Industry 4.0 Maturity Assessment in a Medical Devices Manufacturing Industry

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Industry 4.0 is a unique concept merging information technology and processes to change industrial infrastructure-people-systems and obtain a competitive advantage. The research builds an Industry 4.0 maturity questionnaire and applies it to Malaysia's medical device manufacturing industry. The questionnaire design and deployment were substantial to suit the acatech Industrie 4.0 maturity index model's multifaceted requirements. The study contains 54 employees and a 32-question questionnaire. The industry has a maturity of 2.91 and is set to enter the visibility stage. Higher scores in organizational structures and business culture also indicate human readiness. The outcomes impact organizational policies and strategy development, specifically those associated with data management, digitization, and task orientation in the implementation of Industry 4.0. The research increases the quantitative evaluation methodological and applied to understand Industry 4.0.

Keywords: acatech Industrie 4.0 maturity index, Industry 4.0, quantitative assessment, questionnaire survey.

1. Introduction

Industry 4.0 (I4.0) is a unique concept that would change the infrastructure-people-system of the manufacturing industry to acquire a competitive edge (Qin et al., 2016). This new industrial revolution's expansion and consequence are highly automated, coordinated, and intelligent production processes. To attain this objective, modifications must be made to the company's organizational structure and culture. For instance, dynamic collaboration platforms are necessary to increase collaboration across businesses and value networks. Adaptability encourages organic arrangement.

An agile learning company builds knowledge, cultivates core competencies, and innovates continuously. Employees must be adaptable, engaged in the change process, and lifelong learners. It incorporates these elements into the relevant organizational structural areas, providing a comprehensive perspective of I4.0. They are then polished into easily understood system features (guiding principles and capabilities).

One aspect shared by all I4.0 deployment frameworks is an initial assessment of the organization's existing state about a preset set of maturity or technology adoption levels. In addition to evaluating cultural, strategic, organizational, and technological preparedness, the assessment analyzes goods, processes, and personnel. The obtained data assists management in considering possibilities and formulating action strategies. Schumacher et al. (2019) categorized two forms of evaluation. Web-based assessment solutions provide ease of use, instantaneous results presentation, and the capacity to benchmark against other companies. Nevertheless, companies frequently lack openness because they do not provide their assessment criteria or benchmarking data. The second type presents conceptual maturity and multidimensional guiding models based on interviews, surveys, or company workshops.

Based on a questionnaire survey done in Malaysia's medical device manufacturing business, this study produces an I4.0 assessment. A questionnaire survey collects information from a sample of persons through their responses to a series of questions (Check & Schutt, 2012). A standard instrument for quantitative or qualitative evaluations of the behavior of an organization is a questionnaire survey. Using the evaluation of correlations between variables, questionnaire surveys are used to quantitatively identify particular characteristics of a given population (Young, 2015). Moreover, surveys can elicit information about attitudes that are difficult to measure using observational methods (McIntyre, 1999).

The acatech model serves as the basis for the survey questions. The design and distribution of the questionnaire are crucial for achieving the model's multidimensionality. In addition to the significance of the research in implementing the I4.0 assessment at the level of industrial organizations, the paper is inspired by two additional aspects. First, according to our literature review, I4.0 assessments are relatively new. They are predominantly conducted as general benchmarking at the regional or industry level, such as in Swedish industries (Gürdür et al., 2019), 165 Taiwan-based enterprises (Lin & Wang, 2021), Indian manufacturing industries (Singhal, 2021), South India's public perception (Tippayawong et al., 2021), Turkish manufacturing industries (Mohammad et al., 2021; Sarı et al., 2020).

Second, a survey of the relevant literature showed few instances in which the acatech model was utilized to evaluate specific companies. Bastos et al. (2021) assessed seventeen assessment models, none of which were acatech-based. Çınar et al. (2021) surveyed the I4.0 in automobile component manufacturing using a readiness framework combined with technology forecasts. Compared to other assessment models (Bastos et al., 2021; Häberer et al., 2017; Lin & Wang, 2021), the acatech model's concept of maturity level is more intuitive, making it significantly simpler for the industry to comprehend. In conjunction with guiding principles and capabilities, means-ends analysis can be effectively used in any I4.0 implementation approach based on the predicted maturity level. In addition, the acatech model is not exclusive to I4.0 technology. It offers a more well-rounded perspective on digital transformation by incorporating the organization and culture, which are essential components of I4.0 (Brettel et al., 2014; Sony & Naik, 2019). Rarely are industries prepared to execute and plan for I4.0 (Rajnai & Kocsis, 2018). Before embarking on an enterprise-wide or big strategic initiative, the content would aid them in developing and deploying an I4.0 maturity assessment survey to determine their present level of I4.0 implementation.

The following outline outlines the paper's structure: Section 2 describes the acatech model in depth. Section 3 exposes the questionnaire design. Section 4 describes the evaluation procedure. Section 5 contains the findings. Before the conclusion, Section 6 is the discussion.

2. Acatech model

The acatech Industrie 4.0 maturity index model (the acatech model) is co-developed by multiple research institutes (RWTH Aachen, TU Darmstadt, and Paderborn University), industrial partners (PTC, Infosys, and TÜV SÜD), and the National Academy of Science and Engineering Germany to identify individual and customized recommendations for the Industry 4.0 (I4.0) transformation (Schuh et al., 2017). This maturity index model provides a structured technique for measuring a company's present degree of digital transformation by reviewing the underlying concepts and core principles of I4.0 (Mittal et al., 2018; Zeller et al., 2018). The information is essential for developing a road map for gradual digital transformation (Zeller et al., 2018).

The digital transformation of I4.0 has six value-based stages of maturity. Stage 1 focuses on computerization and IT systems that support tasks with data processing systems and relieve employees of repetitive duties. Stage 1 comprises low-cost, precise manufacture (Kaufmann & Forstner, 2014; Schuh et al., 2017; Schuh et al., 2014; Vogel-Heuser, 2014). Connecting dispersed IT via network components, applications, and interfaces constitutes Stage 2. Enabling complete connectivity in engineering and manufacturing. Stage 3 supports transparency and mandates a single source of truth (SSoT) for all enterprise data. The processes are recorded in real-time via sensors. Real-time monitoring of the company's operations using digital shadow (Bauernhansl, 2013). Stage 4 fosters transparency by integrating digitally obtained data with scientific facts derived from natural, mathematical, or physical laws for knowledge discovery, such as gaining insights into the interplay between operational processes and factors. Stage 5 focuses on system predictability, where prior knowledge is used to comprehend an occurrence and predict the influence of various future scenarios and events. This facilitates preventive measures (Zeller et al., 2018). Stage 6 supports flexibility, the organization's capacity to optimize information processing and tasks swiftly and independently. Dynamic production planning can adapt immediately to machine breakdowns or shipment delays (Zeller et al., 2018). Figure 1 depicts four corporate structural elements within the acatech model: resources (R), information systems (I), organizational structure (S), and corporate culture (C). Each structural area has two guiding principles addressing the technical breadth (horizontal) and depth (vertical) of I4.0 implementation. Each principle defines a set of capabilities that define the applicable technical specification and scope (field of action). The guiding principles are designated by R1, R2, I1, I2, S1, S2, C1, and C2, while the capabilities are appended alphabetically, such as A, B, C, and D, to the principles.

