Application of the Q Method in the implementation of Integrated Information Management Systems in Product Life Cycle Management based on Industry 4.0

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Abstract. From the Integrated Information Management Systems (IIMS) perspective in Product Lifecycle Management (PLM) based on the Industry 4.0 concept, a gap arises in a comprehensive analysis of the interaction on the pillars constituting various contexts. This article aims to study the implementation of IIMS in PLM aligned with the principles of Industry 4.0 against the backdrop of strengthening companies in highly competitive environments. This analysis not only intends to understand each component as an isolated entity but also explore hypotheses and effects that synergistically connect them; the implications and effects that depend on each other were presented and can have a significant role in improving the performance of organisations—increasingly complex environment for the advancement of technology and innovation. The dependency and interdependence relationships between variables will be identified, as well as the effects generated, to validate the preliminary conceptual framework in industrial environments using the Q method and construct validation by Exploratory Factor Analysis (EFA), including Mean Extraction Statistics, Statistical Deviation Error, Statistical Asymmetry and Statistical Kurtosis. The results show the role of implementing Industry 4.0 technologies, that have a positive and significant effect on IIMS, and the effective use of PLM has a positive and significant effect on IIMS. The contribution of this study lies in the clear definition of the interactions between the technologies addressed, representing both a scientific advance and a practical application, providing a guide for decision-making and implementation of technologies in the industry.

Keywords: Integrated Information Management System; Product Life Cycle; Industry 4.0.

1 Introduction

The performance of organizations in a complex scenario of technological advancement and innovation depends on multiple factors that must be connected and in synergy. In the spectrum of integrated information management systems (IIMS), contextualized in product life cycle management (PLM), a gap arises in the analysis of the interaction between the various pillars based on the Industry 4.0 (I4.0) concept. These factors must be addressed together to evaluate the intersection between them, since the synergistic interrelationships between the IIMS, PLM and I4.0 pillars and their technologies impact the market performance of organizations [1].

Interaction analysis can be carried out through the use of established academic techniques, such as the Q method. It is a technique that combines elements of quantitative and qualitative methods to study people's opinions and perspectives on the topics analyzed in the research. This analysis involves evaluating the response patterns of respondents to a given survey.

Among the factors to be addressed in this research is I4.0, which represents the fourth industrial revolution. It is driven by technologies such as the Internet of Things, Automation, Artificial Intelligence and Cloud Computing, considered crucial for the operational efficiency and competitiveness of organizations, directly interfering in improving management. The corporate use of these technologies can directly impact the identification of factors involved in the work process, such as, for example, energy management, in which Industry 4.0 allowed a cloud computing environment for the management of the Energy Cloud [2].

Another factor that is the subject of research, Product Lifecycle Management (PLM) is addressed in its four phases: introduction, growth, maturity and decline. The integration of PLM and IIMS, combined with Big Data analysis, is essential to drive smart and sustainable production [3];[4]. IIMS are fundamental to dealing with the growing complexity of information processing in organizations, being important to guarantee authentication, confidentiality, privacy, provenance and integrity in information systems [5]. The market performance associated with IIMS is explored in terms of productivity, competitiveness and responsiveness [6];[7], being considered as crucial for the sustainability and growth of an organization in the constantly evolving business environment [8].

Within the scope of digital transformation, impacts can be measured to help verify improvements in competitiveness, acting on critical success factors, which are the areas of action where an organization needs to obtain positive results [9]. Measuring competitiveness should be a strategic management tool that monitors and optimizes a company's performance [10];[11]. Using this measure, companies from different sectors can make comparisons and improve their competitiveness by correctly investing their resources, adapting to the market, managing knowledge and integrating new technologies [12]. Still, uncertainties about which I4.0 digital technologies should be adopted in each industrial sector worry managers, making investment in these technologies difficult. Managers need to understand and identify the processes and actors involved in a convergent process to improve the organizational environment [13]. These global uncertainties affect all industrial sectors and are considered barriers to moving forward with I4.0 [14]. Minimizing these uncertainties becomes a necessity to facilitate decision-making for the implementation of technologies in the industry.

