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Vítor Alcácer (✉ [viktor.alcacer@estsetubal.ips.pt](mailto:viktor.alcacer@estsetubal.ips.pt))

Faculty of Science and Technology: Universidade Nova de Lisboa Faculdade de Ciências e Tecnologia  
<https://orcid.org/0000-0001-9485-8777>

João Rodrigues

Faculty of Science and Technology: Universidade Nova de Lisboa Faculdade de Ciências e Tecnologia

Helena Carvalho

Faculty of Science and Technology: Universidade Nova de Lisboa Faculdade de Ciências e Tecnologia

Virgílio Machado

Faculty of Science and Technology: Universidade Nova de Lisboa Faculdade de Ciências e Tecnologia

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## Research Article

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# Industry 4.0 Maturity Follow Up Inside an Internal Value Chain: A Case Study

Vítor Alcácer<sup>1, 2, 3, 4 \*</sup>, João Rodrigues<sup>1</sup>, Helena Carvalho<sup>1, 2</sup>, Virgílio Cruz-Machado<sup>1, 2</sup>

<sup>1</sup> Department of Mechanical and Industrial Engineering, Faculty of Science and Technology, Universidade Nova de Lisboa, Lisboa, Portugal

<sup>2</sup> UNIDEMI, Department of Industrial and Mechanical Engineering, Faculty of Science and Technology, Universidade Nova de Lisboa, Lisboa, Portugal

<sup>3</sup> Department of Mechanical Engineering, ESTSetúbal, Instituto Politécnico de Setúbal, Setúbal, Portugal

<sup>4</sup> CDP2T, ESTSetúbal, Instituto Politécnico de Setúbal, Setúbal, Portugal

\* Corresponding author's email address: [vtor.alcacer@estsetubal.ips.pt](mailto:vtor.alcacer@estsetubal.ips.pt)

**Abstract:** Social, economic, and technological recent developments leading companies to face new production challenges. Companies will need physical and virtual structures allowing cooperation and quick adaptation along all value chain. To this matter, one of the main foundations of industry 4.0 is the use of information and communication technologies systems. Many companies are using information and communication systems without integration with business partners and even also with internal departments. This gap needs to be analyzed and it can be made by measuring the status of the industry 4.0 enabling technologies adoption inside a company using maturity or readiness models transmitting knowledge and pathing initiatives to help on progress and monitorization, looking forward to the future status of the internal value chain. On a qualitative and quantitative matter, this study presents the industry 4.0 enabling technologies readiness level of three departments of an automotive company internal value chain. This case study shows different readiness level on each department and limitations to reach better levels such as potential results if the benefits of industry 4.0 enabling technologies were reach on a company that assumes to be aligned with the industry 4.0 strategy.

**Keywords:** Industry 4.0, Maturity and Readiness Models, Business Partners Integration, Internal Departments' integration.

## 1. Introduction

Recent environmental, social, economic, and technological developments have led production and manufacturing companies to face new challenges. In order to face these challenges, companies will need resources that allow them to manage their entire value chain in an agile and efficient way. These companies will need physical and virtual structures to ease the cooperation and rapid adaptation throughout the entire life cycle, from innovation to production and distribution [1].

Today, we are experiencing and making part of the fourth industrial revolution, brought to the world by the German government in 2011, known as Industry 4.0 (I4.0), which features the development of Information and Communication Technologies (ICT). The I4.0 goal is to work with a high level of automation through systems called Cyber-Physical Systems (CPS), with decentralized control and advanced connectivity, that allow to reach a high level of operational productivity, flexible custom mass production and flexibility on the quantity of production.

Most current Information Technology (IT) systems are not fully integrated. Supplier companies and customers rarely establish interpersonal relationships. The same goes for organizations' internal departments, such as engineering, production, or services. With I4.0, these connections are expected to be established and to enable truly automated value chains [2].

The main objective of this study is to individually assess the level of technological maturity related to the I4.0 concepts, on a quantitative and qualitative matter, on three internal departments (logistics, board-prep and plastics) of an automotive company that assumes to be aligned with the I4.0 strategy. A secondary

objective of this study is to contribute for the identification of I4.0 enabling technologies that are used on each department in order to check the vertical integration of the company.

The rest of this paper is structured as follows: section 2 overviews the I4.0 environment, the adoption of I4.0 enabling technologies so far, and presents I4.0 maturity and readiness models, section 3 exposes the case study and the research methodology followed on this paper, section 4 describes the analysis and discussion of this study, and the section 5 outlines the conclusions, the research limitations and ongoing research.

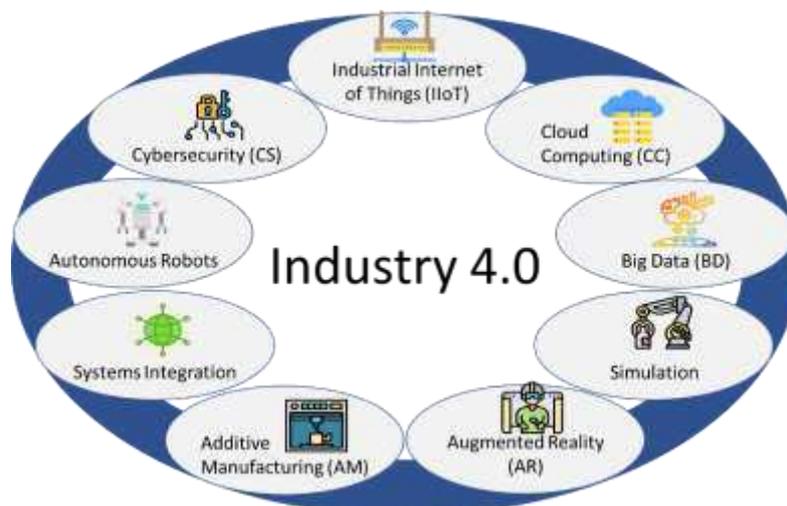
## 2. The I4.0 environment overview

Industry 4.0 (I4.0) term was introduced by the German federal government, according to its high-tech strategy, in 2011. I4.0's goal is to work at a higher level of automation, thus achieving a higher level of productivity and efficiency operational, connecting the “real” and “virtual” worlds [3]. According to Herman et al. [4] it's possible to define I4.0 as a collective term for value chain organization technologies and concepts. I4.0 describes the integration not only of all business areas with added value, but also of the entire value chain with the help of digitization [5]. In general, I4.0 intends to introduce the concept of digital manufacturing, better known as Smart Factory (SF).

