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Impacts of Industry 5.0 Target Dimensions on the Performance of Intra-Logistics Systems: An Assessment Framework

Olivia Bernhard*. Anna C. Cagliano. Andrea Ferrari ****

**Institute for Machine Tools and Industrial Management, Technical University of Munich, 85748 Garching, Germany (e-mail: olivia.bernhard@iwb.tum.de).*

***Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy (e-mail: anna.cagliano@polito.it; andrea.ferrari@polito.it)*

Abstract: Even though there is a growing interest in Industry 5.0 (I5.0), holistic studies assessing the technologies and managerial approaches driving its adoption—especially regarding their impact on intra-logistics systems—are lacking. Based on Design Research Methodology, this paper proposes a framework to evaluate how technologies and approaches related to the three key dimensions of I5.0—human-centricity, resilience, and sustainability—affect the design and performance parameters of material handling, storage, and picking systems. Using methods like a Systematic Literature Review and expert surveys, the study pinpoints key technologies and approaches for I5.0, along with the primary factors influencing the design of intra-logistics systems and their operational and economic performance. An assessment framework has been developed relying on Domain Mapping Matrices. Further research will include a Delphi study with industrial experts to determine the most impactful I5.0 technologies and approaches on intra-logistics systems. In such a way, guidelines for the development of these systems can be derived.

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Keywords: Industry 5.0, Intra-logistics systems, Design, Performance, Design Research Methodology, Systematic Literature Review, Domain Mapping Matrices, Framework

1. INTRODUCTION AND MOTIVATION

Although previous paradigms such as Lean, digitalization, and sustainability have only been partially implemented in manufacturing (Bernhard et al., 2025a), the European Commission introduced Industry 5.0 (I5.0) in 2021 (Breque et al., 2021). This fifth industrial revolution focuses on three dimensions, related to human-centered, resilient, and sustainable production (Ivanov, 2023), and an empirical study highlights its importance internationally (Bernhard et al. 2025b). Unlike Industry 4.0 (I4.0), I5.0 combines social needs with digital innovations to create a harmonious balance between machines and human labor, enhancing environmental and social well-being (Grosse et al. 2023). In this context, intra-logistics emerges as a key application area for I5.0, ensuring the smooth, adaptable, and efficient movement of materials within production systems. Professionals are increasingly discussing I5.0 implementation in intra-logistics systems, emphasizing advanced technologies such as the Industrial Internet of Things, Virtual Reality, and Advanced Automation to boost efficiency (Wu et al., 2022). However, intra-logistics is not only important for improving efficiency, but also plays a crucial role in creating human-centered workplaces, boosting operational resilience, and minimizing environmental impact. While the human element is crucial, Logistics 5.0 emphasizes human-centric approaches where technology complements rather than replaces human skills. Moreover, resilience and sustainability are vital, with Data Analytics and Artificial Intelligence (AI) aiding in disruption forecasts and robotics optimizing resource use (Cagliano et al., 2021). Technological advancements also enhance sustainability, such as digitalizing material handling systems improves fuel efficiency, reduce CO_2 emissions, and minimize energy waste (Pashkevich et al., 2019).

Despite its crucial role, current research on I5.0 in intra-logistics remains fragmented. Most studies examine isolated technologies or single dimensions of I5.0, lacking a comprehensive perspective that considers the interplay between technologies and managerial strategies in enhancing the performance of intra-logistics systems. This gap prevents industries from fully taking advantage of the opportunities offered by I5.0 in intra-logistics. (Ashta et al., 2023a; Grosse, 2024). Thus, the impact of I5.0 on the design and performance parameters of key intra-logistics systems needs to be elaborated. Therefore, this research employs the Design Research Methodology (DRM) to propose a holistic framework for assessing the impacts of I5.0 target dimensions on key intra-logistics systems such as material handling, storage, and picking (Tadić et al., 2024). The paper is organized as follows: Section 2 outlines the current state of research and identifies gaps; Section 3 details the methodology; Section 4 presents results; and Section 5 draws conclusions.