This article aims to investigate the effects and interactions of IIMS on PLM, aligned with the principles of I4.0, evaluating the strengthening of companies in highly competitive environments. The study aims to contribute to the understanding of how the efficient integration of these technologies influences the operational efficiency, competitiveness and success of organizations in the market. Observing the proposed correlations and possible emerging patterns, as well as relating them to the research objectives, it was observed that in the first literature review analysis in the Scopus database, there is no interaction between the 4 (four) pillars of IIMS, PLM, I4.0, and the MP of companies. Therefore, this study seeks to fill this gap, exploring the implications of these pillars and technologies on the competitive advantage of companies, adding value to all stakeholders, representing a fertile field for new investigations, and potentially impacting the development of organizations.

This work's main contribution is using the Q method and the validation of constructs by Exploratory Factor Analysis (EFA) to validate the preliminary conceptual framework of dependence and interdependence between variables in industrial environments. A clear definition of the interactions between the technologies covered will be presented, representing both a scientific advance and a practical application, providing a guide for decision-making and implementation of technologies in industry, not only in Brazil but also in a global context.

The remainder of the article is organised as follows: Section 2 will present the development of the hypotheses, Section will detail the methodology, Section 4 will provide the results, Section 5 will present discussions on the results, and Section 6 will inform the results.

2. Development of hypotheses

Within the concept of constructs, which describe the innovative, distinctive characteristics of a phenomenon and its predictive utility [15], the theme of this article involves four constructs and the technologies applied to them, which are:

(i) Industry 4.0 (I4.0), including IOT (Internet of Things), Automation, Cloud Computing (CN) and AI (Artificial Intelligence). The application of IOT to the manufacturing industry and the extensive use of enabling technologies has constituted the fourth phase of industrialization, also known as I4.0 [16]. The implementation of digital production technologies can have a significant impact on the industrial performance of companies, especially when considering aspects such as flexibility, design, delivery and quality performance [17].

(ii) Integrated Information Management Systems (IIMS) covering Authentication, Confidentiality, Privacy, Provenance and Integrity Technologies. There are links established between technologies and collaborative networks such as smart manufacturing, technological platforms, market reactivity, smart products and flexibility, allowing focus on priorities related to the implementation of I4.0 [18].

(iii) Product Life Cycle Management (PLM), with technologies referred to as Growth and Maturity phases. The use of innovative technologies aims to improve the performance and effectiveness of products, especially when associated with improving the quality of the final product, such as speed, cost or quality performance, constituting a trend in the industry segment [19].

(iv) Market Performance (MD), with technologies addressed as Productivity and Responsiveness of Organizations. In a competitive market, companies must be focused on the performance of their products, becoming more receptive to acquiring competitive advantages and improving their productivity [6]

Proposing a conceptual framework that considers these pillars requires a set of informed technologies and integration of several concepts that lead to a global view of the model and its effects, which will be duly explained in the theoretical review.

In this article, these constructs are used to investigate how the performance of IIMS in PLM, based on the concepts of I4.0, has positive or negative effects on MP, as highlighted in the figure of the Preliminary Conceptual Framework proposed in the figure 1.

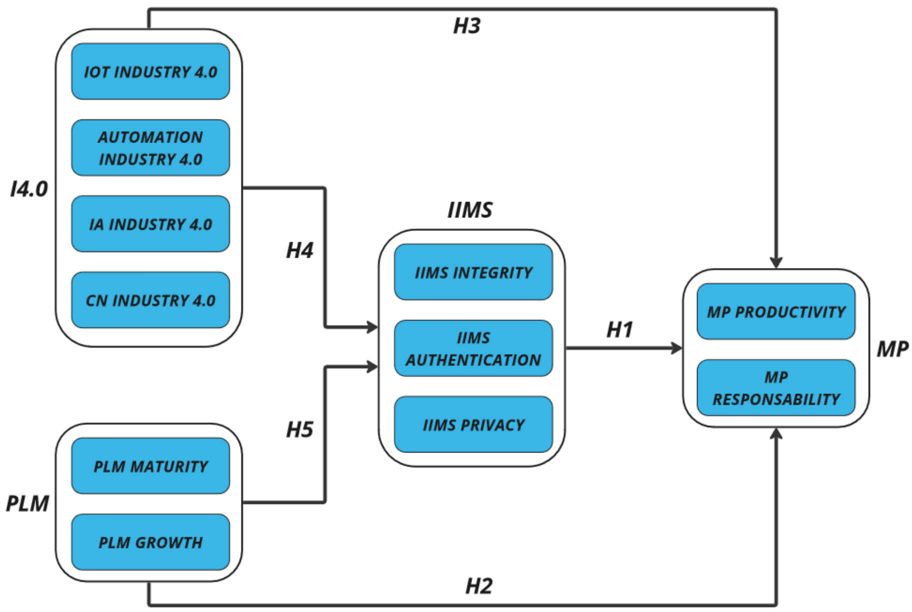

Fig. 1. Preliminary Conceptual Framework.