SF represents smart grids, mobility, flexibility of industrial operations and their interoperability, integration with customers and suppliers, and the adoption of innovative businesses [6]. The components on an I4.0 factory are Cyber Physical Systems (CPS) as physical systems integrated with elements based on Information and Communication Technologies (ICT). The term CPS describes a network of autonomous systems, which make their own decisions based on machine learning algorithms and real-time data collection [7]. The systems are able to work with increasing independence. Through human-machine interfaces, the “real” and “virtual” worlds can work together. A central information system manages smart grids and takes physical factors into account. The human being defines the requirements, while the process management takes place autonomously [8]. Within the I4.0 SF, CPS monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions [4].

The intensive use of technological applications and the increasing use of wireless sensors and actuators contribute to the development of new applications on areas such as production processes, transport systems, logistics processes, autonomous vehicles, machine learning and intelligent structures [6].

Consensually, there are nine main enabling technologies and development trends as showed on Figure 1 that drives I4.0 [2,3,5].



**Fig. 1 Enabling Technologies of I4.0.**

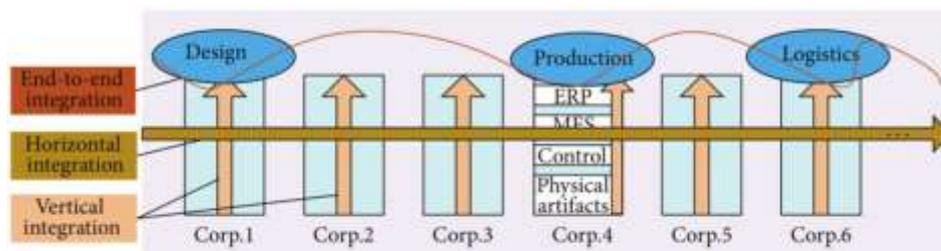
## 2.1. Industry 4.0 Enabling Technologies Adoption

Several national governments keep on developing policies and measures to support financially (through funds) and structurally (through institutional actions) the digitalization path of companies, forecasting the relationship between all stakeholders inside each value chain, involving also within this value chain universities, intermediaries and innovative companies, and training programs [9].

Da Silva et al. [10] states I4.0 is a reality on countries like German, France, USA, United Kingdom, China, Japan, Brazil, among others. Although, it should be admitted that I4.0 enabling technologies' implementation and adequacy could be a challenge for all stakeholders.

Systems integration is the first step to achieve I4.0 vision. Considering all productive flow, the systems are analyzed as a whole [11].

The systems integration, as shows Figure 2, can be understood as the linkage of system components (components like software, hardware or other systems and subsystems), called vertical integration, two or more systems, called horizontal integration, and the system to provide interfaces linking physical and virtual objects of a system is called end-to-end engineering integration. These components interoperate and provide solutions according to collective or individual objectives. Technologies like IoT are integrated with these systems, enabling the interoperability between the “things” (data, people, and/or services) [12].



**Fig. 2 Integration types and their relationships on a manufacturing system [13].**

The vertical integration or intra-company integration (or internal integration mapping) consists of evaluate the system in a different manner in order to identify crucial areas for their assistance [11]. Corporate planning, manufacturing, production management, control and actuators are examples of informational systems, subsystems and physical “things” are elements belonging on a typical manufacturing system. This integration on a manufacturing system, allows flexibility and reconfigurability and a rapid adaptation to different product types. The vertical integration allows processing the collected massive information in a transparent process manner [13].

The horizontal integration or inter-company integration is based on the cooperation or collaboration between two or more companies, achieving common or individual objectives [12]. It allows an efficient ecosystem inside value networks related to information, finance, and material flows between companies [13].

The end-to -end engineering integration mixes virtual and real entities using connected devices to a network, sending information to a cloud or people and communicates with the system using Human Machine Interface [12]. It’s a process of product-centric value creation, involving customer requirements, design and development of products, production planning and engineering, associated services, maintenance and recycle [13].

To be able to perform inside I4.0 environment, companies must have socio-technical environments as well as the virtualization of physical objects with the use of smart systems [11]. The adoption of the I4.0 enabling technologies, from a socio-technical perspective, is not supported by itself. The socio-technical component is complemented with dimensions related to the technological aspect on the digitalization process to achieve the I4.0 implementation, as follows [14]:

- Work organization - rethink how companies will operate with I4.0 enabling technologies;

- Human factors – new operator’s competences and skills are needed to operate with I4.0 enabling technologies;
- External environment – the adoption of I4.0 enabling technologies is maturity dependent where they are implemented.

## 2.2. Maturity and Readiness Models

A maturity model can be defined as a conceptual structure constituted by a state of development of a specific area of interest, with the aim of describing and identifying processes, measuring the maturity of an organization on its current state, and guiding initiatives of improvement, control progress towards a desired future state [15,16].

Models of I4.0 technological maturity for companies are based on self-assessment, with information collected mainly through online questionnaires or by telephone interviews [17]. Maturity can be assessed quantitatively or qualitatively, discretely or continuously [1].

Maturity models generally contemplate dimensions and levels. Dimensions mean the grouping of readiness indicators in thematic groups [17]. The content of each dimension can come from research methods, namely, case studies and other methodologies for creating ideas and decision making. It is possible to quantify the stages of maturity for the different dimensions, through the attribution of levels [15].

Commonly, maturity models are used to measure the maturity of a given system regarding to a specific target state. Maturity models capture the “as-it-is state” [1]. Reaching a given maturity level is the foundation for the evolution to the next maturity higher level that can be planned and further implemented. Thus, the maturity models quantify activities and make them mature along time. In order to assess maturity systems through levels, the maturity models are based on the idea of “state of being complete, perfect, or ready” and it can be addressed as qualitative or quantitative, in a discrete or continuous manner.

As a close approach to maturity models, in order to assess readiness systems through levels, readiness models are based on the idea of “this is the starting point for”, allowing the preparation for the development process of the measured given system. The “readiness” term induces a tendency for change in the given system. Readiness models intend to assess the state of the system before the engagement into the maturity transformation process [1]. Readiness models to assess I4.0 on enterprises are based on self-assessment mostly in the collection of information via internet surveys or via phone interviews [17].

Table 1 summarizes some relevant models based on a literature survey. The selected models are from academia and from practitioners (associations or providers), describing the type, application purpose, dimensions, application method, stages of maturity, evaluation of the model and related comments.