2. STATE OF THE ART

To provide a solid foundation for this study, the following literature review examines existing research on the integration of technologies and managerial approaches in intra-logistics systems within the I5.0 paradigm. In this context, much attention has been paid to picking activities. For instance, Ashta et al. (2023b) addressed human-centricity and evaluated how exoskeletons affect the time performance and muscle

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activity of operators in order picking tasks. Koreis et al. (2023) empirically demonstrated that in hybrid human-robot picking systems, human-robot collaboration can significantly reduce the time required to complete the order picking task. Lucchese and Mummolo (2024) investigated the role of assistive technologies in picking tasks, focusing on how they can support workers both cognitively and physically, improve performance, and enhance the well-being of operators, while also addressing possible human-related challenges. Similarly, Pasparakis et al. (2023) examined how the implementation of collaborative order picking between humans and robots affects job satisfaction and order pickers' evaluations about effectiveness and self-confidence in the short term. Finally, Vijayakumar and Sobhani (2023) designed a mathematical model aimed at optimizing the performance of a picker-to-parts system that relies on picking and transport robots. The performance evaluation focused on productivity, quality, and the well-being of order pickers.

Looking at material handling applications, Dmytriyev et al. (2024) proposed a layout of a robotized end-of-line operation that follows a human-centric approach, taking advantage of the benefits of a collaborative robotic application to free the operators from being restricted by machine-defined timelines, to reduce physical strain, and to empower them with supervisory and management roles. Additionally, Thylén et al. (2023) explored human (physical, cognitive, and psychosocial factors) and organization (roles and responsibilities) related challenges in the introduction of automated material handling systems in production facilities.

Different work was presented by Pereira et al. (2023), who conducted a study to conjugate the introduction of I4.0 technologies with the I5.0 dimension of human-centricity. They developed a methodology to define the requirements for the implementation of Augmented Reality in the processes of intralogistics (picking, material handling, and storage systems). This initiative seeks to minimize risks and enhance workplace conditions. Chivilò and Meneghetti (2023), proposed an operational checklists-based framework to improve production lines feeding within the context of I5.0, aiming to assist in the implementation of innovative material handling solutions. The framework was validated through a real case study, in which a company implemented autonomous mobile robots to move materials between the warehouse and the production lines.

From the literature review (Table 1), it is clear that only a limited number of studies have proposed a holistic view of the integration of technologies and management approaches required to implement I5.0 principles and assess their subsequent impact on the performance of key intra-logistics systems. Existing research predominantly focuses on isolated aspects and does not provide a unified framework that links such advances to measurable outcomes across different intra-logistics operations. The present paper addresses this critical research gap by proposing a comprehensive and systematic framework, which aims to evaluate the interplay between advanced technologies and management strategies in the context of I5.0. Specifically, the framework aims to assess how these innovations contribute to the achievement of the three fundamental dimensions of I5.0, namely, human-centricity, resilience, and sustainability, and their impact on the design and performance parameters of primary intra-logistics processes, i.e., picking, material handling, and storage systems. By bridging the existing knowledge gap, this study not only provides a theoretical foundation for understanding the implications of I5.0, but also paves the way for offering practical insights for managers and policy makers seeking to optimize intra-logistics performance in line with the emerging industrial paradigm.