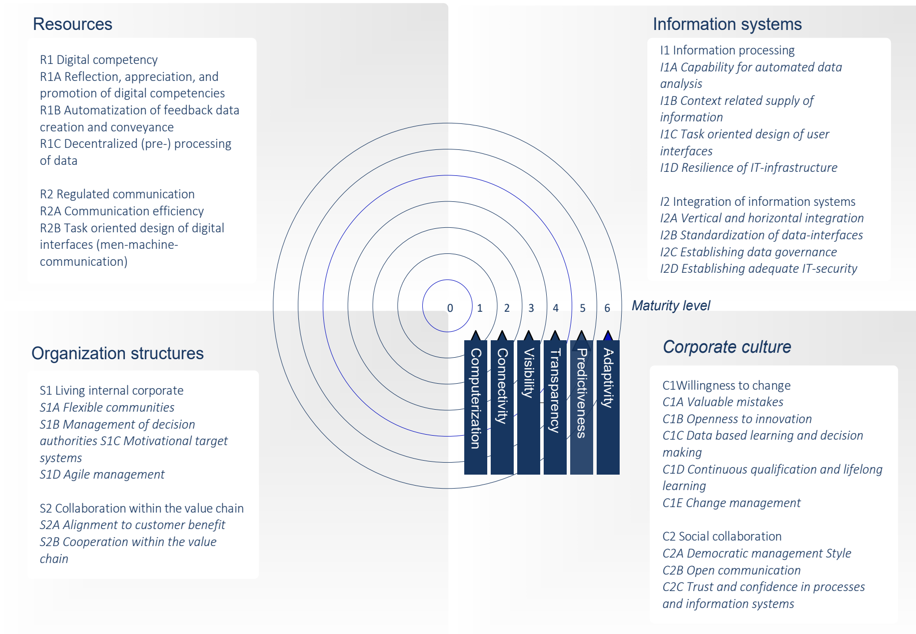


Figure 1. *The acatech Industrie 4.0 maturity index model adapted from Schuh et al. (2017)*

Employees, machinery, equipment, tools, materials, and finished goods are examples of tangible and physical corporate resources (R) that can facilitate digital decision-making. The organization's two guiding principles are Digital Capability (R1) and Regulated Communication (R2) (R2). R1 encourages personnel to adopt an interdisciplinary IT approach and make sound decisions. R1A evaluates the workforce's capacity to access, gather, process, and analyse data utilizing interdisciplinary and integrated IT skills to obtain operational awareness and make smart decisions. R1B refers to using cyber-physical systems (CPS) to collect and process data automatically. Time-sensitive computations in R1C can be performed directly within the resource's embedded system. R2 highlights the necessity for sufficient technical resources to reduce data and action delay. Resource interactions impact the responsiveness and robustness of business process communication. Therefore their management is crucial.

R2A is the capacity to access, retrieve, and make decisions based on real-time data from the applicable business application system that maintains SSoT. To equip daily operations with human-machine assistive devices (R2B), Information systems (I) include the sociotechnical system and its capacity to support decision-making and information system integration to prepare, process, store, and transfer data and information (Schuh et al., 2017). Information Processing (I1) and Integration of Information Systems are the two important guiding principles (I2). I1 comprises four capabilities: I1A, I1B, I1C, and I1D. I1A specifies the capability for automated data analysis that transforms collected data into useful information to aid in decision making. I1B is the context-relevant supply of information that enables the customization of data to meet the specific requirements or needs of the user. I1C pertains to the task-oriented design of user interfaces, which involves adapting the content and presentation to the recipient's needs. I1D emphasizes the resiliency of IT infrastructure to enable real-time data processing and information dissemination. The digitization and integration of physical and cyber systems enable the capture of vast amounts of data to enhance decision-making (Tan et al., 2016). Integrating information systems enhances data accessibility and use, enabling SSoT across the entire value chain. It supports the I2A, I2B, I2C, and 12D protocols. I2A refers to the capacity to simplify and assure that data originates from a single primary logical information system inside and outside the organization. I2B standardizes the data interfaces of all IT systems, whereas I2C regulates the quality of data during storage and processing. Lastly, the success of I4.0 is contingent upon cyber-security (Ben-Asher & Gonzalez, 2015). I2D, for instance, implements proper IT security, including data protection.

I4.0 modifies the type and structure (S) of an organization, including responsibilities, assignments, and relationships (Lichtblau et al., 2015; Wolf et al., 2018). Internal structure and the organization's involvement (structure and operational procedures) inside the value chain. It is a set of rules and regulations necessary to effectively and efficiently coordinate resources inside and beyond the corporation (Schuh & Kampker, 2011). It stresses employee independence in decision-making, task completion, skill diversity, and customer focus. Living internal corporate (S1) and collaboration within the value chain are the two guiding ideas (S2). So far, so good. But I'm uncertain if I'm prepared for the next level (S2). S1 expands staff autonomy and accountability. S1A supports cross-departmental collaboration and adaptable communities.

Additionally, organizational units have objectives. In S1B, various levels or persons have decision-making power. (knowledge specialist) They adapt and learn to optimize costs, time, and resources more effectively (Sony & Naik, 2019). S1C is a motivating target system that prioritizes process efficiency and ongoing development over achieving a single objective. Agile management at S1D encompasses rapid prototyping, measurable outcomes, and frequent feedback cycles. S2A aligns the supply chain for the customer's benefit. In addition, organizational competencies are continuously evaluated and adjusted. S2B facilitates interaction along the value chain by methodically integrating standard knowledge.