**Tab. 1 I4.0 Maturity and Readiness Models.**

Model	Industry 4.0 Maturity Model [1]	SIMMI 4.0 [18,19]	Industrie 4.0 Maturity Index from ACATECH (German National Academy of Science and Engineering) [20]	DREAMY – Digital REadiness Assessment MaturitY model [21,22]	PwC – Industry 4.0 – Enabling Digital Operations [23]	The Connected Enterprise Maturity Model [24]
Type / Application Purpose	Maturity / Descriptive	Maturity / Descriptive	Maturity / Descriptive	Readiness / Descriptive and prescriptive	Maturity / Comparative and prescriptive	Maturity / Prescriptive
Dimensions	1) Strategy; 2) Leadership; 3) Customers; 4) Products; 5) Operations; 6) Culture; 7) People; 8) Governance; 9) Technology.	1) Vertical integration; 2) Horizontal integration; 3) Digital product development; 4) Cross-sectional technology criteria	1) Resources; 2) Information systems; 3) Organizational structure; 4) Organizational culture	1) Process; 2) Monitoring & control; 3) Technology; 4) Organization	1) Business Models, Product & Service Portfolio; 2) Market & Customer Access; 3) Value Chains & Processes; 4) IT Architecture; 5) Compliance, Legal, Risk, Security & Tax; 6) Organization & Culture	1) Information infrastructure (hardware and software); 2) controls and devices (sensors, actuators, ..., that feeds and receives data); 3) networks (that move all this information); 4) security policies (understanding, organization, enforcement)
Application Method	Questionnaire integrated into a webpage, self-assessment tool	General questionnaire, third-party assisted	Questionnaire combined with visits	Questionnaire with normative answers	On-line self-assessment tool, available at: <a href="https://i4-0-self-assessment.pwc.nl/i40/landing/">https://i4-0-self-assessment.pwc.nl/i40/landing/</a>	Third-party assisted

**Tab. 1 I4.0 Maturity and Readiness Models (Continuation).**

Model	Industry 4.0 Maturity Model [1]	SIMMI 4.0 [18,19]	Industrie 4.0 Maturity Index from ACATECH (German National Academy of Science and Engineering) [20]	DREAMY – Digital REadiness Assessment MaturitY model [21,22]	PwC – Industry 4.0 – Enabling Digital Operations [23]	The Connected Enterprise Maturity Model [24]
Maturity Stages	(Likert-scale) stages as: 1) Not Distinct to 5) Very Distinct	1) Basic digitization level; 2) Cross-departmental digitization; 3) Horizontal and vertical digitization; 4) Full digitization; 5) Optimized full digitization	1) Computerization; 2) Connectivity; 3) Visibility; 4) Transparency 5) Predictive capability; 6) Adaptability	1) Initial; 2) Managed; 3) Defined; 4) Integrated & interoperable; 5) Digital oriented	1) Digital Novice; 2) Vertical Integrator; 3) Horizontal Collaborator; 4) Digital Champion	1) Assessment (existing OT/ IT network); 2) Secure & upgraded network & controls; 3) Defined & organized working data capital (WDC); 4) Analytics; 5) Collaboration
Model application testing	Two case studies on industrial enterprises and the results of one Austrian manufacturing enterprise are presented. This enterprise was selected because it was already engaged with I4.0 transformation.	Model evaluated in 6 German companies from manufacturing, services, and commerce sectors. These companies have already successfully implemented I4.0 projects.	Example of model application in a German manufacturing company: Harting AG & CO. This company was already engaged with I4.0 requirements through the implementation of I4.0 pilots on their value chain.	Model was applied on 3 case studies (two-day visits) to identify possible actions and to collect empirical evidence about the maturity model. Investigated domain areas were food industry, mechanical engineering industry and electric power industry, respectively.	Case Studies of PwC model application were not found.	Case Study not found

**Tab. 1 I4.0 Maturity and Readiness Models (Continuation).**

Model	Industry 4.0 Maturity Model [1]	SIMMI 4.0 [18,19]	Industrie 4.0 Maturity Index from ACATECH (German National Academy of Science and Engineering) [20]	DREAMY – Digital REadiness Assessment MaturitY model [21,22]	PwC – Industry 4.0 – Enabling Digital Operations [23]	The Connected Enterprise Maturity Model [24]
Comments	<p>Model developed by academia with tailored focus on manufacturing industry with a clear maturity and assessment. In this research, Schumacher et al. [1] stresses the importance on the questionnaire' respondents. In order to better accurate the I4.0 maturity enterprise assessment, it can be made workshops and meetings to leverage the respondents' knowledge of I4.0 concepts. Schumacher et al. [1] do not present any description about the used dimensions and the lack of some relevant information does not allow the holistic evaluation of the model and even its usage. Guidance or a roadmap to progress between the five stages was not found.</p>	<p>Model developed by academia with focus on IT and software perspective. Leyh et al. [18] presented key technological activities to guide companies to reach the higher level of cross-sectional technology. Organizational aspects such as company vision or employees and environmental aspects such as competitors or market structure are not assessed on this maturity model.</p>	<p>Model developed by academia (in a form of autonomous organization, representing the academic and technology interests) with the main focus on IT, also focusing the entire value chain (specific areas). Action plans will be designed and implemented on each specific area to increase growth. Moreover, if a company is mature at all dimensions, it means that the company will have a huge reduction on reaction time to any company incoming disturbs. On the other hand, this model has no specific dimension for product that is one of the I4.0 main requirements.</p>	<p>Model developed by academia with a “as-is scenario”, representing a manufacturing company into five main areas: Design and Engineering, Production department, Quality management, Maintenance management and Logistic management. (De Carolis et al. [22] noted the necessity of benchmark comparison with competitors. Companies really need to know how they stand in regard to competitors' average position.</p>	<p>Model developed by practitioners (multinational professional services network company), focus on simplicity, wide audience, and “digitalization” strategies. This online tool assessment provides comments and short action plans, but no information was found with respect to the dimensions and their creation. This model enables company benchmarking with competitors.</p>	<p>Model developed by practitioners (technology provider company), making technology as the key enabler and the main model context. No information found with respect to the creation of the dimensions. Undefined maturity criteria and assessment tool not found.</p>