Table 1. Summary of literature

		Industry 5.0 target dimension			Intra-logistics process		
Reference	**Framework**	**D1**	**D2**	**D3**	**P1**	**P2**	**P3**
Ashta et al. (2023b)		✓			✓	✓	
Chivilò & Meneghetti (2023)	✓	✓	✓	✓		✓	
Koreis et al. (2023)		✓			✓		
Pasparakis et al. (2023)		✓			✓		
Pereira et al. (2023)		✓			✓	✓	✓
Thylén et al. (2023)		✓				✓	
Vijayakumar & Sobhani (2023)		✓			✓		
Dmytriyev et al. (2024)		✓				✓	
Lucchese & Mummolo (2024)		✓			✓		
Present study	✓	✓	✓	✓	✓	✓	✓

Note: D1 (human centricity), D2 (resilience), D3 (sustainability), P1 (picking), P2 (material handling), P3 (storage systems)

3. RESEARCH METHODOLOGY

The present research is grounded in DRM, which aims to both create and confirm knowledge to improve the design process of products and manufacturing equipment. DRM consists of four stages: Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS), and Descriptive Study II (DS-II). The RC stage clarifies the current understanding and the overall research objective, establishes a research plan, and provides a focal point for the subsequent stages. The goal of the DS-I stage is to enhance comprehension of design and the factors that influence its success through an examination of the design phenomenon, to inform the development of support. In this context, "support" includes potential methods, aids, and measures for improving the current situation and facilitating the evaluation of the researcher's core contribution. The PS stage aims to systematically develop support, taking into consideration the findings of DS-I. Finally, the DS-II stage concentrates on assessing the usability and applicability of the actual support and its effectiveness (Blessing and Chakrabarti, 2009).

The choice of DRM is due to the ultimate goal of the research effort, which is to create knowledge about how to design internal logistics systems compliant with I5.0 principles and able to provide high performances. As a first step, the present paper discusses the application of the first two DRM stages. The RC stage helps to clarify the object of the research and set it in the current state of the art discussed in Section 2. The application of the DS-I stage provides an understanding of the I5.0 target dimensions as well as the operational and economic parameters that may affect intra-logistics systems. These are the key components of the framework developed. The application of this framework in future steps will serve as the basis for defining guidelines to develop logistics equipment that is more oriented towards I5.0.

Thus, following the DRM, the objective of the paper, as defined during the RC, is to evaluate the impact of I5.0 on the design and performance parameters of material handling, storage, and picking systems. To achieve this objective, three sub-objectives are established within the DS-I stage, along with the methods and tools that will be used to accomplish them (Figure 1).

DS-I subobjective	Description	Method/Tools
1	• Identifying technologies and approaches to implement each I5.0 target dimension • Selecting the most important technologies and approaches for each I5.0 target dimension	• Systematic literature review • Expert knowledge (questionnaire to academic experts)
2	• Identifying and selecting design and performance parameters of logistics systems	• Literature review (combining the results of professional and academic literature)
3	• Developing a framework that will enable to assess how each selected I5.0 technology and approach impacts on each selected design and performance parameter	• Domain Mapping Matrices • Likert assessment scale

Figure 1. DS-I sub-objectives and methods

The first sub-objective aims at understanding the implementation of I5.0 and its three target dimensions. For this reason, a Systematic Literature Review (SLR) has been performed to answer the following question: How can the three I5.0 target dimensions be applied in practice in both manufacturing and logistics? Considering not only logistics, but also manufacturing, ensures that approaches that are well-established in manufacturing, but not yet applied in logistics, are taken into account. The SLR approach is an evidence synthesis method that collects and summarizes studies based on explicit eligibility criteria, minimizing biases and errors to address specific research questions (Tranfield et al., 2003). It has been adopted here because the posed research question asks for a focused and comprehensive analysis. The following inclusion criteria are adopted: (1) Database: Scopus. (2) Time period: 2019-2024, because I5.0 was introduced at the end of the second decade of this century. (3) Document type: Journal Papers, Conference Papers, Book Chapters, and Reviews. Because I5.0 is still in its infancy, many promising studies may be found in conference proceedings or books, not just in international journals. (4) Language: English. (5) Keywords: a three-level structure is adopted to integrate various perspectives and findings about the investigated topic, ensuring a structured and repeatable process: "Keyword 1 AND Keyword 2 AND Keyword 3". Keyword 1 is "Industry 5.0" while Keyword 2 may be either "human centric*", "sustainab*", or "resilien*". The third level includes detailed keywords such for instance "human augmentation," "virtual reality," "energy efficiency," "adaptability," and "flexibility". This level aims to facilitate the identification of works that focus on specific topics related to the three I5.0 target dimensions. (6) Document scope: academic papers that provide concrete insights and discuss strategic and operational ways to apply I5.0 and its target dimensions. Thus, any work that presents general discussions or theoretical frameworks about I5.0 will not be included in the final corpus. The SLR identified various implementation methods for I5.0 target dimensions, including both technological solutions such as AI and Internet of Things, as well as broader methodological strategies like human-robot collaboration and organizational resilience. Thus, they grouped them into technologies and approaches. By adapting the Tiwari et al. (2022) definition, a technology is typically implemented in machinery and equipment, applying scientific knowledge to effectively and efficiently support operations to achieve the target dimensions of I5.0. For the purposes of this study, based on Matt et al. (2015), an approach can be defined as a strategic direction for implementing the target dimensions of I5.0. The same technology or approach can be implemented to achieve more than one target dimension.