The research reflects the relationships that must be tested between the specific constructs/technologies of IIMS, PLM, I 4.0 and Market Performance. Each hypothesis must indicate a direct relationship.

a) H1: The effective use of IIMS has a positive and significant effect on the Market Performance of organisations.

b) H2: The effective Application of PLM has a positive and significant impact on the Market Performance of organisations.

c) H3: The successful integration of Industry 4.0 technologies has a positive and significant effect on the Market Performance of organisations.

d) H4: The effective use of I 4.0 positively and significantly affects IIMS.

e) H5: The effective use of PLM has a positive and significant effect on IIMS.

3. Methodology

Qualitative and quantitative approaches were chosen, focusing the quantitative part on applying the "Q" method to analyse correlations and groupings in the data by Exploration Factor Analysis (EFA). Furthermore, the "Q" method is used to verify the Application results.

Secondly, statistical analysis was performed using IBM® SPSS Statistics to discover latent constructs that can explain correlations between many observable variables. Exploratory Factor Analysis (EFA) was applied.

3.1 Main questionnaire survey demographics

A qualitative questionnaire was prepared with 85 questions covering IIMS, PLM, Industry 4.0 technologies and MP, in which 41 professionals participated. Participants are professionals with varied experiences in terms of training and career.

The demographic details of the Respondents involved in this study are presented in Table 1. In total, 31.71% of respondents are Presidents, 26.83% are Directors, 14.63% are managers, 9.76% are supervisors, 7.317% are owners, 2.44% representing a Data Science Consultant, 2.44% representing a Quality engineer, 2.44% representing a human resources employee and 2.44% representing a third-party manager.

This distribution demonstrates the reliability of the responses, with more than 50% of respondents being presidents and directors, indicating that respondents have sufficient experience to provide accurate and informative data for this research. In total, 7.32% of respondents had up to 1 year of employment with the company, 21.95% had up to 3 years, 12.20% had up to 5 years, 19.51% had up to 10 years and 39.02% had more than ten years of employment with the company.

Table 1. Demographic profile

Category	Classification	Frequency	Percentage (%)
Office	Director	11	26,83
	Data Science Consultant	1	2,44
	Owner	3	7,32
	Quality Engineer	1	2,44
	President	13	31,71

	HR	1	2,44
	Supervisor	4	9,76
	Manager	6	14,63
	Third-party manager	1	2,44
Educational background	Elementary/Middle	3	7,32
	Incomplete higher	5	12,19
	Graduated	10	24,39
	Postgraduate	23	56,10
Link with the company	Up to 1 year	3	7,32
	Up to 3 years	9	21,95
	Up to 5 years	5	12,20
	Up to 10 years	8	19,51
	More than 10 years	16	39,02

3.2 Application of the Q method

The Q method was developed to provide a dynamic means of actively expressing subjectivity. Stephenson argued that methods that remove the subject's frame of reference from an investigation (R-methods), such as Likert scales and other devices that seek to measure a person's opinion, are inappropriate for studying subjectivity. The Q method groups and correlates individual responses, using correlation and factor testing to reveal patterns of perceptions or preferences [20];[21].

This research required collecting data about individuals' beliefs and experiences, as they are subjective. Therefore, it was necessary for the information collected to be validated, that is, to faithfully reflect the participants' opinions and minimise the potential for researcher bias that may arise when analysing traditional questionnaires and research methods. The Q method has been identified as suitable for identifying the underlying motivational influences in voluntary communities that are environmentally active and set sustainable development goals and objectives. The Q method is a semi-quantitative discourse analysis technique that aims to find underlying patterns or meanings to explain the perspectives on a given topic [22];[23] and has been used to investigate patterns of opinion among groups of people on many issues.