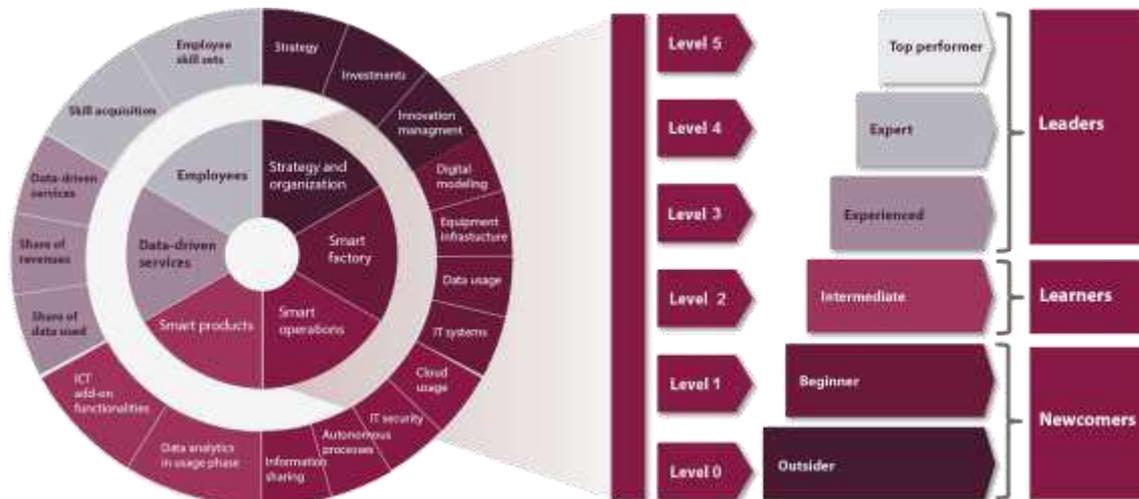
The maturity and readiness models aforementioned are based on the same enabling technologies and concepts of I4.0. All aforementioned models' authors consider the use of enabling technologies as a disruptive change, affecting the companies' competitiveness, and also creating new opportunities with new business models across all value chain of product lifecycle. It's clear in all presented models the concern about the integrity issue, being one of the main aims of the usage of the enabling technologies of I4.0, namely ICT and the operation technologies (OT).

This maturity model research was not restricted to the aforementioned models. Other models were investigated but the lack of information, e.g., scope or measurement criteria do not allow a direct debate on I4.0 modeling.

According to Schumacher et al. [1], the "IMPULS- Industrie 4.0 Readiness" model is based on a comprehensive set of data and details are provided on the dimensions, items and assessment approach that facilitate its implementation, in contrast to the other models presented in Table 1.

One of the reasons for choosing the IMPULS model in this study is due to the fact that Lichtblau et al. [25] demonstrate the validity of the model in the technical report and the fact that this model is a readiness model, that is, presents the level of readiness for the adoption of the I4.0 environment and as Table 1 shows, it's possible to access the online questionnaire which allows a global assessment of the readiness level technology on an organization.

The IMPULS readiness model as six dimensions each one is divided into sub-dimensions, which are operationalized with appropriate indicators to measure the readiness at the level of organizations' I4.0. Figure 3 gives a general idea of how this model is organized.



**Fig. 3 IMPULS Dimensions, Subdimensions and Readiness Levels [25].**

The IMPULS readiness model use six associated readiness levels applied to each dimension and characterized as follows:

- Level 0: Outsider (Newcomers' group) - A company that presents this level demonstrates that it does not meet any of the requirements of I4.0, or that it has marked the concept as unknown or irrelevant;
- Level 1: Beginner (Newcomers' group) - A company that presents this level is involved in I4.0, already taking pilot initiatives in several departments and investments in a single area. Only a few production processes are supported by IT systems. Information sharing in the company, integrated into the central system, is limited to some areas and IT security solutions are still in the planning or implementation phase;
- Level 2: Intermediate (Learners' group) - A company that presents this level already integrates I4.0 in its development strategy, with indicators considered adequate to measure the state of implementation, including with some investments made in this regard. Some of the production data is already collected automatically and used in a limited way. The equipment infrastructure does not meet all the requirements for future expansion. Information sharing is integrated with the central system to a certain extent and solutions are already being implemented to integrate business partners;
- Level 3: Experienced (Leaders' group) - A company that presents this level has already formulated an I4.0 implementation strategy, making investments in several areas, guided by an innovation manage-

ment department. IT systems, including cloud solutions, support production processes, with data collected automatically from the main areas. The equipment's infrastructure is adaptable for future expansions. The sharing of information internally and between business partners is partly integrated into the central system, the necessary IT security solutions have been implemented and cloud-based solutions are planned to accommodate future expansion;

- Level 4: Expert (Leaders' group) - A company that presents this level has already implemented an I4.0 strategy, using indicators considered adequate to monitor its implementation status. There are investments made in all areas considered relevant, and the process is supported by interdepartmental innovation management. Most production processes are supported by IT systems, collecting large amounts of data and using them for process optimization. Expansion is still possible since the equipment is prepared for the integration of other futures. The sharing of information between departments and with business partners is integrated into the central system. IT security solutions are used in areas considered relevant. Workpieces and finished products feature IT-based features that allow data collection and analysis in real time. Data-based services already represent a small amount of the company's revenue;
- Level 5: Top Performer (Leaders' group) - A company that presents this level has already implemented an I4.0 strategy with investments made in all departments. IT systems cover all production and the relevant data is all collected digitally and automatically. IT security solutions are in place and cloud-based solutions offer a flexible IT architecture. Some of the work areas already use Automated Guided Vehicles (AGV) and autonomously reactive processes. Parts and products feature IT-based functionality used for product development, predictive maintenance and sales support. Data-based services for customers represent a significant amount of the company's revenues, with the producer being fully integrated with the customer.

The IMPULS model also includes the allocation of weighting factors for each dimension. These weighting factors were calculated by Lichtblau et al. [25] by asking companies on manufacturing sector to assess the importance of each dimension on I4.0 implementation. From a total of 100 possible points, the weighting factors were assigned as follows:

- Strategy and Organization: 25 %;
- Smart Factory: 14 %;
- Smart Products: 19 %;
- Smart Operations: 10 %;
- Data-driven Services: 14 %;
- Employees: 18 %.

Equation 1 shows how readiness level can be reach for global company score:

$$N = \sum_{i=1}^m \text{Min}(D_i) \times f_i, \quad (1)$$

where  $N$  represents the level of global readiness,  $D_i$  represents the dimension under analysis,  $f_i$  represents the weighting factor for the respective dimension, and  $m$  represents the total number of dimensions.

The IMPULS model is also used by several of the analyzed authors on Table 2, either because of its full implementation, or because it is used as a means of comparison for the development of new models proposed by some of the authors.

