the need for personnel. On the other hand, some improvements in the system, especially the introduction of the VMDT App, made monitoring, communication, and, consequently, decision-making easier, even if they are not completely automatic and autonomous.

The entire database system (local or cloud serves and computer networks) are clustered and have redundancy, ensuring information and data storage security.

5.3.2. Target-oriented KPI (Production Planning / Logistics / Quality)

Here the aim is to find examples that prove changes in KPIs as a consistent reaction to a change of scenario or condition, in real time. The OEE[15] is consistently managed and probably the most impacted by I4.0, since it is directly impacted by the losses of cycle time and, at this time, Bosch has high level of sensors on machines.

5.4. Status Quo (Current Capabilities)

5.4.1. Digital Capabilities

The Bosch's Data Lake shows the success in the projects of collecting and processing digital data from machines. Hierarchical teams analyze the main machine and process indicators identifying deviations and defining actions. The teams also define the level of reaction and response to ensure project application.

[14] 24 hours and 7 days in a weekly time worked

[15] Overall equipment effectiveness

Bosch's digital capability for communication and data sharing is spread-out in the whole organization and used from top level to shop floor in real time, especially with KPIs management. Some employees are familiar and well trained to use the main tools (SAP, MES, VMDT and Active Cockpit) since they are used and managed in daily bases.

When an issue is identified in a manufacturing process, the machines communicate to the MES system that blocks the product and/or the batch and informs by an alarm, which normally requires an employee action with an input to the system.

5.4.2. Structured Communication

The communication flows through the Bosch's systems consistently via standard electronic devices like doc station computers, notebooks, Andons, tablets, and smart phones, connected to the systems SAP, MES, Active Cockpit and the App VMDT, as previously demonstrated.

5.4.3. Information Processing

The information is collected via MES and made available on the data lake with pre-defined limits and monitored daily and on the continuous improvement workshops, generating added value. Thus, any deviation or opportunity for improvement is evaluated and the gains are calculated, which are classified by relevance for adding value. This data can be obtained remotely in real time by the Active Cockpit or VMDT App. This process can be observed by the monitoring KPIs and the respective graphs. Figure 4 shows a representation of a Quality (defects) and Logistic costs savings through a Continuous Improvement program.

5.4.4. Willingness to Change

The availability of the database via data lake for decision making shows this characteristic. The machines and/or employees, either those responsible or those who generate it, feed the database and decision-making is carried out through the various interfaces, which can be verified, for example, in the daily action plan of the Active Cockpit.

5.4.5. Social Collaboration

The implemented culture in the organization that promotes knowledge exchange in an agile way shows this characteristic. In the Bosch Brazilian plant, the organization is implementing a training plan about the I4.0 theme, in partnership with SENAI[16], where all new employees learn basic concepts and receive some practice in a specific I4.0 Laboratory room. Theoretical teaching explains to employees what I4.0 means, the concept and the expectations. Once the theory is taught, employees go to the lab for practice. The practice consists of simulating a real business condition in a small assembly line, from customer order, line feed, using technology like RFID tags and readers, sensors installed in the equipment, a screen like the Active Cockpit with production data added by MES, and a delivery of a small 3D printed truck samples at the end of line, completing a hands-on experience.

The training program is running for shop floor employees and leaders and is incentivized by upper levels and HR (Human Resource Department). For the staff, like engineers, supervisors and high-level leaderships, the training is estimated by 2022, considering also online classes, videos, and a Web Basic Web Basic Training - a Bosch training center (WBT) - with many trainings about I4.0, Artificial Intelligence (AI) and Enabling for Digital Transformation (EDT).

Despite the participation control and training evaluation, it only shows reports or minutes of meetings, with the description of the concepts explained, lacking a correlation remark to the implemented projects showing real gains obtained.

In general, employees seem very satisfied and motivated by the training itself, offering spontaneous positive feedbacks.

5.4.6. Operational Challenges #1

Here the search is for examples of decisions made by the lower hierarchical level (shop floor) that could diverge from the company's strategic orientations, showing decision making autonomy, and the results achieved, registered as lessons learned. An example was identified where the factory team had evidenced that the bottleneck process, the washing & grinder machine, which serves two different lines, needed a cycle time reduction to meet the new demand. They realized that, despite the global strategy of reducing cycle time and application cost, a simple reduction of the machine's cycle time would yield no productivity gain and would cause technical losses since it would increase the risk of tool breakage

[16] Serviço Nacional de Aprendizagem Industrial - National Industrial Training Service

and then greater downtime for maintenance, which could worsen the supply level. Then the team has started to change the approach analyzing OEE motivations that could impact the increase of machine availability and, thus, meet the new demand request. The chosen action implemented in the end of 2019 and beginning of 2020 was to replace the linear guides and install new high-pressure hydraulic pumps, which increased their availability and avoided the risk involved in cycle time reduction.