3.3 EFA Analysis

Exploratory Factor Analysis (EFA) is a statistical technique used to determine the underlying structure of a collection of observed data, employed to discover latent constructs that can explain correlations between many observable variables. EFA seeks to discover a smaller collection of latent variables or underlying factors that explain most of the covariance structure of observable variables. Major [24] and Yang [25] stated that PCA is the primary state of various numerical software programs widely used in EFA. The researcher and data determine the range of factor loadings. Some studies prefer −1 to 1, while others prefer 0 to 1. The type of data affects range selection. A range of −1 to 1 may not be suitable for binary variables or dichotomous.

Cronbach's alpha coefficient normally varies between 0 and 1 [29]. The minimum acceptable value for alpha is 0.70. The Cronbach's alpha of the constructs (Industry 4.0, PLM, Market performance and IIMS) with values respectively 0.962, 0.982, 0.915 and 0.981, all above 0.90. On the other hand, the maximum expected value for alpha is 0.90 since higher values could mean the presence of redundancy or duplication, which could mean that several items measure the same element of a construct [30].

4. Results

This section will present the results of the Exploratory Factor Analysis (EFA), the research's Main Demographic Questionnaire and the Correlation Matrix.

4.1 Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis can also provide commonality: the percentage of variation in each observed variable, which is accounted for by all factors and factor loadings. EFA simplifies complicated observable variables and identifies hidden components. EFA is exploratory, so results should be considered with caution. Confirmatory factor analysis is typically required to validate the factors. In Principal Component Analysis (PCA), the Varimax rotation is more appropriate, being commonly used and preferred among orthogonal rotations, when factors are expected to be independent, maximises the dispersion of loadings within the factors and tries to load a number fewer variables highly in each factor, which results in more interpretable groups of factors [26]. Tables (1, 2, 3 and 4) show the EFA results of IIMS, PLM, Industry 4.0 and MP. Table 2 presents the IIMS EFA results; the variables are grouped into 3 clusters: IIMS INTEGRITY, IIMS AUTHENTICATION, and IIMS PRIVACY.

Table 2. EFA IIMS results.

IIMS Variables	Component		
	1	2	3
IIMS INTEGRITY1	0.658		
IIMS INTEGRITY2	0.590		
IIMS INTEGRITY3	0.682		
IIMS INTEGRITY4	0.711		
IIMS INTEGRITY5	0.725		
IIMS INTEGRITY6	0.838		
IIMS INTEGRITY7	0.807		
IIMS INTEGRITY8	0.525		
IIMS INTEGRITY9	0.877		

IIMS AUTHENTICATION1	0.622	
IIMS AUTHENTICATION2	0.783	
IIMS AUTHENTICATION3	0.725	
IIMS AUTHENTICATION4	0.763	
IIMS AUTHENTICATION5	0.656	
IIMS AUTHENTICATION6	0.623	
IIMS PRIVACY ***1***		0.626
IIMS PRIVACY2		0.609
IIMS PRIVACY3		0.642
IIMS PRIVACY4		0.801
IIMS PRIVACY5		0.763
IIMS PRIVACY6		0.873
IIMS PRIVACY7		0.791
IIMS PRIVACY8		0.617
IIMS PRIVACY9		0.773
IIMS PRIVACY10		0.672

Table 3 presents the PLM EFA results; the variables are grouped into 2 clusters: PLM MATURITY and PLM GROWTH.

Table 3. EFA PLM results.

PLM variables	Component	
	1	2
PLM MATURITY*1*	.771	
PLM MATURITY2	.749	
PLM MATURITY3	.775	
PLM MATURITY4	.824	
PLM MATURITY5	.745	
PLM MATURITY6	.745	
PLM MATURITY7	.657	
PLM MATURITY8	.690	
PLM MATURITY9	.700	
PLM MATURITY10	.732	
PLM MATURITY11	.854	
PLM MATURITY12	.867	
PLM MATURITY13	.793	
PLM MATURITY14	.842	

PLM MATURITY15	.807	
PLM GROWTH1		.772
PLM GROWTH2		.751
PLM GROWTH3		.831
PLM GROWTH4		.812
PLM GROWTH5		.890

Table 4 presents the results of the Industry 4.0 EFA; the variables are grouped into 4 clusters respectively: IOT INDUSTRY4.0, AUTOMATION INDUSTRY4.0, IA INDUSTRY 4.0 It is CN INDUSTRY4.0.

Table 4. EFA Industry 4.0 results.