Corporate culture (C) is an organization's common values, conventions, behaviors, and beliefs (Schuh & Kampker, 2011). It focuses on flexibility (C1) and social collaboration (C2). C1 requires the capacity to notice, initiate, evaluate, and adjust to workplace changes. C1 acknowledges five skills (C1A, C1B, C1C, C1D, and CIE). C1A values open discussion and systematic error, and solution documentation. C1B highlights the ability to have confidence in the processes and technologies used to initiate change and take the necessary precautions. C1C is data-driven decision-making and learning. C1D incorporates lifetime learning and continual qualification to acquire interdisciplinary process comprehension and specialized expertise. To attain C1E, technical specialists must share their expertise and individuals must initiate, implement, and complete reforms. C2 is a three-featured corporate social collaboration and information sharing tool. With a flexible approach to decision-making and an employee-centric organizational structure, C2A encourages swifter decision-making and honors the contributions of individuals. C2B encourages employees to speak openly to obtain information efficiently. Lastly, C2C increases trust in processes and information systems by integrating employees in the change transition process and utilizing information systems in an organized manner.

3. Questionnaire Survey

3.1 Design methodology

The design process commenced with a facilities visit to identify the scope of the assessment, the primary corporate functional divisions (departments), and the pertinent process steps. Schuh et al. (2017) reviewed the fundamental principles of corporations' structural domains and competencies.

Based on these essential concepts, scenarios were developed and translated into pertinent questions. Important considerations are the representativeness of situations to the growth of maturity level (where possible) and their relevance to the respondents' works. Given the 27 capabilities that must be addressed, we agreed to one question per capacity or more if the capability's scope is expansive. In the latter scenario, we would assign weights (Table 1) to individual questions for score aggregation. The questionnaire should not be limited to a particular product type or procedure. Still, it should be as generic as possible to collect data from various functional divisions and processes from a wide variety of respondents. Because the scope and concentration of these capacities vary, various closed-ended questioning techniques are utilized. The information will be provided in the part that follows. We examined the choices with senior management and a few of our intended respondents. Each question should provide as many possible possibilities to aid the respondent in selecting the appropriate answer. With the assistance of a focus group, the questionnaire's technical resilience is developed iteratively by refining its content and analytic approach.

The format should be clean, uncluttered, and employ an appropriate font (Young, 2015). The terms and alternatives used in survey questions should be understandable (McIntyre, 1999). Rephrasing, cosmetic modifications, and instruction all constitute refining. Finally, validity and reliability are necessary to verify that the estimates are usable and to detect any survey-related resource limitations (Levy & Lemeshow, 1999). A spreadsheet is used to collect and analyze responses. The inserted formula is reconsidered, and the results are compared to the manual computation. This facilitates error identification and rectification.

3.2 Questionnaire structure

Table 1 provides a summary of 32 questions designed for the survey. The questionnaire has four sorts of analysis methods depending on the question and information solicited. For example, a binary option (e.g., true/false) is best for gathering observational data, whereas a survey scale is best for gathering subjective data, such as opinion or agreement. They are described as follows. Weighting is used in the questionnaire to indicate the relative value of each question or sub-question in the study context.

Option binary (true/false) Assign target t to the statement of the sub-question and receiver r. The sub-questions are arranged to reflect the gradation of maturity levels. The percentage of respondents' responses matching the target response, $P_{t=r}$, is computed. To obtain the maturity level measured by this question, $L_{T/F}$, the average of these percentages is then rescaled to six (the maturity levels). The computations are shown in Eq (1) and (2).

$$P_{t=r} = \frac{\sum_i^Q n(r=t)_i}{Q \times N_R} \tag{1}$$

$$L_{T/F} = P_{t=r} \times 6 \tag{2}$$

where

$n(r = t)_i$= number of respondents matching the target response, *t* for sub-question *I*,
Q = Total number of sub-questions,
N_R = the Total number of respondents.

ii. Multiple statement selection. The respondent must select at least one statement from the question. Individual statements are given a weight (0,1,2,...6) based on their reflected maturity. The maturity level, L_{MSS} , which is the weighted average, is found by multiplying the number of responses by the statement's weight and then dividing by the number of responses, as shown in Eq(3).

$$L_{MSS} = \frac{\sum_i^Q w_i n_i}{\sum_i^Q n_i} \tag{3}$$

where

Q = Total number of statements,
w_i= weight assigned to statement *i*,
n_i = the Total number of responses received for statement *i*.

iii Multiple choices. A respondent selects a sub-question option. Each option has a weight (*0,1,2,...6*) indicating its maturity level. This allows computation of the maturity level based on the weighted average. When a question has multiple sub-questions, the maturity level, L_{mc} will be based on their average. The calculation is represented by Eq(4) and Eq(5)

$$l_j = \frac{\sum_i^{S_j} w_i n_i}{\sum_i^{S_j} n_i} \tag{4}$$

$$L_{MC} = \frac{\sum_i^Q l_i}{Q} \tag{5}$$

Where

Q = Total number of sub-questions,
l_j = Maturity level determined by responses for sub-question *j*,
S_j = Total number of options in sub-question *j*,
w_i= weight assigned to sub-question option *i*,
n_i = the Total number of responses received for sub-question option *i*.

iv. Scale (or intensity). The question normally consists of multiple sub-questions. The respondents are given a 5-point Likert scale to rate their level of agreement/disagreement or experience with a statement in the sub-question. The possible linguistic variables for the scales in the former type of question are "completely disagree (1)," "disagree (2)," "neutral (3)," "agree (4)," and "completely agree (5)." “Very poor (1),” “poor (2),” “fair (3),” “good (4),” and “excellent (5)” are possible linguistic variables to associate with scaling to rate the latter type of question. The response is numerically valued, and the average is computed and rescaled to 6 (maturity level). Hence L_{CI} based on Eq(6)

$$L_{CI} = \frac{\sum_j^Q \sum_i^{C_{Max}} r_{ij} n_{ij}}{Q \times N_R} \times \frac{6}{C_{Max}} \tag{6}$$

Where

Q = Total number of sub-questions,
N_R = Total number of respondents,
C_{Max} = Total number of points on the Likert scale,
r_{ij} = Scale i to sub-question j,
n_{ij} = the Total number of responses with the scale i received for sub-question j.

At the capability level, when two questions (hence sub-questions) respond to a capability, e.g., Q1 and Q2, Q20 and Q21, Q26 and Q27, the maturity level, L_C is computed based on a weighted average of the result, as shown in Eq(7).

$$L_C = \frac{\sum_i^Q w_i l_i}{Q} \tag{7}$$

Q = Total number of sub-questions,
w_i = weight assigned to sub-question i,
l_i = Maturity level determined by responses to sub-question i, $l_i \in \{L_{T/F}, L_{MSS}, L_{MC}, L_{CI}\}$.