**Tab. 2 I4.0 IMPULS Readiness Model Usage.**

<b>Author</b>	<b>IMPUS model usage</b>
Lichtblau et al. [25]	Model creation, development, and application on 232 companies on mechanical engineering and manufacturing industry.
Hamidi et al. [16]	Model application on 250 small and medium-sized companies in the industrial sector in Malaysia.
Maasz & Darwish [26]	Model application on 7 companies on mining sector in South Africa.

### 3. Research Methodology

The present study has as main objective to carry out an evaluation of a company' vertical integration that allows to verify the level of technological readiness related to the I4.0 concept on a quantitative and qualitative matter on three departments of an automotive company. A secondary objective of this study is to contribute to the identification of the used I4.0 enabling technologies on each department, using the IMPULS readiness model questionnaire, which allows a survey of these technologies. Thus, the chosen methodology is a case study since this method allows applicability on a real context.

The head of each department answered to the questionnaire, making it possible to assess the level of I4.0 technological readiness of each department, making a comparative analysis of the obtained results.

Shopfloor visits were made to each department, to the logistics, board-prep and plastic departments, to survey the used processes, as well as the used technologies. During these visits, interviews were carried out with employees who perform tasks on the assembly lines and on the logistics warehouse (operators, maintenance technicians and process engineers), because these employees establish connections with the existing technologies.

Each department was assessed autonomously and according to the IMPULS readiness model levels, allowing to understand on which dimensions there is an opportunity for improvement and if the levels of I4.0 implementation differ between departments. Based on given answers by each of the respondents, it was made the analysis and presentation of results, with the levels' attribution for each dimension and the overall assessment of the department.

#### 3.1. Company Characterization

This anonymous company is a worldwide supplier dedicated exclusively to car cockpit electronics and with the largest product portfolio on this segment. Is uniquely positioned to meet the needs of smart digital cockpit manufacturers for electric and automated vehicles. It is estimated that in 2017 this company had sales in the order of US \$ 3.146 billion and approximately 10 000 employees, on more than forty facilities being present on eighteen countries.

This company is intended to operate on the industrial installations for the assembly, manufacture, manufacture and processing of electronic, electrical and electro-mechanical devices, namely for the manufacture of radios, graphic equalizers and amplifiers for automobiles. There are several departments associated with the company's facilities in Portugal, essential for its business model. On this study, three departments were analyzed in order to assess the level of technological maturity of each one individually, making it possible to draw comparative conclusions from the I4.0 development status. The departments evaluated were logistics, board-prep and plastics.

#### 3.2. Data Collection

Processes were monitored for logistics, board-prep and plastics departments. At this stage, it was possible to verify how it's made the reception of essential products for production, as well as how the production

lines establish communication between departments, for line supply. For a better understanding of the production flow, 26 informal interviews were carried out with employees (technicians, operators, and engineers) who operate on each evaluated department. On logistics department, 18 employees were interviewed, on board-prep department it was 5 employees, 1 maintenance technician and 2 process engineers and on the plastics' department it was 4 employees and 2 process engineers. These interviews allowed to assess not only the way that which employees establish connections with the enabling technologies, but also to collect information on how production processes work.

On the second phase, after 37 direct observations made on the shop floor on each department, their managers were questioned, according to the IMPULS questionnaire. It was possible to individually evaluate each department and quantify the dimensions presented in the IMPULS model based on this collection.

The first respondent is responsible for logistics' warehouse, a professional with more than 11 years of experience on the area and also on the company. The second respondent is responsible for the production line on the board-prep department, graduated with engineering degree with more than 3 years of experience on this company. The last respondent is responsible for the plastics department, with 23 years of professional experience on the area and on this company.

#### 4. Results and Discussion

The first part of the assessment aims to know the knowledge level of each of the respondents related to I4.0 concept. Table 3 allows visualizing the answers given by each respondent, with no quantitative assessment being made in relation to the answers presented.

Logistics presents itself as the department with the highest business volume, since it establishes links with other production departments, supplying these lines. It is possible to observe that the responses of the production departments (board-prep and plastics) are identical and that there is an adaptation to the concept due to market competition. In relation to the logistics department, due to the lack of proximity of the interviewee with the I4.0 concept, the answers are different from other respondents.

The last question on the first part of this assessment is related to I4.0 planned activities, underway or implemented on each department as Table 4 shows.

**Tab. 3 Characterization of departments and familiarity with the i4.0 concept.**

Question	Logistics	Board-prep	Plastics
What is the approximate number of employees on the department?	250 or more employees	250 or more employees	From 50 to 249 employees
What was the turnover in 2018?	Above € 50 million	Between 10 and € 50 million	Between 2 and € 10 million
What is your knowledge about I4.0 concept?	Superficially and I want to know more to assess I4.0 performance on the company	Enough to already have some pilot projects underway	Enough to already have some pilot projects underway
What motivates the department to embrace I4.0 challenges?	The department has an innovative spirit aligned with new concepts experiments	Market requirements and competitive pressure	Market requirements and competitive pressure
Which objectives do you intend to achieve with the adoption of I4.0 concepts?	Increased efficiency of the manufacturing system	Increased efficiency of the manufacturing system	Increased efficiency of the manufacturing system

**Tab. 4 Planned I4.0 Activities.**

Activities	Logistics	Board-prep	Plastics
Digitization of processes with the implementation of information systems	Don't know how to answer	Ongoing	Implemented
Integration between systems and / or machines using IoT	Don't know how to answer	Planned	Implemented
Systems implementation that allows efficient control of processes, products and services and performance analysis in real time	Don't know how to answer	Ongoing	Implemented
Hiring essential technicians for digital transformation	Don't know how to answer	Planned	Not relevant
Conversion of technicians to respond to the digital transformation	Don't know how to answer	Ongoing	Ongoing