Figure 6 shows the Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) figures evolution, during and after the implemented actions.

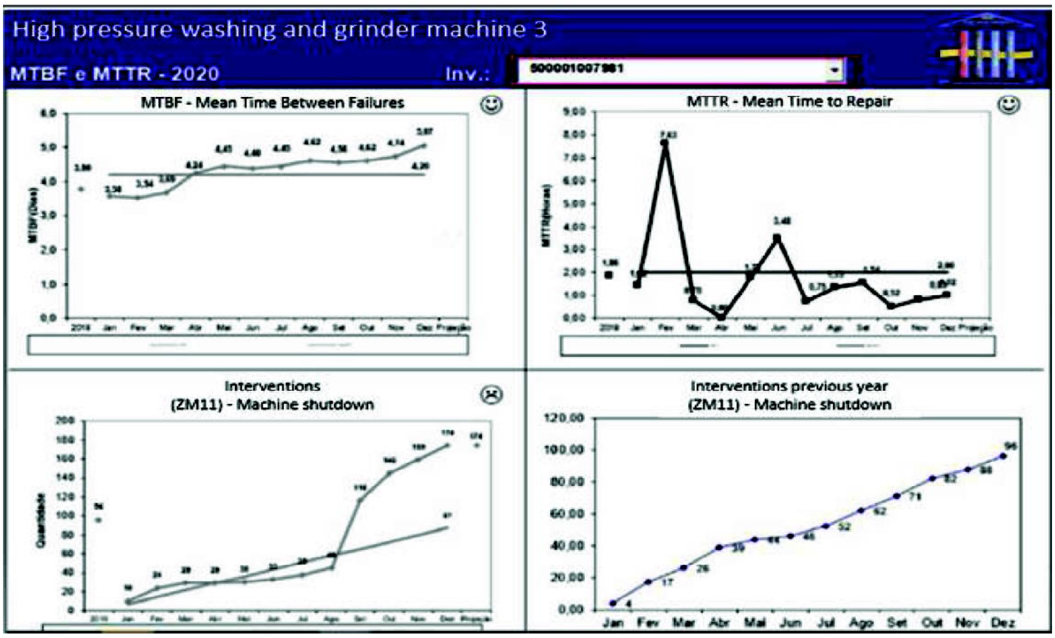

Figure 6: MTBF and MTTR of Washing and Grinder Machine 2020

Source: Robert Bosch Brazil GmbH (2020)

After the modification, the MTBF has improved in 2020, from 3.58 days in January to 5.07 in December. The MTTR has improved from 1.52 in January to 0.83 in December and, despite some variation, the average MTTR had a slight improvement from 2.34 hours in January to 2 hours in December. On the other hand, the number of interventions has also increased, which is bad, but was motivated by the interventions and the respective required adjustments of the modification. However, in the end, the average repair time is slightly smaller.

5.4.7. Operational Challenges #2

Here we look for examples of cooperation in the value chain, like a cooperation within the network as partnership, part of the horizontal integration.

Despite the labeling being manual, an automatic register of production data was identified at the end of the line, ensuring the traceability of parts about the batch, the layer on the pallet, and the KLT box used. This is an example of an interface between manufacturing, logistics, and customer, seeking interface and quick identification of parts or lots in cases of quality issues. In this way, cooperation increased, and value was added to the final product delivered to the customer.

6. Conclusion

Since this article aims to show ACATECH's evaluation of the I4.0 Maturity Index of the Brazilian Robert Bosch GmbH's Operation plant and to identify the elements and actions the company has been applying, we have presented some evidence of how the company is conducting the environment and how its behavior connected to the I4.0. Clearly separating I3.0 and I4.0 is often difficult since, as already stated, still lacks a final definition and the matrix of Figure 1 shows the complexity of applying those concepts throughout the organization.

The paper shows actions in the day-to-day environment that can inspire and support companies, especially in the manufacturing area, to implement the I4.0 approach. For this purpose, in the topic 3.1 it was identified the main concepts of I4.0 like, real-time capability, systems integration, decision support systems (visualization), automated decision making, vertical and horizontal process and systems integration, and Cyber-Physical Systems (CPS). Also, some concepts and approaches cited are: decentralized decision making, self-learning, agile methods, big-data, adaptability, interconnectivity, tailor made attendances, AR-Augmented Reality, digital shadow (digital twin), data acquisition, Radio-Frequency Identification (RFID) and auto-ID solution. The topic 3.2 shows the elements defined by Acatech using the same concepts and, in the topics 5.1 to 5.3, summarized on 6.1 to 6.9, their correlation and actions the company has been applying into I4.0 implementation.