Table 1 *Summary of the question structure in the questionnaire.*

Question	***Capabilities***	***Weight to the capability***	***Number of sub-questions***	***Question type****	***Question***	***Capabilities***	***Weight to the capability***	***Number of sub-questions***	***Question type****
Q1	R1A	75%	5	iv	Q17	S1A	100%	8	iv
Q2	R1A	25%	8	i	Q18	S1B	100%	3	iv
Q3	R1B	100%	5	iv	Q19	S1C	100%	8	iii
Q4	R1C	100%	4	iv	Q20	S1D	50%	1	iii
Q5	R2A	33.3%	6	iv	Q21	S1D	50%	3	iv
Q6	R2A	33.3%	3	iv	Q22	S2A	100%	3	iv
Q7	R2A	33.3%	3	iv	Q23	S2B	100%	3	iv
Q8	R2B	100%	2	iv	Q24	C1A	100%	5	i
Q9	I1A	100%	5	ii	Q25	C1B	100%	5	i
Q10	I1B	100%	4	i	Q26	C1C	40%	4	iv
Q11	I1C	100%	1	iv	Q27	C1C	60%	6	iv
Q12	I1D	100%	2	iv	Q28	C1D	100%	6	iv
Q13	I2A	100%	3	i	Q29	C1E	100%	3	iv
Q14	I2B	100%	1	iv	Q30	C2A	100%	3	iv
Q15	I2C	100%	8	i	Q31	C2B	100%	3	iv
Q16	I2D	100%	5	i	Q32	C2C	100%	6	i

* i. Binary option (true/false); ii. Statement (single-selection or multiple-selection); iii. Statement (multiple choices); iv. Statement (scale, agreement/disagreement or intensity).

3.3 Survey Process

Four months are allotted for the assessment process, which includes design and analysis. According to Schuh et al. (2017), the evaluation must be conducted on-site. The evaluation included 54 responders. They have either a high level of relevant expertise or institutional authority (process responsibility and power of decision). Therefore, most respondents are middle management (50%) and executive functions (50%). The number of respondents is estimated using Cochran (1977)'s formula with a confidence level of 95 percent and a margin of error of 15 percent (16.67 percent or 1/6, which means the mistake is contained within one maturity level). Figure 2 depicts the distributions of responders by functional areas, age, and departmental (production/non-production) personnel. They are selected randomly from the company's 180 employees based on the size of departments and functional units along the value chain. For example, Production B employs the most personnel, resulting in 21 responses. Schumacher et al. (2019) demonstrate that the lack of introductory workshops leads to considerably divergent, if not contradictory, maturity judgments and expectations. Therefore, six workshops with eight to ten participants were held to brief the evaluation and address any questions. The respondent's personal information was kept private. Respondents were given one hour after the briefing to complete the printed survey questionnaire. During the submission process, the workshop assistants assist in verifying the accuracy of the completed surveys. Three of the 32 questions (Q12, Q13, and Q16) required a separate technical panel to address because the relevant information is IT backend system-specific. Following Section 3.2, the findings of the questionnaire analysis are created by first determining the mean of the scores and then aggregating based on the predetermined weights.

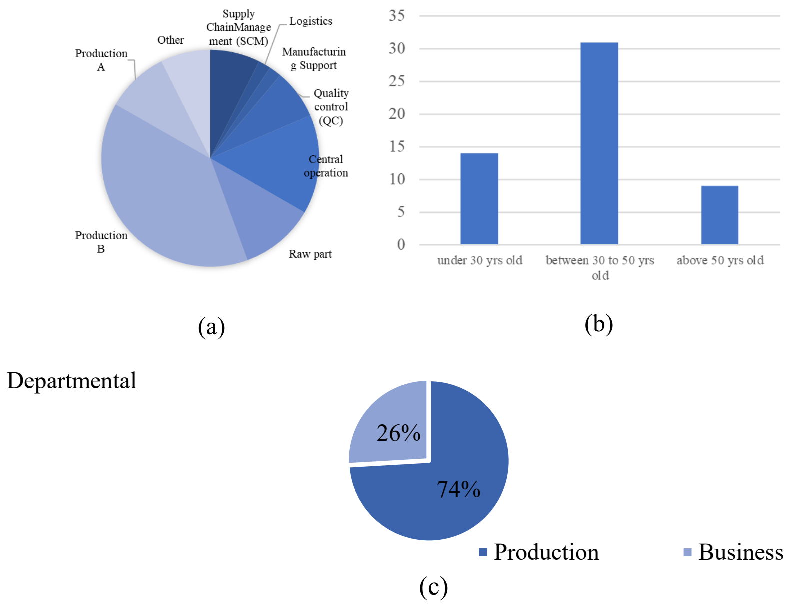


Figure 2. *The distributions of respondents by (a) functional areas, (b) age, (c) departmental*

4. Results

The findings of the evaluation (Figure 3) revealed that the organization reached a maturity level of 2.66. The connectivity phase (Stage 2) has been substantially completed. However, the results were not uniform, with scores ranging from 2.03 to 3.18 for the individual principles and from 1.3 to 4.60 for the individual talents. The indexes for organizational structures and culture are 2.94 and 3.07, respectively, indicating relative maturity.

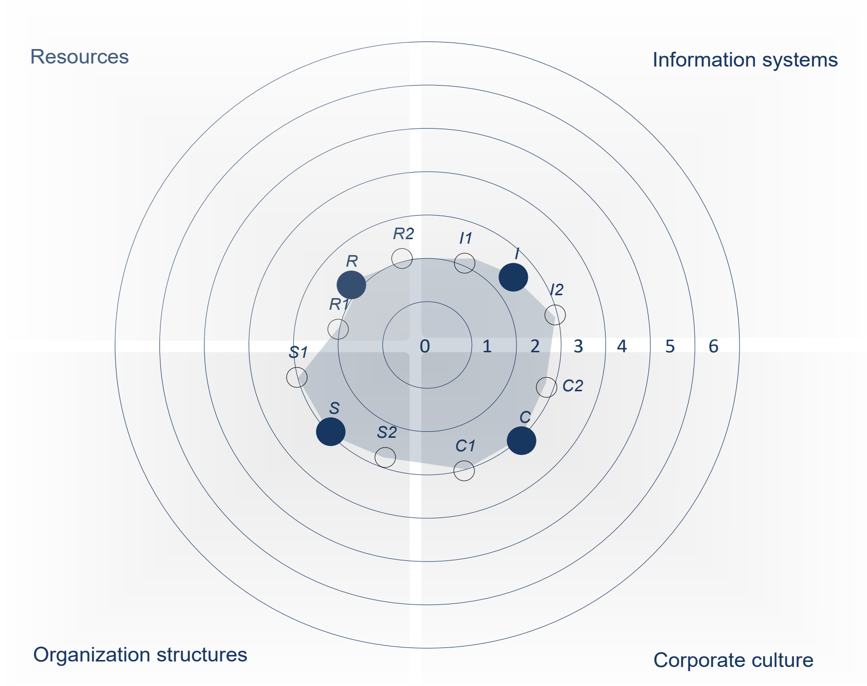


Figure 3 *The spider chart shows corporate structural areas' maturity levels and guiding principles.*

4.1 Resource

R1 = 2.12 demonstrates that workers comprehend the influence of digital technology. Approximately 87.04 percent of respondents in R1A (3.65) think that technology-gathered data is valuable. Respondents concur that digital technologies and software are essential for timely (85.19%) and high-quality (77.78%) task completion. Most staff appear to be familiar with the I4.0 principles and objectives. 83.33 percent of respondents agree that data and information are superior to intuition. 85.19 percent believe that the digital revolution is about automation and robot technology, 74.07 percent believe it is about general technology use, and 62.96 percent believe it is about enhancing efficiency through ICT. R1B (1.37), as well as R1C (1.35), are juvenile. In R1B, there were many manual operations without digital support. 11 percent of respondents indicated that locally generated data is processed and utilized immediately at the same site.