Variables I. 4.0	Component			
	1	2	3	4
IOT **INDUSTRY4.0** 1	.849			
IOT **INDUSTRY4.0** 2	.800			
IOT **INDUSTRY4.0** 3	.870			
IOT **INDUSTRY4.0** 4	.839			
IOT **INDUSTRY4.0** 5	.819			
IOT **INDUSTRY4.0** 6	.646			
AUTOMATION **INDUSTRY4.0** 1		.735		
AUTOMATION **INDUSTRY4.0** 2		.699		
AUTOMATION **INDUSTRY4.0** 3		.642		
AUTOMATION **INDUSTRY4.0** 4		.659		
AUTOMATION **INDUSTRY4.0** 5		.831		
AI **INDUSTRY4.0** 1			.811	
IA **INDUSTRY4.0** 2			.877	
IA **INDUSTRY4.0** 3			.760	
AI **INDUSTRY4.0** 4			.687	
CN **INDUSTRY4.0** 1				.916
CN **INDUSTRY4.0** 2				.904
CN **INDUSTRY4.0** 3				.896
CN **INDUSTRY4.0** 4				.923
CN **INDUSTRY4.0** 5				.873

Table 5 presents the results of the MP EFA; the variables are grouped into 2 clusters, MP PRODUCTIVITY and MP RESPONSIVITY, respectively.

Table 5. EFA MP results.

MP variables	Component	
	1	2
MP PRODUCTIVITY1	.807	
MP PRODUCTIVITY2	.601	
MP PRODUCTIVITY3	.843	
MP PRODUCTIVITY4	.572	
MP PRODUCTIVITY5	.909	
MP RESPONSIVITY 1		.859
MP RESPONSIVITY 2		.692
MP RESPONSIVITY 3		.817
MP RESPONSIVITY 4		.500
MP RESPONSIVITY 5		.720

4.2 Correlation matrix

Table 6 shows the results of a correlation analysis of respondents' perceptions about whether adopting digital technologies, such as the Integrated Information Management System (IIMS), can affect the market performance of organisations. It is a statistical method used to determine whether a relationship exists between two variables or sets of data, as well as how strong that relationship may be.

The correlation matrix is examined, and it was observed that the significant values of the correlation between the control variable company size matter for the IIMS; the larger the company, the stronger the correlation with the IIMS, presenting values r= 0.400 and r=0.463 with significance level 0.001 and r=0.373 with significance level 0.01, between the control variable company size and the IIMS clusters respectively (**IIMS** INTEGRITY, **IIMS** PRIVACY and **IIMS** AUTHENTICATION), the control variable company size about **PLM** GROWTH and IA **INDUSTRY 4.0** presented values respectively r= 0.348 and r= 0.330 with a significance level of 0.01. The correlation between the clusters about IIMS (**IIMS** INTEGRITY, **IIMS** PRIVACY and **IIMS** AUTHENTICATION) is very strong with values r=0.823, r= 0.815 and r= 0.856 with a significance level of 0.001. A strong correlation was obtained between the IIMS clusters about the PLM clusters (**PLM** MATURITY and **PLM** GROWTH) and the industry 4.0 clusters (IOT **INDUSTRY4.0**, AUTOMATION **INDUSTRY4.0**, IA **INDUSTRY 4.0** It is CN **INDUSTRY4.0**) as can be seen in Table 6.

The correlation between AUTOMATION INDUSTRY4.0 and MP PRODUCTIVITY presented the weakest correlation, r= 0.320, with a significance level of 0.01. The correlation between MP PRODUCTIVITY and MP RESPONSIVITY, with r= .589 with a significance level of 0.001, is the only positive correlation of the P MP PRODUCTIVITY cluster. However, the market performance (MP) clusters (MP PRODUCTIVITY and MP RESPONSIVITY) showed the weakest correlation among the other clusters.