The method of self-evaluation used seems very helpful, despite being subjective the correlation between questions and concepts, and on people's perception, but the operation is certainly running in the right direction with people very well committed and motivated with the object, at least in manufacturing team.

6.1. Digital Shop Floor

The 2.9 score shows the company has just started the digitalization process on that area, meaning it is in the very early stage, which we can demonstrate in the summary:

The company is using a QR Code identification for products connected to the machines and to the MES and SAP systems, keeping products and processes traceable. This allows machines to make their own decision but only for approving or rejecting the process flow with an alarm in the MES.

The company is using RFID tag for boxes or racks identification, connecting with AMR and milk run service. The data is not used for predicting actions.

Daily meetings using the Active Cockpit and MES manage stabilizing the process, addressing the needs of balancing process parameters and controlling production.

6.2. Agile Organization

The 4.5, score shows higher maturity in structure and guidelines, which we can demonstrate in the summary:

Some projects show constant attention to modifications to the products and/or processes, such as identifying modifications based on predictive views of future scenarios.

Spontaneous internal and external value-adding collaboration is verified in a connected and interactive manner, where comparing processes and regularly sharing lessons learned and best practices is possible to improve global efficiency in the Benchmarking worldwide workshops, but as a predictive decision and not an automation.

Evidence shows that agile team-members receive incentives to achieve goals, which go beyond financial incentives (CLIC program), including training in a specific I4.0 laboratory room.

6.3. Integrated Business Processes

The 4.5 score shows higher maturity in communication and information exchange, which we can demonstrate in the summary:

The company does communication and data sharing via mobile devices or fast delivery systems like Active Cockpit, Data Collector, Tooling Monitoring, Andons, and VMDT. For PPC, the planning of the production is physically shared by using a heijunka board. For production, demand versus capacity is controlled by using the digital Andon with the Tooling Monitoring system when applicable. For maintenance, the technical downtime and equipment wear is controlled by comparing with produced parts instead of availability time, which is done by a digital A3 Lean tool. For the operation as a whole, a 15-minute daily briefing meeting analyzes the KPIs, discusses the main issues, and makes decisions based on them.

Despite the 24/7 IT personal support, the company lacks automatic decision-making response or intervention engines.

KPIs is managed daily in a briefing meeting in the production area and weekly or monthly in management meetings and is yearly used for the Operational Strategic Plan. Despite the quick responses, we found no examples of KPIs changes in real time.

6.4. Production Area

With a 3.2 score, shows intermediate skills and competences of employees and connectivity abilities of machines with the system.

6.5. Production Planning

With a 4.7 score, shows a better interface with shop floor, using good IT resources.

6.6. Quality Approach

With a 4.7 score, shows product testing and information exchanging.

6.7. Maintenance

With a 3.4 score, shows that employees are notified by machine and system, which leads to opportunities of predictive maintenance contribution.

6.8. Logistic

With a 4.4 score, shows how the company manages customers' orders with internal processes.

6.9. Overall Process

With a 4.3 score, shows internal cultural changes and organizational structures adaptation.

In general, after many demonstrations and analysis of data and graphics, an improvement in the efficiency of processes, quality and commitment of people was identified, based mainly on increased automation, real-time decision making as an agile organization, and intelligent analysis of the database by a higher level of maturity in communication and information exchange, showing a an internal cultural and organizational structures adaptation, leading to short-term gains through cost reduction, but also to an intelligent medium-long-term strategic plan based on projections by prediction, envisioning more robust and accurate future scenarios.

The Bosch representative team was requested to provide a feedback summary of the self-evaluation process, and, about its strength, the team stated it was a good questionnaire connecting the whole value chain clearly and maturely. The team remarked the self-evaluation was an opportunity to interact with the ACATECH group for each question or group of questions.

Despite Robert Bosch Brazilian Operation achieving a I4.0 Maturity Index Level of 4.2, which placed it among the best rated companies analyzed up to that time (September 2020), it is still evolving and has opportunities for new evaluation and/or new research to demonstrate it.

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Appendix 1

Access the URL below:

https://pages.toolingmonitoring.com/hubfs/Bosch_Materiais_Ricos/maturity_scan_basic_report_bosch.pdf

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