The score of 2.12 for R2 indicates organized but ineffective communication. R2A (2.18), information is often documented following business policy (66.67 percent). However, finding and retrieving information is time-consuming (46.30%), resulting in lengthy wait times (38.89 percent). Moreover, just 48.76 percent of respondents concur that the quality of the information is high. In R2B (2.05), digital interfaces, particularly graphical user interfaces, exhibit low task orientation (given that 64.81 percent of the respondents scored 3 and below in Q8).

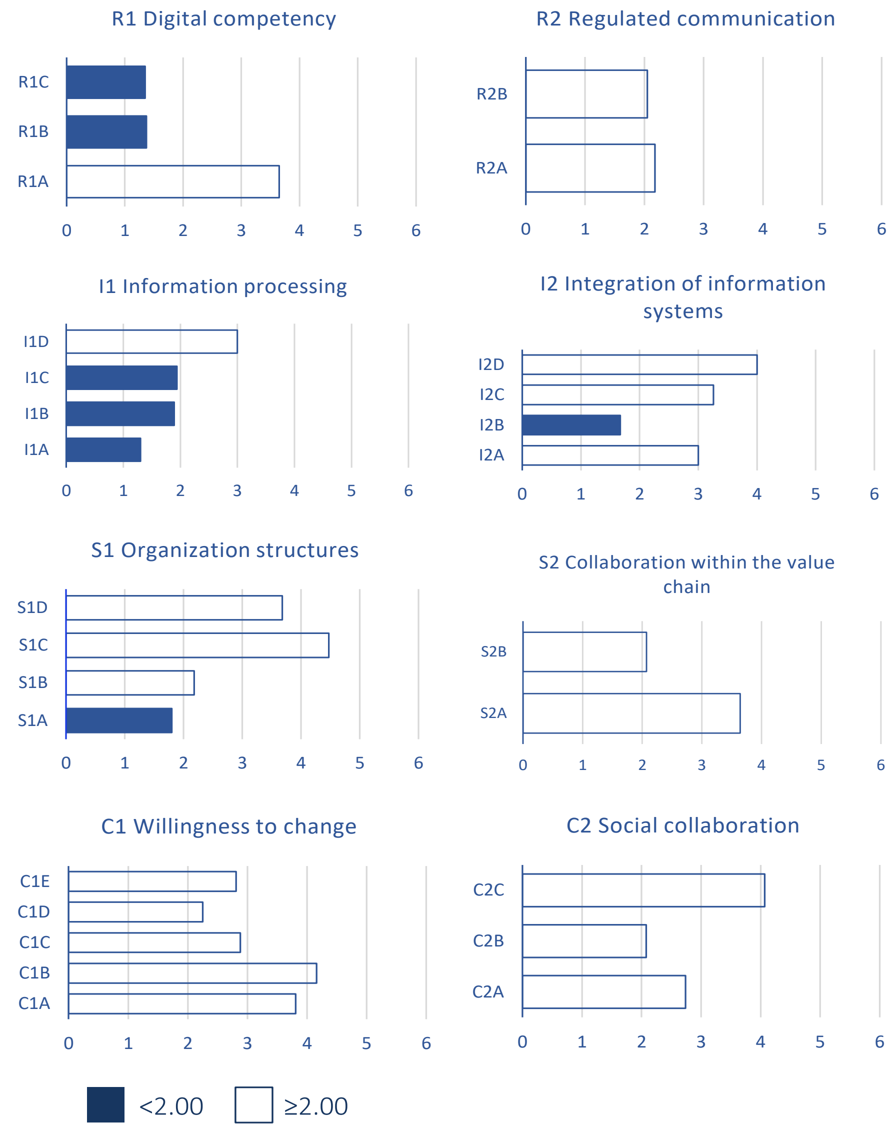


Figure 4. *Maturity levels of capabilities.*

4.2 Information systems

I1 is 2.03, and I2 is 2.98. In Q10, 53.7% of respondents concur that data analysis tools update datasets manually, showing insufficient IT compatibility for automated data analysis. Workplace I1B (1.89) results indicate a lack of context-relevant knowledge. 57.41% of respondents are required to seek and edit data in distinct IT systems. 83.33% of the dataset must be sorted, processed, and analyzed manually. Eighty-three percent of respondents deny automatic information distribution. In Q11, only 27.78 percent agreed that the digital user interface prioritizes tasks. Current IT systems do not fully automate the display of information to users. Most respondents believe an IT failure would harm them (Q12). Q13, which corresponds to I2A (3.00), reveals divergent perspectives (vertical or horizontal). In addition, 81 percent of respondents received three or fewer responses in Q14, demonstrating standardization of data interfaces. Q15 demonstrates that the present data governance laws and policies have advanced. 75.93 percent of respondents confirm the existence of established data storage and processing structures and procedures. Additionally, 74.07% concur that data governance promotion is adequate. Only 59.26% believed that the majority of employees adhere to data governance. Over 70% of respondents affirm that IT security and data protection are adequately promoted.

4.3 Organizational structures

The suggestion of a partial realization of live internal organization (S1=3.03). Q17: 61.11 percent of respondents support close employee supervision. Roughly half (48.15 percent) concur with the statement that technology and process knowledge is essential, while about a third (35.19 percent) concur with the statement that self-management abilities are essential. Almost half of those surveyed experienced job and team rotation. Another finding is consensus on the management of decision-making authority (S1B=2.18). More specifically, over sixty percent of respondents concur in response to question 18 that decision-making authority is delegated to those with the most relevant information.