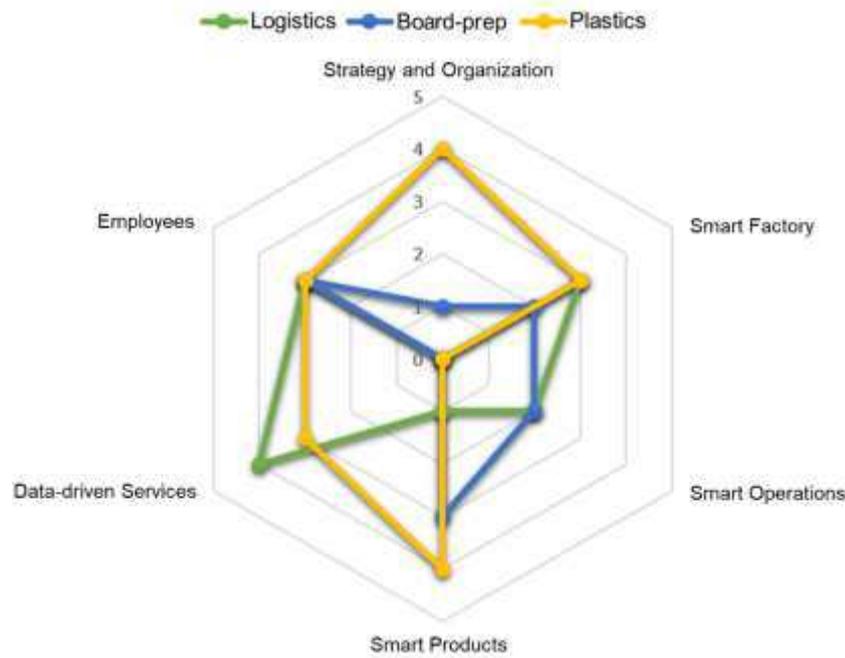
It was not possible to make a qualitative assessment regarding the I4.0 activities on logistics department due to the lack of information that the respondent has about the existence of these activities. The higher level of knowledge revealed on board-prep and plastics departments makes it possible to know that on board-prep department these activities are all ongoing or planned and on plastics department, most of the activities have already been implemented or are in progress and hiring technicians for digital transformation is not relevant for the plastics department.

#### 4.1. Global Assessment

According to IMPULS readiness model on Table 5, plastics department has a greater I4.0 readiness obtaining a score of 3.14 and clearly distancing itself from the other departments. The logistics and board-prep department scores are very similar, being 1.91 and 1.84, respectively. Figure 3 shows the obtained readiness levels from each department under analysis for each IMPULS model dimension.

**Tab. 5 Readiness level of Each Department.**

Activities	Logistics	Board-prep	Plastics
Strategy and Organization	0	1	4
Smart Factory	3	2	3
Smart Operations	2	2	0
Smart Products	1	3	4
Data-driven Services	4	0	3
Employees	3	3	3
$N = \sum_{i=1}^m \text{Min}(D_i) \times f_i$	1.91	1.84	3.14
Overall Evolution	1	1	3



**Fig. 4 Comparison of all Levels on Each Department.**

#### 4.2. Improvement Opportunities

The absence of a defined I4.0 strategy, lack of indicators to monitor the state of implementation and the lack of I4.0 investment, are the main factors that limit a higher final readiness level on the logistics department. Another factor that penalizes the final level on this department is related to the lack of more ICT-based functionalities. Finally, the least significant factor is related to information sharing with customers and suppliers. The I4.0 implementation strategy, the definition of indicators allowing the monitor of the state of I4.0 strategy development needs to be developed and the start of investment to be carried out at the level of I4.0 are activities related to the same dimension (Strategy and Organization) and were classified as readiness level 0.

On board-prep department, the main factor that limits a higher level of readiness, is the lack of services based on data collection and the client's integration, since the other departments already carry out this activity. The absence of indicators to monitor the state of I4.0 strategy implementation is another factor with an opportunity to improve increasing the final readiness level. Finally, the fact that the infrastructure features are poorly adaptable and scalable, also limits a better final assessment, although it is the field that has the least impact on an opportunity for improvement.

On plastics department, the main factor that does not allow a better final evaluation, lies on the fact that the internal information shared between departments is not integrated with the company's central system.

## 5. Conclusions

I4.0 refers on particular to recent technological advances, where its enabling technologies are the basis for the integration of physical objects, smart machines, production lines, logistics and processes, thus creating a smart network. Most of an organization's current IT systems are not integrated with its customers

and suppliers, nor with its internal departments. I4.0 then expects to establish full integration within an organization and also with its business partners.

With the application of maturity and readiness assessment models, it is possible to measure the current state of a company to guide improvement initiatives and to monitor progress towards a future state. On this matter, data were collected on shop floor in order to understand the sequence of operations in each analyzed department, as well as the used enabling technologies.

This research allows to notice that the most limiting fields for a more positive assessment of technological development level on logistics department are related in particular to the absence of an I4.0 implementation strategy with its indicators to monitor the development status of a company' future strategy and investments on that direction. Other less significant, but also important factors are the lack of a more varied range of ICT-based functionalities on the products involved on this department and the information sharing with its business partners.

On board-prep department, the lack of services provision based on data collection, presents itself as the field with the most impact as an opportunity for improvement, added to its integration with customers. The lack of indicators to monitor the state of I4.0 strategy development and the low adaptability of functionalities of the current infrastructures are the other fields where there are also opportunities for improvement.

The best final evaluation is on plastics department where the real opportunity for improvement is related to the integration of the information shared between the department with the central system of the organization.

An important limitation of this study is related to the fact that some responses given by the respondents on each department may not be representative with the current reality, due to lack of information or because they are not relevant to the department in question. This fact leads to an important barrier on the adoption of the I4.0 environment placing the human being at the center of this digital transformation, needing to be I4.0 skilled. This fact leads to an important barrier on the adoption of the I4.0 environment placing the human being at the center of this digital transformation as human been needs to be I4.0 skilled.

## **Ethical Approval**

All surveyed respondents are anonymous and have given their consents to participate on this study under the General Data Protection Regulation (GDPR).

## **Consent to Participate**

All surveyed respondents have agreed on participating and they have understood the aim of the study. All participants have given their consents to use surveyed data on this study on an anonymous manner.

## **Consent to Publish**

The publication of the manuscript is consented by all authors, which include all relevant details of this research such as figures, tables, or all relevant information to be published on The International Journal of Advanced Manufacturing Technology.

## Authors Contributions

Vítor Alcácer designed, coordinate this study, João Rodrigues drafted the manuscript, Helena Carvalho supervised and revised the manuscript, and Virgílio Cruz-Machado supervised the project and the manuscript. All authors read and approved the manuscript.

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## Competing Interests

The authors declare they have no competing interests.

## Availability of data and materials

All datasets and datasheets used to support the discussion and conclusions on this study are available upon request to the corresponding author.

