Smart Industrial Products' Role in achieving Cross-functional Integration: Information Processing Theory Lens for an unified framework

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Abstract. Currently, Smart Industrial Products and their embedded technologies are driving unprecedented efficiency and organisational sustainability. This study aims to provide a unified framework for seamless SIPs adoption, employing a mixed-method approach comprising a Systematic Literature Review, Expert Interviews, and Interpretive Structural Modelling. The results identify barriers, capabilities and, through ISM, illuminate Cross-Functional Integration facilitated by inter-functional synergy. The discussion offers insights into a unified framework for SIPs adoption, contributing to Information Processing Theory by providing an unified framework that helps to understand the cognitive process involved in Cross-Functional Integration. Overall, the proposed framework is a strategic tool for managers to enhance SIPs' autonomy efficiently.

Keywords: Cross-Functional Integration, Information Processing Theory, Smart Industrial Products.

1 Introduction

The increasing digitisation and automation of industrial processes have propelled a never-seen significant transformation in production environments. In this context, Smart Industrial Products (SIPs) pave the way for improving organisational efficiency and innovation. However, their effective and seamless integration into industrial operations requires a deep understanding of the complex process involving the evolutionary behavioural features of SIPs, that go from a completely dependent to a fully autonomous resource. This deep understanding should include comprehension of the challenges, especially concerning CFI. According to [1], divisional organisational structures can also create uncertainties within a firm, and the increase in the amount of information creates a myriad of opportunities for equivocality [2].

In this regard, organisations can either reduce the necessity for information processing (via the creation of slack resources, butters, and self-contained tasks) or increase the capacity to process information (via investment in vertical information systems and the creation of lateral relations) [3], which include SIPs adoption, given its embedded information processing systems. From their initial conception to the most advanced versions today, SIPs have evolved exponentially, incorporating technologies such as IoT, AI, and advanced data analytics [4]. These intelligent resources not only collect and process relevant information but also dynamically interact with the production environment, enabling agile and adaptive responses to market demands and operational conditions.

Therefore, different departments and organisational units often operate in isolation, resulting in information silos and difficulties in communication and collaboration between teams. Furthermore, the lack of a unified framework for SIP adoption can further hinder the effective integration of these technologies into industrial operations.

This paper aims to explore the role of SIPs in enabling CFI, using the theoretical lens of Information Processing Theory (IPT) to provide an unified framework for efficient SIPs' adoption in industrial organisations.

IPT provides a robust conceptual explanation for understanding how CFI is shaped through SIPs capacity of process, store, and utilise information to make decisions and perform tasks. By applying IPT to the context of SIPs, we can elucidate the cognitive processes involved in inter-functional integration, identifying effective strategies to maximise the potential of these technologies in the industrial environment.

This article seeks to investigate the role of SIPs in enabling CFI, in light of IPT by analysing the evolutional path SIPs should follow to amplify its decisional autonomy, mitigating structural barriers faced by organisations in each phase of the SIPs implementation. Additionally, it seeks to develop a unified framework to guide the effective adoption and implementation of SIPs in industrial organisations, promoting seamless integration between different functions and departments.

To meet the proposed objective, this research uses a theoretical conceptual analysis of the proposed frameworks in literature to unify. The remainder of this article is organised as follows: Section 2 briefly reviews relevant literature on SIPs, CFI, and IPT in an integrated way. Section 3 presents the methodological aspects of our research. Section 4 shows the unified framework. Section 5 discusses the proposed model in the light of IPT. Finally, Section 6 shed light in the theoretical and practical implications as well as the limitations, proposing future research directions.

2 Theoretical Background

In this section, we conceptualise the main constructs addressed in this research in an integrated manner. Thus, we present the interface between SIPs, IPT, and CFI to characterise our study. These conceptualisations provide theoretical underpinnings to further discuss the role of SIPs in addressing CFI using IPT as a theoretical lens, thus supporting our explanations of the theoretical framework.

2.1 Information Processing Theory, Cross-Functional Integration, and Smart Industrial Products: An Integrated Approach

If on one hand IPT states that organisations are viewed as entities that seek constantly maximise value in decision-making through gathering, interpreting and synthesising information [5], on the other hand, these same organisations are composed of people. In other words, they are social systems, governed by bounded rationality [6]. In this context, according to [3], when the amount of information surpasses the human capacity to treat them, it is necessary to develop mechanisms to reduce the amount of information or improve the capacity to process it. In this context, the adoption of SIPs may improve the organisation's capacity to deal with a high amount of information in real-time through its embedded systems and use of integrated disruptive technologies such as Big Data, Analytics, Digital Twin, Cloud Computing, and other technologies.