S1C (4.47) has an incentive mechanism that goes beyond monetary compensation. 59.30 percent of respondents in Question 19 concur that the performance measurement system covers individual and organizational objectives. In addition, 57.4% agree the system accurately evaluates performance. The performance measurement is high (50.0%) or moderate (50.0 percent). (40.71 percent). Rare (exceptional) errors are viewed as having a low (48.10) or moderate (37%) influence on performance. They correspond to S1D. (3.68). In Q20, the majority (55.56%) of respondents observed the organization changing its decisions in response to new information. In project management (Q21), 73.91 percent had comprehensive planning experience, and 68 percent had detailed control experience. 72.73 percent of respondents agree that initiatives are altered or abandoned freely as new knowledge becomes available.

Regarding value chain collaboration (S2 = 2.86), the organization aligns its efforts to optimize customer value. In Q22, the majority of respondents (90.7%) concur that the company focuses on its core capabilities, which include supplying distinctive products and services and the capacity to address the specific demands of each customer. 43.14% of those surveyed in Q23(a) cannot decide whether a standard information request should be processed manually or automatically. In Q23(b), 54 percent of respondents concur that standard value chain information is easily accessible (against 16.0 percent disagree). In addition, nearly 48.98% of respondents to Q23(c) believe that the existing specifications for information in the value chain are very clear.

4.4 Corporate culture

C1 scores 3.07, suggesting a willingness to adapt. The data on business culture indicate that employees are cautious about committing errors (C1A=3.8). 62.96% of respondents will attempt to avoid committing errors, while 46% will rapidly repair them after determining that errors can lead to discovering new, useful information. The majority (82 percent) agree that errors are not punished severely.

The business culture encourages innovation (C1B=4.16). Most respondents in Question 25 (81.48 percent) disagreed that change is risky and should be avoided. While only 59.26% choose to play it safe and utilize traditional methods, 100% feel that using digital technology will create new technological opportunities. Another 85% concur that understanding and employing technology in the workplace is crucial, and 91% stress the importance of evaluating technology through trials.

C1C (2.88) defines data-driven decision-making. Quick identification of problems is supported by 79.63 percent of Q26 respondents. However, there is no consensus that using data and facts exclusively when confronted with critical difficulties (Q26B) and making hasty decisions is preferable (Q26D). 88.89% of respondents in Question 27 believe that data is always used to control performance or operations. 77.78 percent of respondents saw data used for learning and process improvement. However, only 44.44 percent have faith in the gathered data.

40.74 percent of employees agree that knowledge and information may only be valid for a limited time (Q28, C1D=2.25). According to 70.37 percent, specialized knowledge will be more significant than broad information in the future, and 68.52 percent feel that certifications will remain relevant throughout time. 74.07 percent of respondents surprisingly appreciate lifelong learning. In addition, 81.48 percent of respondents concur that individuals can identify their training requirements and that employers must give training. Half of the respondents believe that affected employees must be involved in the change planning. At the same time, 66.67 percent disagree that changes should be presented only by management, as shown in Q29 of C1E (2.81). C2 gets 2.96. C2A views leadership styles as democratic and inclusive (2.74). In Q30, 74.07 percent agree that employees' talents and knowledge are respected. The majority (51.85 percent) agree that management must involve directly affected employees in decision-making.

On C2B (2.08), communication is open despite individual distrust. Only 51.85 percent of responders in Question 31 concur that explicit and implicit knowledge should be provided. 61.11% concur that employees support and educate their peers freely. Only 38.89% observed high mutual trust across departments or teams, and 44.4% felt that information is hidden on purpose from individuals. 59.26% of C2C (4.07) respondents have faith in the information systems, whereas 62.96% believe in the stated procedures. Almost 79.63% of respondents believe that processes and information systems can only be completely exploited if all designated individuals are willing to follow and utilize them.

5. Discussions

The discussion contextualizes the results (from the management standpoint) and their larger implications for management. It begins with management's perspective on the results and observations. The second section is action planning for I4.0 in light of the findings. The questions, results, management interpretations, and planned actions are depicted in Figure 5. The management review is organized according to the organizational structure.

5.1 The management's perspective

R1A (3.65), potentially due to a recent digitization awareness initiative, displays staff affinity for digitalization. The evaluation (R1B = 1.37) indicates a low capability of CPS to automate data collection and processing. Most automated production machines are outdated, have rudimentary mechatronic operations, lack data-gathering sensors, and are not close enough to the state for data to be processed and supplied back to actors locally. The company has recently replaced outmoded equipment and enhanced machine computerization, such as the switch from conventional to CNC milling for semi-finished goods.

R2A=2.18 and I2B=1.88 indicate poor SSoT data management. The information management system of the local area network provides access to documents such as generic process descriptions and master device data (IMS). During production planning, the customer shares the monthly total demand prediction in Excel via a file server. Because production orders are strictly made-to-order, a short-term adjustment in the article mix is necessary. The planning tool does not instantly reflect daily updates to the shared Excel file.

Consequently, there are gaps between the medium-term and short-term planning horizons, resulting in unnecessary adjustments to the production schedule and shop-floor planning. Existing function-specific IT systems (PIMS, CAD, QMS) have diverse outcomes due to different handling, which prevents seamless data flow. Due to incompatible interfaces or communication mechanisms, automation technologies are misaligned (Gruhier et al., 2017).

IT resiliency (I1D=3.0) and security (I2D=4.0) are necessary for the current level of digitalization. The IT department routinely inspects system integrity and dangers such as data theft, data leakage, and sabotage. Multiple backup servers and centralized data storage facilitate data recovery. Data access, manipulation, and modification, as well as the installation of third-party applications, are restricted. I4.0 integrates diverse data and knowledge to enable autonomous decision-making (Lichtblau et al., 2015; Lu, 2017). The existing digital (I1C=1.94) and user interfaces (GUI) (R2B=2.02) lacked task orientation. This hampers automated and real-time data analysis (I1A=1.37). The utilization of ICT for business tasks is shown by employees' access to IT systems via desktop or mobile computer. Mostly "typical" Windows software with a low focus on tasks. For example, MS Excel for daily production planning and WMP for time studies. Standard software is used to execute tasks, wasting time. Nonetheless, some IT choices (e.g., the ERP filter) permit customization and streamlining context provision; hence, a significant amount of standard data is transferred manually.

Transparency in operational and strategic planning is influenced by how much a business uses sensor data (Lichtblau et al., 2015). The production information is not context-sensitive (I1B=1.89) and must be processed locally. With technology, supervisors update ERP using a PC-Terminal (e.g., Barcode-Scanner). For most procedures, workers must fill out production data (good amount and scrap) and sign off on step completion on paper papers. IT interfaces (I1C=1.94) are neither planned nor implemented in production. Digitalizing data processing and decision-making will enhance resource usage (Storey & Song, 2017). However, companies primarily rely on analog data for decision-making (e.g., printouts and shop floor visual boards). Incomplete or erroneous product data (discrepancies) result in redundancies and delays. Also suggested (I2A=3.00) is a collaborative ERP system with the direct customer to share information such as order information, order process status, stock levels, etc. Horizontal integration is hindered by an uneven IT landscape, isolated databanks, and incompatible IT solutions.