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# Figures

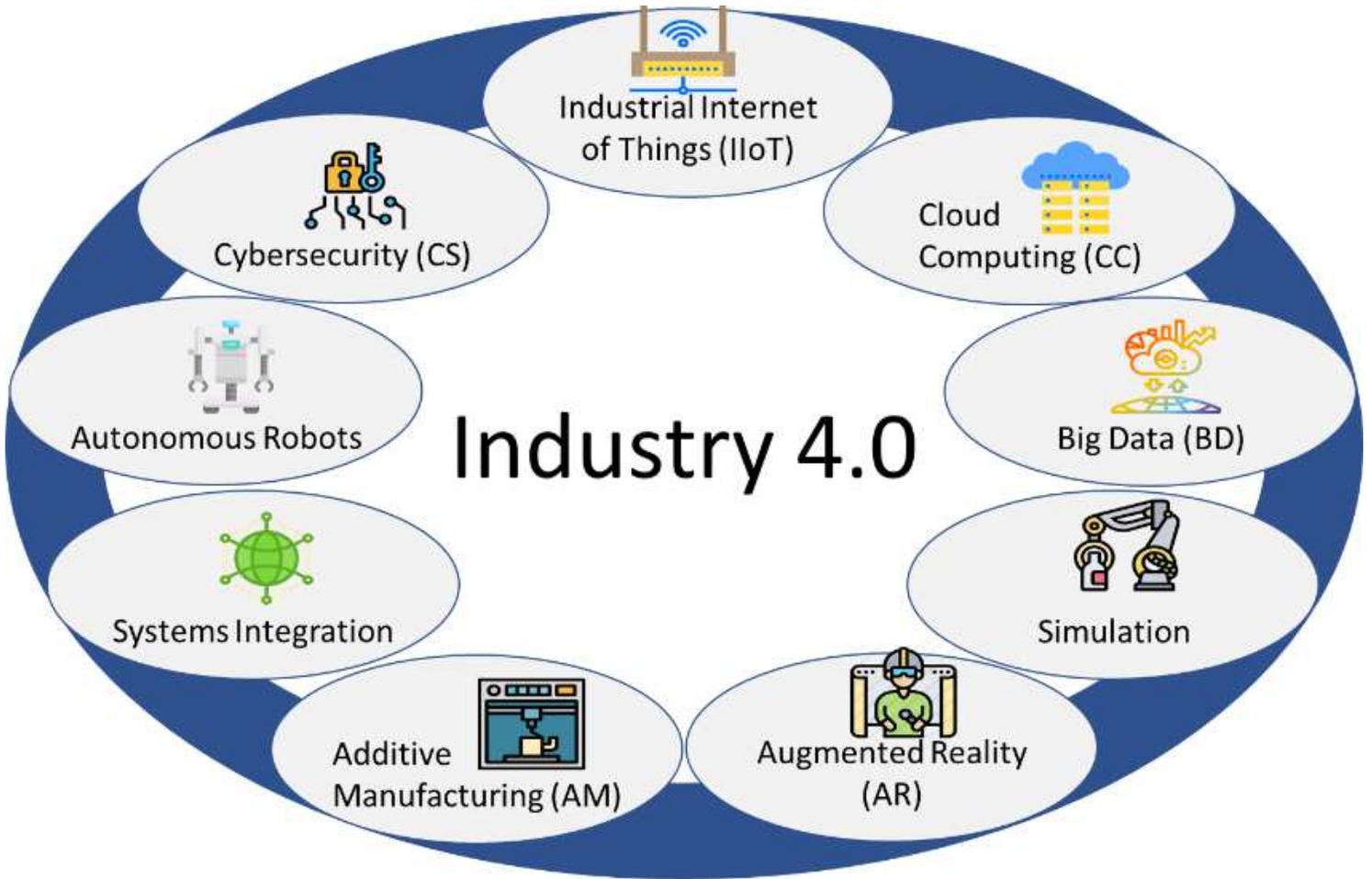


Figure 1

Enabling Technologies of I4.0.

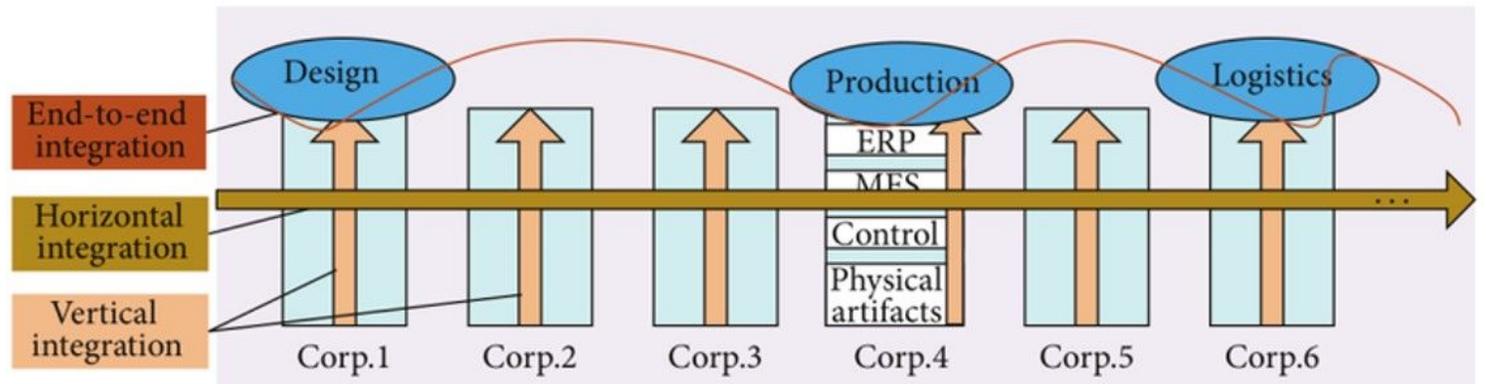
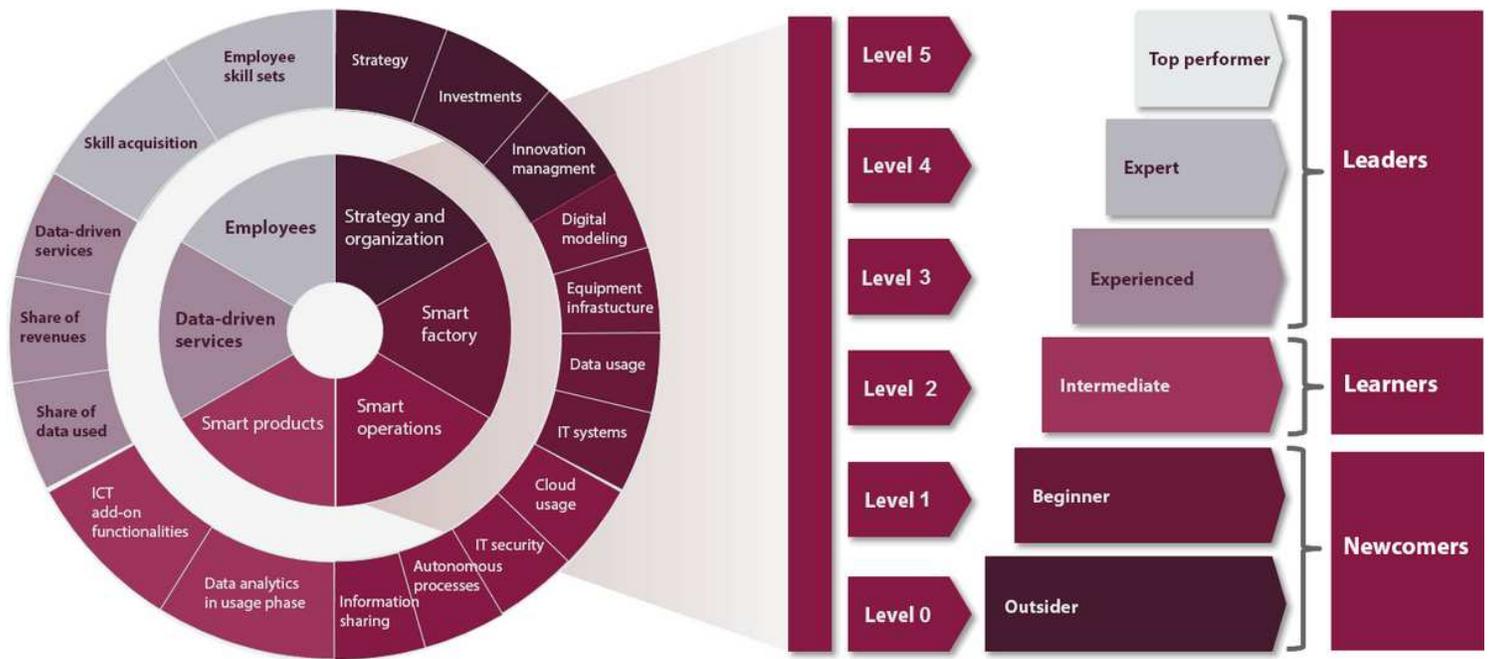