[7] defines SIPs as "products containing elements of the physical, connected, and smart dimensions, responsible for integrating physical and digital parts. These products should have embedded systems that allow smartness to recognise, analyse, and autonomously exchange data regarding the customer, the goods being produced, the process, and the environment in an integrated and real-time way. Further, SIPs should offer innovative integrated services through the self-improvement of its configuration to provide the best possible performance and maximise value for the organisation. The structured adoption of SIPs may reduce issues related with bounded rationality, however, there is a structural relationship hierarchy that reshapes CFI. The comprehension of these mechanisms is essential to empower the SIPs' potential, maximizing value for organisations.

Regarding CFI, it provides mechanisms to afford efficiencies through greater immediacy and breadth of information processing, while preserving some degree of departmental specialisation and autonomy [8]. Besides, CFI is also called inter-functional, interdepartmental intra-organisational or even internal integration [9], being conceptualised by the same authors as an ongoing process of collaboration, coordination and communication, in which the different internal functions that manage a company's supply chain work together to maximise outcomes for their firm and external exchange partners. By shedding light in these three constructs we can evaluate the SIPs' role in shaping CFI through IPT.

3 Research Methodology

This section details the steps followed to meet the research objective. We used as base a mix-method study composed of Systematic Literature Review (SLR), previously performed by [7] and [10]. Experts Interview, Interpretive Structural Modelling (ISM) approach applied to capabilities provided to SIPs for the main organisational functions. In sequence, through content analysis, we classify barriers according to the evolution stage of the SIPs, from a traditional product to a completely autonomous one. Furthermore, through content analysis, we integrate barriers to propose a final unified framework for SIPs' adoption in industrial organisations.

3.1 Capabilities and Barriers provided for the main organisational functions

Table 1 presents the capabilities provided by SIPs for organisational functions. Table 2 presents structural barriers faced by organisations to adopt SIPs. These data were raised up during the first two phases of this research, being adapted from [7] and [10].

3.2 ISM applied to Capabilities to identify CFI

In this second phase, after raising and validating the barriers and capabilities identified in literature through a SLR, we apply ISM to identify how CFI is shaped through SIPs adoption.

To perform ISM, we asked the experts to follow 4 steps according to [11]. So, we calculated the "mode" for the 16 matrices previously filled by academic and practical experts. Then, we calculated the Initial and Final Reachability Matrix (FRM) by substituting V and A by "1" and X and O by "0" Table 4. In sequence, Table 5 applies the transitivity property (If *i* influences *j* and *j* influences *k*, then *i* influences *k*). In the following, to perform level partitions we built a sheet with 4 columns: Reachability, Antecedents, Intersection and Level. In the first column, we write the position of the numbers "1" rows of the FRM. In the second column, we repeat the process of inserting the position of the numbers "1" in the columns of the FRM. In the third column, we insert the number that repeat in both columns. To determine the level we compare the first two columns, filling the third with the numbers that repeat in both columns. Finally, we take all variables where column 1 and 3 shows the same numbers and consider that these variables are of first level. After that, we exclude this variable from the system and repeat the process for the remaining variables until all variables are eliminated. The results of these steps are shown in Section 4.

3.3 Integrating Barriers

After identifying the barriers we use the Software NVivo 13 to perform a content analysis to classify the identified barriers according to the moment of adoption each one of them impacts. The results are in the third column of the table 2.

3.4 An unified framework for SIPs adoption

In this step, after identifying the synergy between organisational functions through SIPs capabilities, we adapted the framework proposed by [12] to consider the impact of the barriers in the levels of the CFI.

4 Results

This section presents the results of this research. Section 4.1 presents the matrices obtained through the ISM approach. Section 4.2 presents the configuration of the barriers and 4.3 shows the proposal of an unified framework for efficient SIPs adoption.

4.1 ISM Results

In this section, Tables 3 to 6 detail the steps described in Section 3.2. In sequence, Figure 1 shows the Cross-Functional Synergy between the main organisational functions.