Table 6. Correlation matrix

	Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	**CONTROL**												
2	**IIMS** Integrity	.400 **											
3	**IIMS** Authentication	.373 *	.823 **										
4	**IIMS** Privacy	.463 **	.815 **	.856 **									
5	**PLM** *Maturity*	.246	.651 **	.689**	.665 **								
6	**PLM *Growth***	.348 *	.603 **	.656 **	.625 **	.892 **							
7	IoT **INDUSTRY4.0**	.210	.522 **	.435 **	.440 **	.714 **	.700 **						
8	Automation **INDUSTRY4.0**	.302	.620 **	.634 **	.539 **	.659 **	.725 **	.775 **					
9	Ia **INDUSTRY 4.0**	.330 *	.465 **	.368 *	.445 **	.535 **	.583 **	.681 **	.713 **				
10	Cn **INDUSTRY4.0**	.275	.675 **	.617 **	.653 **	.673 **	.576 **	.495 **	.471 **	.348 *			
11	**MP** Productivity	.279	.279	.285	.230	.250	.256	.161	.320 *	.062	.273		
12	**MP Responsibility**	.170	.136	.089	.181	.194	.155	.152	.144	.169	.154	.589 **	
	Average Est.	.290	1.680	1.817	1.637	1.415	1.420	1.411	1.507	1.390	2.117	.704	.737
	Est deviation error	.461	1.291	1.362	1.284	1.204	1.211	1.352	1.388	1.326	1.539	.380	.370
	Est Asymmetry	.946	.207	.157	.227	.395	.365	.433	.378	.490	-.165	-.965	-1.052
	Kurtosis Est.	-1.164	-1.236	-1.334	-1.191	-.982	-1.011	-1.308	-1.348	-1.336	-1.487	-.681	-.558

5. Discussion

This research was conducted on an overarching topic, particularly bibliometric analysis, literature review, research data, and EFA. The structural model metric R^2 explains the endogenous constructs (Market performance and IIMS). Values around 0.75, 0.50 and 0.25 represent substantial, moderate and weak effect sizes, respectively [27]. Considering its explanation is weak, the performance construct, which is an endogenous construct, has an R-squared value below 0.25, being 0.138. The IIMS construct is also endogenous, considering its explanation is moderate, with an R-squared value of 0.577. The greater the difference in R^2, the more influential the construct.

The concurrent validity model metric is established when the items of a given measure converge to represent the underlying construct. The average variance extracted (AVE) is calculated as the average of the squared loadings of each indicator associated with a construct. Statistically, convergent validity is established when the Average Variance Extracted (AVE) is >0.50 [28]. The AVE of the constructs (Industry 4.0, PLM, Market performance and IIMS) with values 0.582, 0.734, 0.505 and 0.686, respectively, are higher than 0.50.

Model metric f^2, the explanatory power of exogenous constructs that explain the effect size f^2 is the impact that one latent construct produces on another, calculated by running the SEM-PLS algorithm twice, once with all constructs and then again omitting the constructs one by one. Values around 0.35, 0.15 and 0.02 represent large, medium and small effect sizes, respectively [31].

The industry 4.0 construct, which is an exogenous construct, considering the effect size (0.024) of its explanation about the Market Performance construct, is small, with a value of around 0.02, invalidating hypothesis H3. Industry 4.0, considering the effect size (0.110) of its explanation about the IIMS construct, is medium, with a value close to 0.15, validating hypothesis H4. PLM is an exogenous construct, considering the effect size of 0.002 of its explanation about the Market Performance constructs is small, invalidating hypothesis H2. Considering the effect size of 0.146 of its explanation about the IIMS construct, the PLM is average, with a value close to 0.15, validating hypothesis H5. The IIMS construct, which is an endogenous construct, considering the effect size (0.002) of its explanation about the Market Performance construct, is small, with a value below 0.02, invalidating hypothesis H1.

Hypothesis H1 proposes that the effective use of IIMS has a positive and significant effect on the market performance of organisations. The result obtained from H2, which statistically did not support the hypothesis, goes against the findings of Lemos [32], who present that integrated management systems bring benefits to the company as they optimise the management process, reduce operational costs, allow improvements in access to information, speed in decision making, security in controls, increased productivity and management efficiency, early decision-making and improvement of economic, financial and operational results.

Hypotheses H4 and H5 were the only ones supported and validated by the model, which respectively state that the effective use of I 4.0 has a positive and significant effect on IIMS and the effective use of PLM has a positive and significant effect on IIMS, demonstrating the great influence of IIMS in the model. These findings were supported by research by Sassanelli [33], demonstrating how integrating I4.0 technologies can enhance product development strategies and product lifecycle management. We have observed that companies focusing on acquiring I4.0 capabilities, such as advanced technologies and applications, can better navigate all stages of the PDP, including pre-development, development, and post-development. Hypothesis H5 is in line with the thinking of Arnold [34] and the observation of Abramovici [35] that, based on his research, PLM is the optimised configuration of processes, especially the product development process, and management of all product information throughout its life cycle. Updated information can be accessed directly by all authorised people at any time. This makes it possible, for example, to reduce the time needed to develop new products at lower costs.