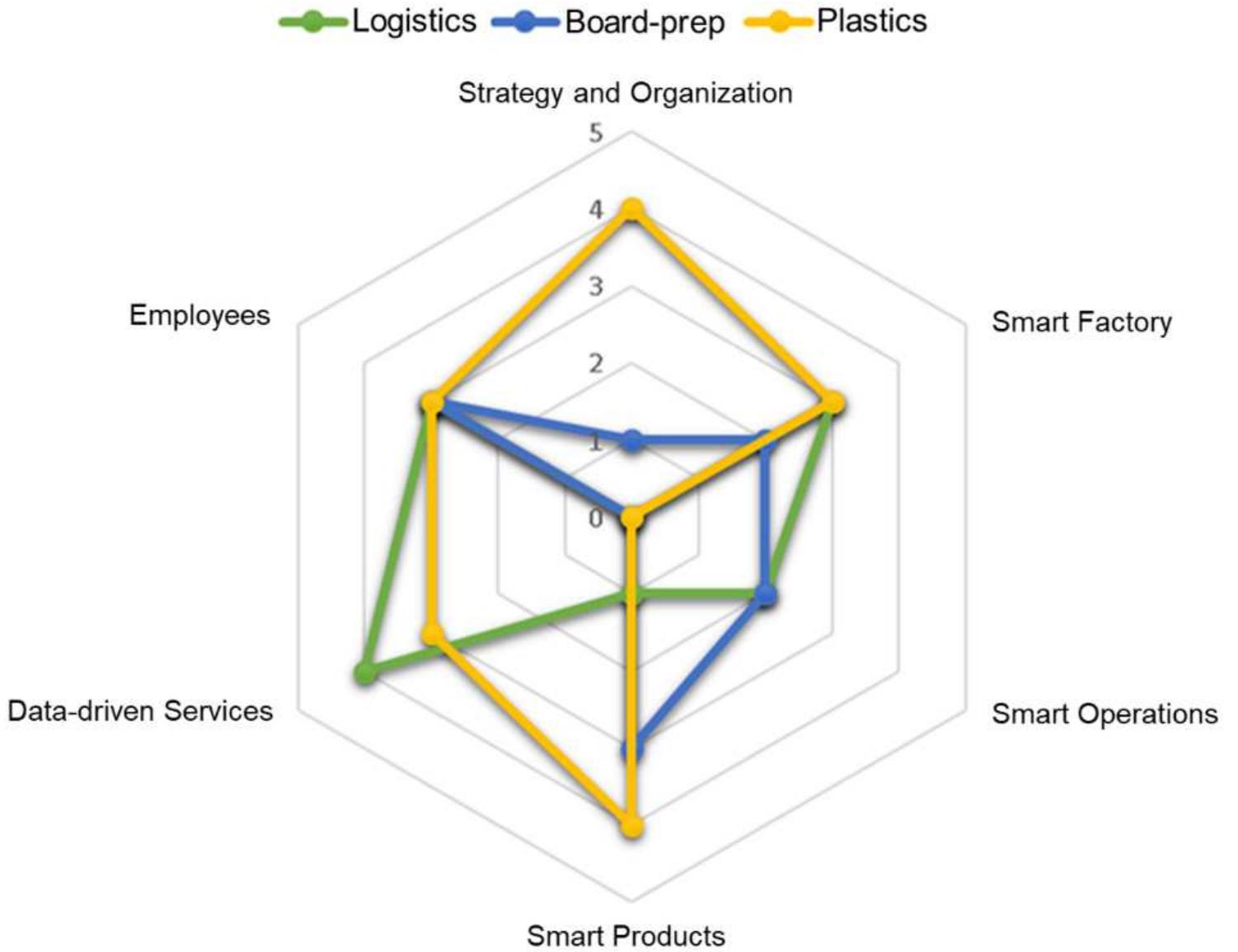
Figure 2

Integration types and their relationships on a manufacturing system [13].



**Figure 3**

IMPULS Dimensions, Subdimensions and Readiness Levels [25].



**Figure 4**

Comparison of all Levels on Each Department.