4.2 Configuration of the Structural Barriers to SIPs adoption

In this section, we adapted the framework developed by [12] to describe the cumulative complexities of the structural barriers faced by organisations to implement SIPs. The model is presented in Figure 2.

4.3 Unified framework for efficient SIPs adoption by industrial organisations

This section proposes an unified framework that seeks to enable efficient SIPs adoption by industrial organisations. The proposed model is presented in Figure 3.

5 Discussion

This section discusses the framework, highlighting how CFI is shaped at each of the three different levels of SIPs' autonomy (e.g. connectivity, transparent, and autonomous decision-making), as well as the configurational aspects involving barriers and the capabilities enabled for each functional integration when organisations overcome barriers related to each level. The discussion sheds light on the main aspects of IPT to support the framework explanations.

5.1 CFI in initial implementation stage: The connectivity level

Analysing our framework, during the implementation stage, organisations encounter certain structural barriers. By overcoming these barriers, organisations elevate their traditional products to the status of connected products. At this initial level, organisations should invest in enhancing the CFI between Production Planning and Control (PPC) and Maintenance (e.g. from PPC 1 to MA 3), where the integration of sensing technologies into passive RFID tags enables the Maintenance function to collect and carry information about its life cycle.

Although there is no synergy between two identical functions, by improving the autonomy level, this function enables new capabilities. For example, PPC, by transitioning from traditional to connected levels, enables PPC 1.

By enhancing connectivity capabilities, (SIPs) enable capabilities such as PPC 2 and PPC 9. Even though the synergy is perceived as unidirectional, transitioning from connectivity to transparent levels enables synergy not only between PPC and Maintenance but also between Maintenance and PPC. This synergy demonstrates that PPC and Maintenance are the most important functions, serving as drivers for other functions and more complex synergies.

Moreover, at this initial level, organisations should invest in enhancing the CFI between PPC and Maintenance (e.g. from PPC 1 to MA 3), where the integration of sensing technologies into passive RFID tags enables the Maintenance function to collect and carry information about its life cycle. By enhancing connectivity capabilities, (SIPs) enable capabilities such as PPC 2 and PPC 9.

Table 1. Capabilities provided for SIPs for the main organisational functions

Capabilities	Function
Improved efficiency in terms of asset investment	ACC
The process becomes more sustainable.	SUS
Improvement in maintenance accuracy, including preventive and prescriptive by viewing, drawing, and designing data	MA1
Remote repair services	MA2
Collecting and carrying information about itself during its lifecycle	MA3
Integration of sensing technologies into passive RFID tags	PPC1
Interoperability among various autonomous intelligent resources inside/outside the organisation	PPC2
Automatic reconfiguration of the SIP/ production line	PPC3
Dynamic reconfiguring of the team's resources within the production process	PPC4
Complete integration physical, cyber, and social environments with a high autonomy level, improving the performance of organisational information systems	PPC5
Remote process control	PPC6
Self-performance optimisation through the reuse of experiences to enhance its decisional performance	PPC7
Machines linking together in systems	PPC8
Data collection capability is improved	PPC9
More robust and flexible production systems	PPC10
Better complexity management of the combined offer of products and services within and between organisational units	PPC11
Increased visibility of ongoing operations	PPC12
High-value aggregation	QM1
Ongoing quality management	QM2
High process security	QM3

Source: Adapted from [7]

Table 2. Barriers faced by organisational to adopt SIPs

Barriers	Moment
Social, psychological, and cultural individualistic behaviour barriers	Before
Lack of technological maturity	Before
Cost strategy is not adherent to innovative SIP solutions	Before
Lack of adequate computational resources	Before
Full adoption difficulties and lack of system stability (operational practicality and decision execution)	Before
Lack of technical and economic feasibility in the early stage of utilisation	Before
Lack of infrastructure, including and/or network latency, in some regions of the country where industries are based	Before
Uncertainty about ROI, payback, high costs and investments to (internally) develop a SIP	Before
Contractual and revenue-sharing challenges	During
Vulnerability in data security	During
Complicated system introduction or even its affinity with already existing business systems	During
Difficulties in aligning old industrial technologies with the implementation of a new SIP	During
Self-adaptation difficulties among the SIP and its environment (plug-and-play technologies)	During
Communication difficulties	During
Tracking technology remains a challenge transforming several operational information into accurate/timely control decisions	Post
Decreased planning efficiency when control is decentralised	Post
Difficulties in integrating many different SIP	Post
High energy consumption	Post
Risk of bad event propagation	Post
High complexity of management	Post
Lack of security and trust in using data	Post
High complexity of system management due to the increase in the number of agents used	Post
Cyber-attack vulnerability	Post