The technologies and approaches are assessed by a panel of academic experts, and only the most relevant ones are included in the next steps of the research. Eight professors and research associates in the fields of logistics and production from two university institutions were involved to assess the relevance of the technologies and approaches. In addition to a cross-national assessment in Italy and Germany, care was taken to ensure that the experts had different areas of expertise and research focus, as well as different levels of experience. For example, the expert panel included an expert in intra-logistics systems as well as an expert in innovation management and technology assessment. To identify the most important approaches and technologies, the experts are therefore asked to complete a questionnaire using a five-point Likert scale: 1– Very Unimportant, 2 – Unimportant, 3 – Neutral, 4 – Important, 5 – Very Important. Using a Likert scale with a neutral option allows experts to express opinions on newer, lesser-known technologies and approaches they are unfamiliar with without introducing bias into the evaluation. The median values of the obtained scores for each technology, approach, and I5.0 target dimensions are calculated. The median is selected as the summary statistical measure since the Likert scale utilized for gathering responses is ordinal, making it impossible to ensure an equal distance between scores (Rosano et al., 2022). According to the scale used, technologies and approaches with a median greater than or equal to "4" (clear position of importance) were considered relevant.

The goal of the second sub-objective of the research (Figure 1) is to define the main design and performance parameters for material handling, storage, and picking systems. A design parameter of an intra-logistics system refers to a specific variable or characteristic that influences the functionality and efficiency of the system (Gialos and Zeimpekis, 2020). Examples of design parameters include speed, storage capacity, and automation level. Instead, a performance parameter is a measure of how well an intra-logistics system performs under given conditions (Coşkun and Erturgut, 2022). Performance parameters include productivity and flexibility, among others. A two-phase approach is adopted, beginning with a review of grey literature, including technical catalogs, company websites, and professional journals discussing the latest intra-logistics solutions. Special attention is given to automated solutions as they are better suited for integration with I5.0. This focus allows for the identification of design and performance parameters that manufacturers prioritize, ensuring alignment with the latest technological advancements. Second, the design and performance parameters are validated against academic literature to ensure their relevance to the scientific debate. Here Scopus searches focus on papers about the intra-logistics systems at issue that mention these parameters in the author keywords. The analysis of these keywords helps to identify design and performance parameters that reflect current research priorities. The selected timeframe for this literature search is 2010-2024 to ensure that the relevant works related to I4.0 and I5.0 are included in the outcomes. A Pareto analysis is conducted on the literature contributions citing each parameter in the author keywords, focusing separately on material handling, storage, and picking systems. The parameters categorized in classes A and B of the Pareto analysis for each kind of intra-logistics system are considered for the next step of the present research.