Hypothesis H2 proposes that the effective Application of PLM has a positive and significant effect on the Market Performance of organisations. The result obtained from H2, which statistically did not support the hypothesis, goes against the findings of Feldhusen and Gebhardt [36], who present that PLM aims mainly to increase productivity and improve the effectiveness of business processes related to planning, development, manufacturing, maintenance and withdrawal of products from the market. To achieve these objectives, PLM includes methods and tools to increase the integration of processes, information and people involved throughout all life cycle stages, from the initial idea to the final disposition of products after use.

Hypothesis H3 proposes that integrating Industry 4.0 technologies has a positive and significant effect on the Market Performance of organisations. The result obtained from H3, which statistically did not support the hypothesis, goes against the findings of Schuh [37], which presents the Application of industry 4.0 technologies that enable intelligent operations, including the exchange of information in real-time between production systems and operators. With this, it is possible to obtain quality gains and increased productivity, providing robustness, autonomy, self-organisation, self-maintenance, transparency, predictability, efficiency, interoperability, and traceability, which are some of the benefits of Industry 4.0.

6. Conclusion

This research seeks to fill gaps identified in the literature and, at the same time, meet the objectives outlined. By formulating hypotheses that explore the relationships between IIMS, Industry 4.0, PLM and market performance, the aim is to expand existing knowledge and provide valuable insights for strategic decision-making at the business level. Critical analysis of these interconnected variables has the potential to shed light on emerging opportunities and challenges, culminating in tangible benefits for organisations engaged in the pursuit of excellence and innovation in the current scenario. Following the advancement of industrial computerisation within factories, the combination of Internet technologies and intelligent production appears to result in a new paradigm shift in industrial production.

This paper has entered this discussion, and we can now summarise the key lessons learned and contributions to research and practice. This article presented the Application of the Q method and an analysis of correlations and groupings in the data. The dependency and interdependence relationships between variables will be identified, as well as the effects generated, to validate the preliminary conceptual framework in industrial environments using the Q method and construct validation by Exploratory Factor Analysis (EFA), including Mean Extraction Statistics, Statistical Deviation Error, Statistical Asymmetry and Statistical Kurtosis, average variance extracted (AVE), R^2, f^2 and Cronbach's alpha coefficient.

Industry 4.0 has established a very weak correlation with market Performance. Industry 4.0 has a strong correction with the IIMS, presenting values above 0.5. But IIMS integrity has established a weak correlation across almost all Industry 4.0 technologies.

PLM established a very weak correlation with market Performance. PLM has a strong relationship with IIMS, but a weak correlation was observed between IIMS integrity about the plm maturity phase. However, PLM has a very strong correlation with Industry 4.0, presenting values close to 1 between Iot and PLM´s maturity and PLM's growth phases. The same scenario of very strong correlation is repeated with other industry 4.0 technologies (automation and artificial intelligence) about the PLM growth and also the PLM maturity phases.

IIMS does not correlate with market Performance or has a very weak correction. The company's MP presents a weak correlation in the matrix concerning almost all clusters, indicating improvement and investments in other areas of the scenario To improve its Performance. It presents a single average correlation between the cluster and automation.

Information sharing between the parties involved improves interaction, sharing speed and error detection, which was observed as one of the main gaps in the companies investigated. Integrating SGII with PLM from the initial design and design phase reduces manufacturing errors, resulting in cost savings. The lack of investment and knowledge about the SGII was a very relevant factor, justifying the weak correlations between some research clusters. Integrating technologies such as the Internet of Things, Automation, Artificial Intelligence and Cloud Computing allow the generation and sharing of information in real-time, which does not represent the current scenario of companies.

Based on data analysis, the results obtained highlighted significant discoveries, identified correlations and possible emerging patterns. Hypotheses H4 and H5 were supported by the model, which discusses the role of implementing Industry 4.0 technologies that have a positive and significant effect on IIMS and the effective use of PLM has a positive and significant effect on IIMS; these effects were proven and compared with other researchers' results, which agrees with their objectives and thoughts.