Source. Adapted from [10]

Table 3. Final Structural Self-Interaction Matrix (MODE)

MODE	QM3	QM2	QM1	PPC12	PPC11	PPC10	PPC9	PPC8	PPC7	PPC6	PPC5	PPC4	PPC3	PPC2	PPC1	MA3	MA2	MA1	SUS	ACC
ACC	X	A	V	A	A	A	A	A	A	V	A	O	A	A	A	A	O	A	O	
SUS	A	A	A	A	A	A	A	A	A	A	A	A	A	O	A	A	A	A		
MA1	V	O	V	A	V	V	A	V	O	A	A	V	O	A	A	A	V			
MA2	V	V	V	V	V	V	V	A	O	X	A	V	V	V	V	A				
MA3	V	V	V	V	V	V	X	V	V	V	V	V	V	A	A					
PPC1	V	V	V	V	V	V	V	V	O	V	V	V	V	V						
PPC2	V	V	V	V	V	V	X	V	V	V	X	V	V							
PPC3	V	V	X	A	V	V	A	A	A	X	X	X								
PPC4	O	V	A	A	V	V	A	O	A	O	A									
PPC5	V	V	V	V	V	V	V	X	V	V										
PPC6	V	V	V	V	V	O	A	A	V											
PPC7	V	A	V	A	A	V	A	O												
PPC8	O	V	V	V	V	V	V													
PPC9	V	V	V	V	V	V														
PPC10	V	V	V	A	A															
PPC11	O	A	V	A																
PPC12	V	V	V																	
QM1	A	X																		
QM2	V																			
QM3																				

Source: The author

Table 4. Initial Reachability Matrix (IRM)

MODE	ACC	SUS	MA1	MA2	MA3	PPC1	PPC2	PPC3	PPC4	PPC5	PPC6	PPC7	PPC8	PPC9	PPC10	PPC11	PPC12	QM1	QM2	QM3
ACC	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1
SUS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MA1	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	1	0	1	0	1
MA2	0	1	0	1	0	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1
MA3	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
PPC2	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC3	1	1	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	1	1	1
PPC4	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	1	0
PPC5	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC6	0	1	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1	1	1
PPC7	1	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	1	0	1
PPC8	1	1	0	1	0	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0
PPC9	1	1	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1
PPC10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1
PPC11	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0
PPC12	1	1	1	0	0	0	0	1	1	0	0	1	0	0	1	1	1	1	1	1
QM1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0
QM2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	1
QM3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1

Source: The author

Table 5. Final Reachability Matrix (FRM)

MODE	ACC	SUS	MA1	MA2	MA3	PPC1	PPC2	PPC3	PPC4	PPC5	PPC6	PPC7	PPC8	PPC9	PPC10	PPC11	PPC12	QM1	QM2	QM3
ACC	1	1*	1*	1*	0	0	0	1*	1*	0	1	1*	0	0	0	1*	1*	1	1*	1
SUS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MA1	1	1	1	1	0	1*	1*	1*	1	1*	1*	1*	1	1*	1	1	1*	1	1*	1
MA2	1*	1	1*	1	1*	1	1	1	1	1*	1	1*	1*	1	1	1	1	1	1	1
MA3	1	1	1	1	1	1*	1*	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC1	1	1	1	1*	1	1	1	1	1	1	1	1*	1	1	1	1	1	1	1	1
PPC2	1	1*	1	1*	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC3	1	1	1*	1*	0	0	1*	1	1	1	1	1*	1*	1*	1	1	1*	1	1	1
PPC4	1*	1	0	0	0	0	0	1	1	1*	1*	1*	0	0	1	1	0	1*	1	1*
PPC5	1	1	1	1	1*	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PPC6	1*	1	1	1	0	1*	1*	1	1*	1*	1	1	1*	1*	1*	1	1	1	1	1
PPC7	1	1	0	0	0	0	0	1	1	1*	1*	1	0	0	1	1*	0	1	1*	1
PPC8	1	1	1*	1	1*	1*	1*	1	1*	1	1	1*	1	1	1	1	1	1	1	1*
PPC9	1	1	1	1*	1	0	1	1	1	1*	1	1	1*	1	1	1	1	1	1	1
PPC10	1	1	0	0	0	0	0	1*	1*	0	1*	1*	0	0	1	1*	0	1	1	1
PPC11	1	1	0	0	0	0	0	1*	1*	0	1*	1	0	0	1	1	0	1	1*	1*
PPC12	1	1	1	1*	0	0	0	1	1	1*	1*	1	1*	0	1	1	1	1	1	1
QM1	1*	1	0	0	0	0	0	1	1	1*	1*	1*	0	0	1*	1*	0	1	1	1*
QM2	1	1	0	0	0	0	0	1*	1*	0	1*	1	0	0	1*	1	0	1	1	1
QM3	1	1	0	0	0	0	0	1*	1*	0	1*	0	0	0	0	0	0	1	1*	1