The I5.0 technologies, approaches, and the design and performance parameters of intra-logistics systems identified in the second research sub-objective are related in the third one (Figure 1). In particular, the goal here is to develop a framework to assess how the adoption of each technology and approach impacts the design and performance of intra-logistics systems. To achieve such a purpose, Domain Mapping Matrices (DMMs) are applied because they facilitate mapping between two distinct domains. DMMs, used in engineering design and management, provide simplicity and clarity, revealing significant patterns through appropriate analysis (Eppinger and Browning, 2012). Each DMM maps a set of technologies or approaches associated with an I5.0 target dimension against the design and performance parameters identified for one of the three types of intra-logistics systems under consideration. In order to assess the impact on these parameters, the following question is associated with each cell of every matrix: *"In what way does the implementation of the technology (or approach) in the row affect the design (or performance) parameter in the column?"* A five-point Likert scale is adopted to answer the question: 1 – Significant decrease; 2 – Decrease; 3 – No change; 4 – Increase; 5 – Significant increase. Here the decrease/increase is associated with the value of the parameter considered.

4. RESULTS

The present section discusses the results achieved to meet the three sub-objectives of this research.

4.1 Sub-objective 1: I5.0 technologies and approaches

Using the inclusion criteria defined for the SLR, 2,343 documents were initially retrieved from Scopus. Their titles and abstracts were carefully reviewed. Those papers that did not meet the SLR objective were excluded from the initial corpus, resulting in 1,757 potentially interesting papers. A total of 24 papers were then selected after thoroughly reading their full texts. The remaining papers were excluded because, based on the document scope defined for the SLR inclusion criteria, they did not provide detailed insights into implementing I5.0 and its key dimensions in production and logistics systems. 46 % of the corpus papers were published in 2023, with only 12 % appearing between 2019 and 2022, demonstrating high attention to I5.0 implementation in recent years. The corpus works are almost equally split among the three I5.0 target dimensions.

Based on the SLR outcomes, 51 ways to implement the I5.0 target dimensions were identified and classified into technologies (e.g., AI, Intelligent Smart Wearables) and approaches (e.g., human-robot co-working, predictive maintenance) (Zafar et al., 2024). Academic experts assessed the technologies and approaches retrieved from the literature via the questionnaire introduced in Section 3, identifying 22 technologies and 15 approaches as important or very important. As an example, relevant technologies for the Resilience dimension include Big Data, Machine Learning, AI, Internet of Things, Cyber Physical Systems, and NextG Wireless Networks (NGWNs). The full list of selected technologies and approaches is available from the authors upon request.

4.2 Sub-objective 2: design and performance parameters of intra-logistics systems

The analysis of grey literature identified 17 design and performance parameters for material handling systems, 21 for storage systems, and 11 for picking systems. The comparison with the white literature helped to eliminate parameters not relevant to the academic discussion. A total of 41 design and performance parameters were analyzed using Pareto analysis. Focusing on classes A and B, about 50 % of the parameters for each type of intra-logistics system were considered, capturing about 95 % of the papers that include in their keywords the design and performance parameters related to this type of system. Design parameters for material handling systems include load capacity, operating speed, cycle time, battery autonomy, and level of automation. The performance parameters are utilization rate, scalability, level of energy consumption, system lifetime, investment costs, and operating costs (Ghelichi and Kilaru, 2021). The design parameters for storage systems are storage capacity, storage density, storage depth (single, double, triple, or multi-deep systems), selectivity, storage height, operating speed, and level of automation. The performance parameters are scalability, productivity, utilization rate, system lifetime, investment costs, and operating costs (Dai et al., 2021). Finally, the level of automation is considered as the main design parameter of picking systems, while the performance parameters include picking productivity, picking accuracy, picking operation time, investment costs, and operating costs (Liu et al., 2019).