The reasons for this study stem from the observation of companies' growing demands for solutions that optimise information management in an increasingly digital environment, combined with the desire to deepen the understanding of the mechanisms that link information management, PLM, I4.0 and market performance; this article had as its central objective the search for validation of the hypotheses. Only hypotheses H4 and H5 were supported and validated by the model.

However, it is also worth highlighting that there is a need to mature and improve the tested scale since the reliability of Cronbach's alpha coefficient was not satisfactory to what is suggested by the literature for the constructs, presenting values higher than 0.90, which may mean the presence of redundancy or duplication. It is possible to observe that the constructs present similar points for measuring each one. Future research can develop the same and adopt it.

Finally, another limitation was the number of respondents obtained to develop this research; the total of 41 respondents was below what Bentler and Chou [38] proposed, who stated that the minimum number of elements that make up the sample must be between 100 and 150. For future research, an expansion of the respondent database and a possible sample segmentation is suggested, analysing different segments, sectors and company sizes to revalidate the tested model.

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(b) except where stated otherwise in this Agreement, any claim which either Party may have against the other for damages or otherwise in respect of any rights or liabilities arising prior to the date of termination;
(c) the Publisher's right to continue to sell any copies of the Work which are in its power, possession or control as at the date of expiry or termination of this Agreement for a period of six months on a non-exclusive basis.

12. General Provisions

12.1 This Agreement, and the documents referred to within it, constitute the entire agreement between the Parties with respect to the subject matter hereof and supersede any previous agreements, warranties, representations, undertakings or understandings. Each Party acknowledges that it is not relying on, and shall have no remedies in respect of, any undertakings, representations, warranties, promises or assurances that are not set forth in this Agreement. Nothing in this Agreement shall exclude any liability for or remedy in respect of fraud, including fraudulent misrepresentation. This Agreement may be modified or amended only by agreement of the Parties in writing. For the purposes of modifying or amending this Agreement, "in writing" requires either a written document signed by both the Parties or an electronic confirmation by both the Parties with DocuSign or a similar e-signature solution. Any notice of termination and/or reversion and, where applicable, any preceding notices (including any requesting remediable action under the Clause "**Termination**") must be provided in writing and delivered by post, courier or personal delivery addressed to the physical address of the relevant Party as set out at the beginning of this Agreement or any replacement address notified to the other Party for this purpose. All such notices shall become effective upon receipt by the other Party. Receipt is deemed to have taken place five working days after the respective notice was sent by post or left at the address by courier or personal delivery. If the Publisher is the terminating Party the notice need only be provided to the address of the Corresponding Author. If the Author is the terminating Party a copy of the notice must also be sent to the Publisher's Legal Department located at Heidelberger Platz 3, 14197 Berlin, Germany.

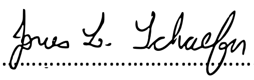
12.2 Nothing contained in this Agreement shall constitute or shall be construed as constituting a partnership, joint venture or contract of employment between the Publisher and the Author. No Party may assign this Agreement to third parties but the Publisher may assign this Agreement or the rights received hereunder to its affiliated companies. In this Agreement, any words following the terms "include", "including", "in particular", "for example", "e.g." or any similar expression shall be construed as illustrative and shall not limit the sense of the words preceding those terms.

12.3 If any difference shall arise between the Author and the Publisher concerning the meaning of this Agreement or the rights and liabilities of the Parties, the Parties shall engage in good faith discussions to attempt to seek a mutually satisfactory resolution of the dispute. This Agreement shall be governed by, and shall be construed in accordance with, the laws of Switzerland. The courts of Cham, Switzerland shall have the exclusive jurisdiction.

12.4 A person who is not a party to this Agreement (other than an affiliate of the Publisher) has no right to enforce any terms or conditions of this Agreement. This Agreement shall be binding upon and inure to the benefit of the successors and assigns of the Publisher. If one or more provisions of this Agreement are held to be unenforceable (in whole or in part) under applicable law, each such provision shall be deemed excluded from this Agreement and the balance of the Agreement shall remain valid and enforceable but shall be interpreted as if that provision were so excluded. If one or more provisions are so excluded under this Clause then the Parties shall negotiate in good faith to agree an enforceable replacement provision that, to the greatest extent possible under applicable law, achieves the Parties' original commercial intention.

The Corresponding Author signs this Agreement on behalf of any and all co-authors.

Signature of Corresponding Author:



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Jones Luís Schaefer

[Name of Author]

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SPRINGER NATURE

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