Source: The author

Table 6. Level Partition Matrix

Capability	Reachability Set	Antecedent Set	Intersection Set	Level
ACC1	1, 3, 4, 8, 9, 11, 12, 16, 17, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 3, 4, 8, 9, 11, 12, 16, 17, 18, 19, 20	II
SUS1	2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	2	I
MA1	3, 4, 5, 6, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 10, 13, 14, 17	IV
MA2	3, 4, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 6, 7, 10, 13, 14, 17	IV
MA3	5, 6, 7, 14	5, 6, 7, 14	5, 6, 7, 14	V
PPC 1	6	6	6	VI
PPC 2	5, 7, 14	5, 6, 7, 14	5, 7, 14	V
PPC 3	1, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	II
PPC 4	1, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20	II
PPC 5	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	IV
PPC 6	1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	II
PPC 7	10, 12, 15	3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 17	10, 12, 15	III
PPC 8	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	3, 4, 5, 6, 7, 10, 13, 14, 17	IV
PPC 9	5, 7, 14	5, 6, 7, 14	5, 7, 14	V
PPC 10	12, 14, 15	3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 17	12, 14, 15	III
PPC 11	12, 14, 15	3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 17	12, 14, 15	III
PPC 12	3, 4, 10, 13, 17	3, 4, 5, 6, 7, 10, 13, 17	3, 4, 10, 13, 17	IV
QM 1	1, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19	1, 8, 9, 10, 11, 12, 15, 16, 18, 19, 20	II
QM 2	1, 8, 9, 11, 12, 15, 16, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 8, 9, 11, 12, 15, 16, 18, 19, 20	II
QM 3	1, 8, 9, 11, 18, 19, 20	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20	1, 8, 9, 11, 18, 19, 20	II