4.3 Sub-objective 3: development of the assessment framework

The authors created six DMMs for each type of intra-logistics system, two for each I5.0 target dimension. One links technologies to design and performance parameters, and the other links approaches to such focus parameters. For example, Figure 2 displays the DMM for storage systems and the technologies for achieving the I5.0 target dimension resilience, following validation by an academic expert in automated warehouses and an industrial developer in intra-logistics systems. All 18 DMMs in the framework are available from the authors.

		STORAGE SYSTEMS												
		DESIGN PARAMETERS							PERFORMANCE PARAMETERS					
		Storage capacity	Storage density	Storage depth	Selectivity	Storage height	Operating speed	Level of automation	Scalability	Produc-tivity	Utilization rate	System lifetime	Investment costs	Operating costs
RESILIENCE	TECHNOLOGIES													
	Big Data													
	Machine Learning													
	Artifical Intelligence													
	Internet of Things													
	Cyber-physical systems													
	NextG wireless networks													

Figure 2. Example of DMM part of the assessment framework

5. SUMMARY AND OUTLOOK

The fifth industrial revolution offers both challenges and opportunities for companies, particularly in logistics. By integrating sustainable, resilient, and human-centered technologies, intra-logistics systems can improve their performance. Currently, there is a lack of comprehensive analysis of the impact of I5.0 on key intra-logistics systems. Existing literature mainly focuses on specific dimensions, especially human-centricity (Dmytriyev et al., 2024), and often examines only one or two systems, such as picking and material handling (Ashta et al., 2023b). Furthermore, there are very few frameworks available to guide the implementation of I5.0 in intra-logistics (Chivilò and Meneghetti, 2023). This work applies the first two stages of DRM, RC and DS-I, to propose an evaluation framework based on the identification and selection of relevant technologies and approaches to apply I5.0, as well as the design and performance parameters of picking, material handling, and storage systems. The framework assesses how these technologies and approaches impact the selected parameters. Both white and grey literature has been analyzed to ensure that the framework covers relevant theoretical and practical aspects. Furthermore, DMMs guarantee a rigorous approach to structuring the framework and facilitate a clear understanding of the I5.0 and logistics dimensions to be assessed. Initial results show that approaches and technologies are relevant in all three dimensions of I5.0, and that the number of assigned approaches and technologies is almost the same in all three dimensions. Furthermore, it can be seen that the total number of technologies and approaches is almost evenly distributed in the dimensions of sustainability and resilience, while there are more technologies than approaches in the dimension of human-centricity.

This research encourages studies on managerial and technological strategies to effectively implement the three I5.0 target dimensions. In addition, it emphasizes the importance of studying the interrelationships between I5.0 and the performance of intra-logistics systems in a holistic manner rather than focusing on specific aspects, logistics processes, or types of equipment. In this context, the present study also underscores the need to explore sustainability and resilience as key pillars that complement the focus on human-centricity in logistics 5.0. The contribution provides professionals with valuable insights into the technologies that facilitate the achievement of I5.0 when used in conjunction with appropriate managerial approaches. In addition, it helps both developers and users of intra-logistics systems identify the technical and economic parameters of picking, material handling, and storage systems that derive the greatest benefits from I5.0. This guidance may prompt developers to provide intra-logistics equipment that better meets the current needs of manufacturing and supply chains. However, only the first two DRM stages have been carried out, and the framework has yet to be applied. In future research, aimed at completing the application of the PS and DS-II stages of DRM, a Delphi Study will be conducted with developers and users of intra-logistics equipment, thereby involving industrial and academic experts. Participants will be asked to evaluate the impacts of I5.0 on these systems using the framework dimensions and the Likert scale outlined in Section 3. Once a consensus is reached among the experts involved in the Delphi Study, their ratings will allow to identify which technologies and approaches have the most significant effects on design and performance parameters of intra-logistics systems. The usability of the framework for supporting the development of I5.0-oriented intra-logistics equipment will then be evaluated through pilot tests conducted at logistics equipment manufacturers.

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