S1D (3.68) and ongoing efforts to eliminate management stiffness indicate that management is relatively flexible. In a highly competitive economy, managerial agility is essential to swiftly adapt to shifting client needs (Fatorachian & Kazemi, 2018). According to S1B (2.18), R1C (1.35), and C2C (4.07), decentralized decision-making is necessary to provide transparency in decision-making to realize superordinate objectives. Regular management meetings are suitable venues for the alignment and sharing of information. However, numerous management actions inhibit decision-making at lower organizational levels.

I4.0 explores multifaceted, long-term partnerships between businesses and ecosystems (such as local communities) in resource efficiency, system integration, and sustainability (Sony & Naik, 2019). Compared to the conventional supply chain, the company's supply chain is aligned with consumer benefits. S2A (3.64), and C1B (4.16), indicate that the organization is focused on enhancing its core capabilities and relevant technology while transferring others to value chain partners. Although the survey reveals low-value chain collaboration (S2B=2.07), there are unusual network obstacles. Additionally, the raw material provider is the only internal customer of the corporation. Rarely are production processes externalized. Due to cultural and geographical variations, miscommunications arise despite no cooperative attempts being rejected.

Corporate culture is characterized by democratic management (C2A=2.74) and transparent communication (C2B=2.01). When making decisions, employees thought their superiors valued their opinion. Occasionally, employees are not solicited for their input or lack the confidence to voice it because of their lower level. Additionally, with C1E (2.81), some employees follow orders and directives from their superiors rather than initiating and driving change freely. In both instances, democratic management and genuine consensus in decision-making are thwarted. Workers must adjust to I4.0's increased skill requirements, as the CPS will render most conventional skills useless (Palazzeschi et al., 2018). The results demonstrate that employees are not always aware of the new requirement. For instance, metalwork is the company's largest and least automated function. The position requires substantial knowledge. A restricted number of procedures are taught on the job instead of through a structured apprenticeship program. They despise training because it diminishes their incentive based on production. Additionally, flexible communities (S1A=1.80) struggle to modify their resources dynamically.

5.2 Action planning for management

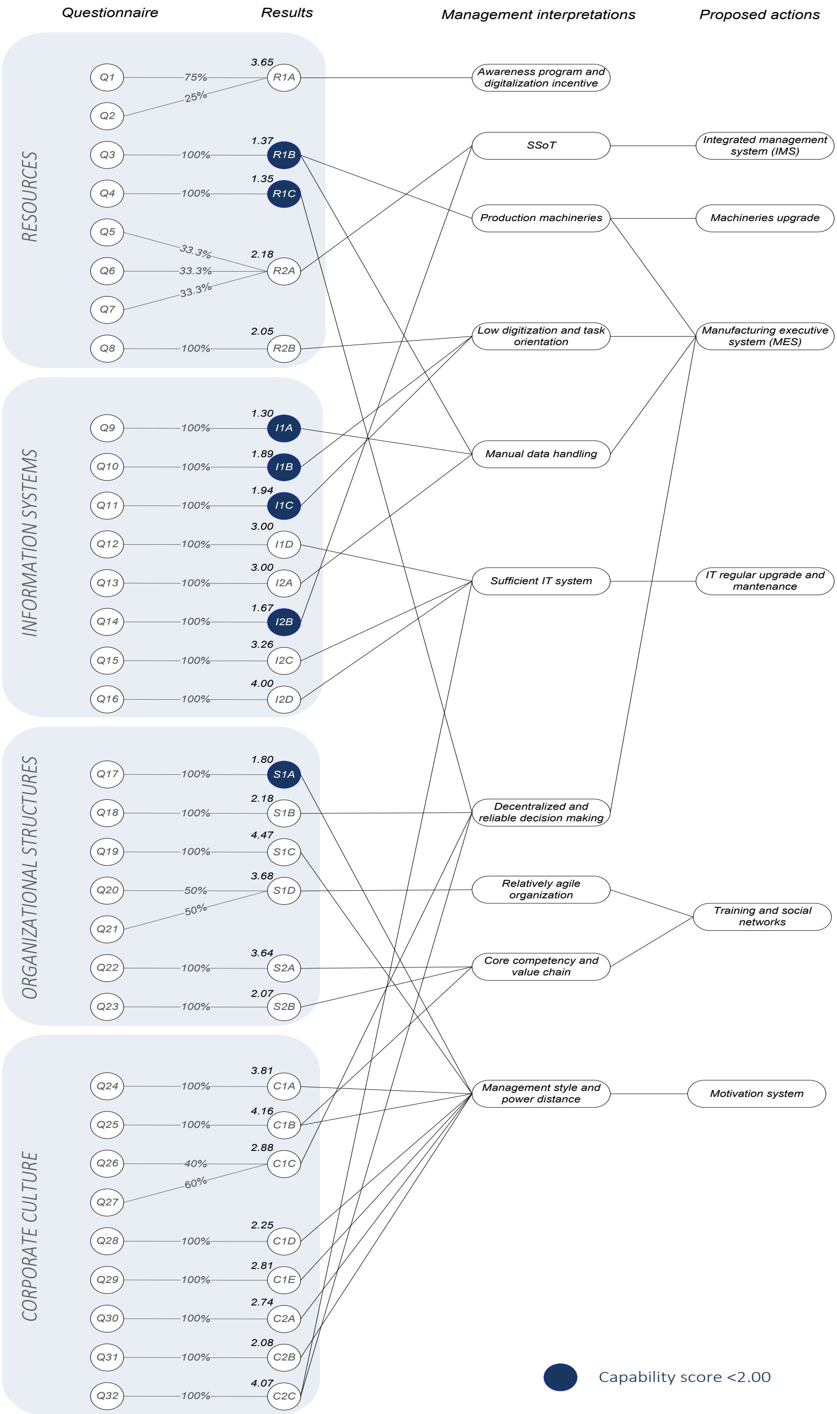
The findings and management review assist senior management in conceiving methods to enhance I4.0 maturity. Their participation will positively influence the organisation's digitisation (Rajnai & Kocsis, 2018). Additionally, they realized that each designed solution affects a collection of capabilities instead of a single skill. All systems and solutions must be integrated for digital transformation to reach its full potential.