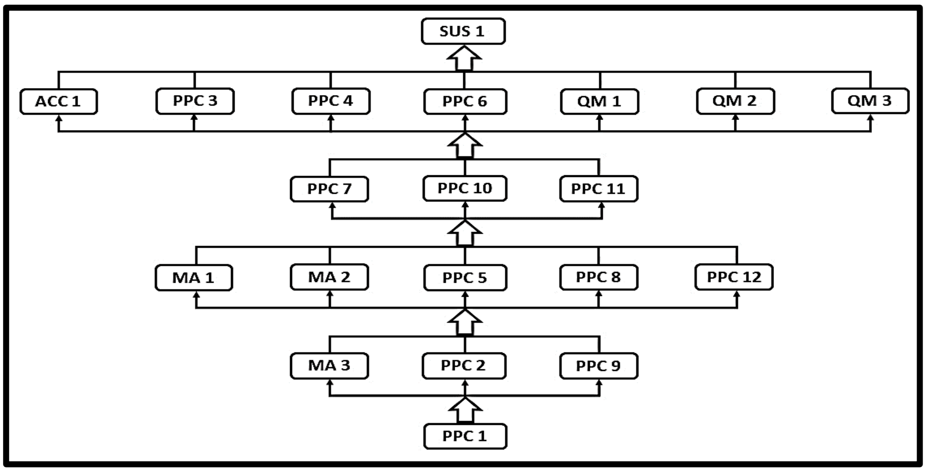

Fig. 1. Cross-Functional Synergy shaped by SIPs' adoption

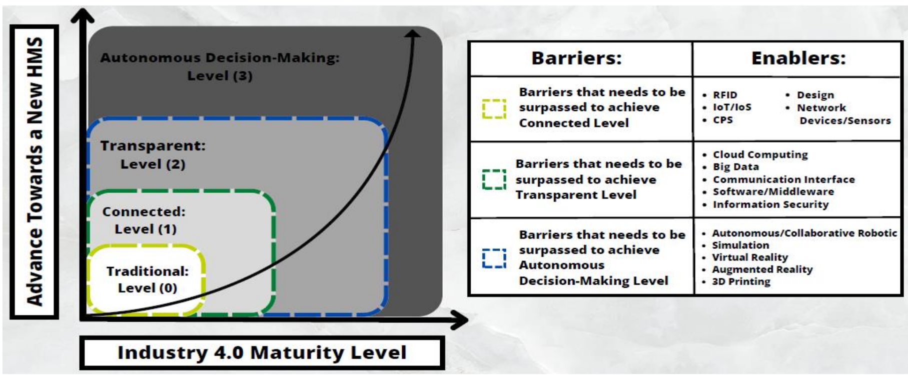

Fig. 2. Cumulative aspects of the structural barriers faced to implement SIPs

5.2 CFI during implementation stage: The transparent level

Within the transparent level, we can observe the synergistic power of CFI between the Maintenance and PPC functions. This synergistic power occurs through improvements in maintenance accuracy, including preventive and prescriptive measures, by accessing, visualising, and designing data, as well as remote repair services (Maintenance). These factors enable self-performance optimisation through the reuse of experiences to enhance decision-making performance, linking machines into systems, and consequently improving data collection capabilities.

However, to enable these new and more complex capabilities, organisations will need to address a new set of barriers. This new group of barriers include challenges such as contractual and revenue-sharing issues, vulnerabilities in data security, and the complexity of introducing new systems or aligning them with existing business systems, among others identified in Table 2.

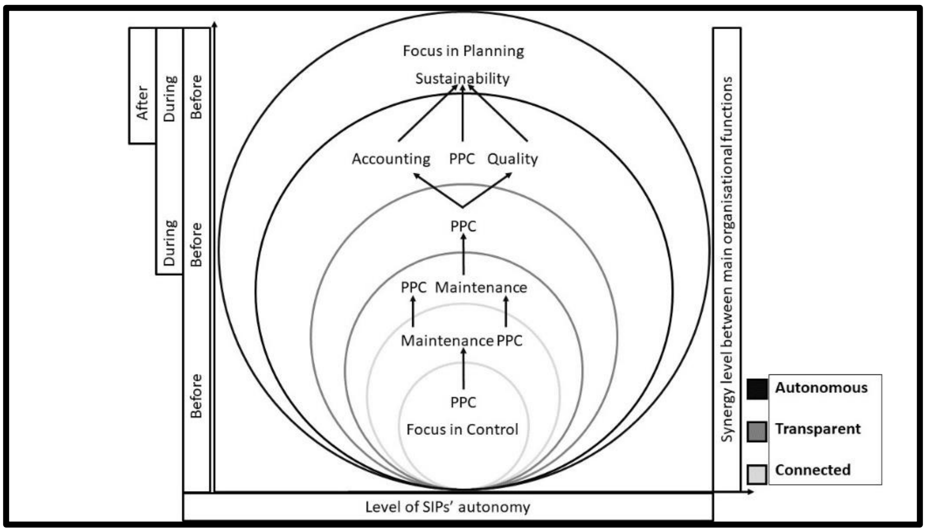

Fig. 3. Unified framework for efficient SIPs adoption

It's important to note that alongside these new barriers, the barriers encountered at the connectivity level will continue to be faced by organisations, exponentially increasing the challenges not only in implementation but also in increasing the autonomy level of SIPs. Complementing, the barriers faced during SIPs implementation are more related to the new technologies necessary to elevate the SIPs level, making all production systems transparent. These technologies may comprise for example Big Data, Analytics and Cloud Computing.

5.3 CFI in the post-implementation stage: The fully autonomous level

At the highest level of autonomy, CFI occurs between PPC and Accounting, as well as between PPC and Quality. Subsequently, these three organisational functions exhibit synergy with the Sustainability function. This level of CFI is the most challenging to achieve, as organisations face barriers related to the first two levels, as well as barriers related to post-implementation issues (e.g. decreased planning efficiency when control is decentralised, difficulties in integrating various SIPs, high energy consumption, risk of adverse event propagation, high complexity of management, lack of security and trust in data usage, high complexity of system management due to the increase in the number of agents used, among others).