The first is an integrated system that permits monitoring, self-regulation, and optimization of resources (Bassi, 2017). To replace manual data handling and analysis, such as rescheduling all orders affected by customer-centric planning, an integrated manufacturing executive system (MES) can be implemented. For performance analysis, the equipment must be connected to a monitoring system. Auto-ID systems for tracking and tracing can drastically minimize manual paperwork while enhancing data quality (accuracy and timeliness). Specifically, to equip manual labor and machining activities with the proper amount of decentralized processing. Digital assistance systems and other ICT infrastructure provide for data-driven decision-making (C1C=2.88).

Standardization and horizontal integration of fundamental collaborative business software, tasks, and communication. Information and its carriers/sources can be visible through digital technology and explicit network mapping. Integrated Management System (IMS) for document management (GDPR) (GxPDoc). To save money, new or planned IT would require standardized data interfaces and capabilities and the flexibility to replace IT systems modularly. Due to the immaturity of standardized data interfaces (I2B=1.67), a multi-IO universal interface box based on the OPC unified architecture can be utilized to standardize output (add suitable reference). Streamlining and integrating IT solutions eliminates information delays and saves time.

Increasing digitalization, automation, and user base emphasize the need for IT security (I2D=4.00). It is routinely upgraded to accommodate the expanding data traffic demands (storage and processing servers, network communication controllers). Data traffic and responses will surge as automation and convergence with the internet of things increase. Having appropriate capacity reserves will prevent future infrastructure shortages.

In addition, the management aims to continue investing in organizational structures and corporate culture since they feel these two elements are required in positions of authority over resources and information technology to drive I4.0. A better motivation system (S1C=4.47) has stated objectives and incentives that encourage process efficiency and ongoing development. The motivation system is matched with the capacity C1A (3.81), which recognizes errors as opportunities and a catalyst for change in the I4.0 environment. To exhibit a desire to change (C1D=2.25), the organizational culture must support continuing education and lifelong learning. The company is collaborating with educational institutions to build an accredited apprenticeship program based on I4.0 technology. Other initiatives include physical and digital help systems for on-demand qualification solutions, digital collaboration platforms, and a system that encourages employees to participate in additional training. Training hours must be compensated not to jeopardize an employee's motivation and are therefore considered productive time. Job-rotating employees could create formal and informal interpersonal relationships to promote open communication (C2B=2.08). Individuals from groups aim to exchange information and expertise via open communication when they create digital social networks.


Questionnaire
Results
Management interpretations
Proposed actions
RESOURCES
INFORMATION SYSTEMS
ORGANIZATIONAL STRUCTURES
CORPORATE CULTURE
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
Q15
Q16
Q17
Q18
Q19
Q20
Q21
Q22
Q23
Q24
Q25
Q26
Q27
Q28
Q29
Q30
Q31
Q32
75%
25%
100%
33.3%
33.3%
33.3%
50%
50%
40%
60%
3.65 R1A
1.37 R1B
1.35 R1C
2.18 R2A
2.05 R2B
1.30 I1A
1.89 I1B
1.94 I1C
3.00 I1D
3.00 I2A
1.67 I2B
3.26 I2C
4.00 I2D
1.80 S1A
2.18 S1B
4.47 S1C
3.68 S1D
3.64 S2A
2.07 S2B
3.81 C1A
4.16 C1B
2.88 C1C
2.25 C1D
2.81 C1E
2.74 C2A
2.08 C2B
4.07 C2C
Awareness program and digitalization incentive
SSoT
Production machineries
Low digitization and task orientation
Manual data handling
Sufficient IT system
Decentralized and reliable decision making
Relatively agile organization
Core competency and value chain
Management style and power distance
Integrated management system (IMS)
Machineries upgrade
Manufacturing executive system (MES)
IT regular upgrade and mantenance
Training and social networks
Motivation system
Capability score <2.00

5.3 The questionnaire survey's design and implementation

Strategically and operationally, the concept of I4.0 presents businesses with formidable obstacles (Schumacher et al., 2019). Frequently, holistic I4.0 models are judged too broad for implementation in actual industrial settings. For instance, the I4.0 digital revolution stresses learning orientation, knowledge, abilities, and attitudes. Therefore, practitioners have difficulty applying and evaluating these concepts within their organizations. Consequently, the study is essential for offering crucial theoretical and practical implications by demonstrating a desirable I4.0 assessment approach in a business. The evaluation has successfully gathered employee feedback from many departments. Implementation from the top down may be interpreted differently by employees at different organizational levels. A survey of employees can assist human resource and leadership teams in identifying the essential areas for improvement. The high-priority, severely deficient regions become the top management's highest-priority action items. When drafting the questionnaire, it is important to remember that the survey measures employee understanding and presence in relation to I4.0, not satisfaction. The questionnaires utilized a variety of question formats. They proved useful in revealing the relationship between employee opinions and the organization's strategy, as well as the organisation's effectiveness, suppliers or customers, management quality, and cooperation between organizational divisions. The questionnaire is quantitative and allows for a straightforward examination of the data. Employees' names are concealed so they may respond honestly and openly to the inquiry.

According to Hiatt (2006), awareness is more easily attained when the cause of change is external and readily observable. At the beginning of the I4.0 journey, the questionnaire survey is a terrific way to open communication channels with employees. The questionnaire demonstrates the gradation of maturity, which may be related to the changing interests and concerns of the recipients. As a result, the survey questionnaire promotes change by explaining its direction and generating knowledge of industry 4.0.

6. Conclusion

The I4.0 maturity evaluation with content based on the acatech model has been successfully implemented in the medical device manufacturing business using a questionnaire survey. The maturity stages describe the advancement of industry-comprehensible manifestations of I4.0 in technology and people. Multiple questions were used to assess the level of maturity concerning eight guiding principles and 27 competencies. 54 respondents answered 29 of the questionnaire's questions, while a panel of experts answered three. The outcomes are crucial for strategic planning. It indicates that the organization is near achieving transparency and significant score disparities amongst capabilities. The second observation is that (information and resource) digitization is overdue for development, given that culture and organizational structures are more mature. Six of the seven competencies scored below 2 are associated with technological depth, indicating that the industry must accelerate cutting-edge technology. Planned technological depth was applied to high-value or bottleneck processes, such as CNC machining.

Meanwhile, the technological breadth would be solved using a mature technology, such as MES, to ensure a widespread effect. Given relevant literature with industry-wide comparisons, the case study exhibits a proper, comprehensive I4.0 maturity evaluation in the industry, which is uncommon. The paper contributes original research value in terms of quantitative assessment technique and a real-world case study closely tied to I4.0's theoretical premises. Future studies may include cross-industry benchmarking and study into the value chain and road mapping of I4.0 based on the survey results.

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