The cross-functional integrations between PPC and Accounting enable organisations to enhance their efficiency in asset management, as organisations have already achieved self-performance optimisation through the reuse of experiences to enhance decision-making performance. This culminates in more robust and flexible production systems, resulting in better complexity management associated with the combined offering of products and services within and between organisational units.

These three capabilities also provide a synergistic effect with the Quality function through high-value aggregation, ongoing quality management, and high process security. These functional synergies are entirely dependent on all the other synergies and CFI integrations discussed earlier, allowing organisations to achieve a previously unseen level of value aggregation and organisational sustainability, in social, environmental, and financial terms.

5.4 Theoretical Implications

This section delves into the theoretical implications of our study, highlighting the contributions it makes to IPT, organisational synergy research, and deepening the understanding of technology adoption and integration within industrial contexts. So, our research’s contributions are threefold:

First, by examining the SIPs’ role in enabling CFI, this research contributes to the refinement and extension of IPT. Specifically, it sheds light on the cognitive processes involved in cross-functional synergy enabled by SIPs, thereby enhancing our understanding of how organisations process and utilise information to achieve strategic goals.

Second, through the analysis of functional integrations and synergies enabled by SIPs, this study deepens our understanding of how different organisational functions interact and collaborate within industrial settings. The identification of synergistic relationships between PPC, Maintenance, Accounting, Quality, and Sustainability functions provides valuable insights into the mechanisms underlying effective organisational synergy, contributing to theories of organisational behaviour and management.

The development of an unified framework for understanding the adoption and integration of SIPs within organisational contexts offers theoretical contributions to the field of technology adoption and implementation. By including the barriers into the model of SIP adoption, as well as the stages of autonomy and CFI, this research provides a theoretical basis for future studies on technology adoption processes and their implications for organisational performance and competitiveness.

5.5 Managerial Implications

This section explores the managerial implications of our research, elucidating how the findings can inform strategic decision-making and operational practices within industrial organisations.

By uncovering the SIPs' role in enabling CFI, this study offers managerial insights into opportunities for streamlining and optimising organisational processes. The identification of functional synergies and barriers to SIP adoption guides managers seeking to enhance efficiency and effectiveness not only across diverse functional areas but also in making the process of adopting SIPs smoothly.

In sequence, the framework developed in this research provides managers with a structured approach to strategic resource allocation and development, particularly in the context of technology adoption and integration. By understanding the stages of autonomy and functional integration, managers can allocate resources effectively to support the successful implementation of SIPs, maximising the potential for organisational performance improvement.

Through the identification and integration of barriers and capabilities into a unified model, as well as the mechanisms underlying functional synergies, this study enables managers to develop a strategic sequence of actions to systematically overcome structural barriers to SIPs' adoption, thereby enhancing organisational resilience and sustainability. By leveraging SIPs to enable CFI and subsequently enabling new and more complex operational capabilities, managers can position their organisations for long-term success in a dynamic and competitive business environment.

5.6 Limitations and Future Research Directions

While the current study provides valuable insights into the SIPs' role in enabling CFI, it is important to acknowledge certain limitations inherent in the methodologies employed, in addition, to suggesting potential avenues for future research.

Thereafter, the limitations inherent in the systematic literature review (SLR) may introduce subjectivity in data interpretation, as well as objective filters such as the period of analysis and type of work. Concerning expert interviews, limitations may arise in the representativeness of the sample of interviewed experts, possibly not encompassing a diverse enough range of perspectives. Additionally, restrictions related to the knowledge and experience of the interviewees may prevent coverage of all nuances of the subject matter. Regarding ISM, limitations may include bias in the matrix-filling process, influenced by the background of each expert. The matrix-filling process may also entail subjectivity in data interpretation.

Seeking to refine our model, future research may apply ISM and Fuzzy MICMAC approaches to identify the driving and dependence power between barriers faced by organisations in adopting SIPs. This may provide a roadmap for effective practical actions that can accelerate the adoption and subsequent improvement in SIPs' autonomy. Additionally, our model could be validated in a practical environment, enabling researchers to make improvements tailored to specific application contexts.

Furthermore, exploring the impact of cultural differences on the adoption and implementation of SIPs could offer valuable insights into cross-cultural management strategies in industrial organisations.

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