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Original Article

Demand Driven Material Requirement Planning and Industry 4.0 Integration: Conceptual Framework and Hypotheses

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Abstract *- This study aims to examine the impact of the integration between the adoption of Demand Driven Material Requirement Planning (DDMRP) implementation and Industry 4.0 (I4.0) technologies on improving operational performance in firms. To achieve this, a literature review was conducted a literature review to develop a conceptual framework that explains how the DDMRP and I4.0 technologies influence each other and how they relate to manufacturing system performance indicators. The proposed conceptual framework includes drivers, barriers, processes, and benefits and discusses their inter-relationships. The results showed that integrating DDMRP and I4.0 helps organizations adapt to changes in the dynamic market. This paper is among the earliest research efforts to present a conceptual framework for integrating DDMRP and I4.0. As a result, a new concept is developed, which is referred to as DDMRP 4.0.*

Keywords *- DDMRP, Industry 4.0, DDMRP 4.0, Integration, Conceptual framework.*

1. Introduction

Recently, with a dynamic and turbulent environment, firms must be able to reduce product lead time, adapt, and respond rapidly to volatile demand and new customer requirements. As a result, it is considered essential that the DDMRP and I4.0 concepts have emerged as major parts of the firm's competitive advantage to satisfy these demands quickly and to be improved [1,2]. Their goals of managing production planning are rather similar, and therefore, both methods can be used in conjunction [3].

DDMRP is an innovative method to pace with the demand change of customers [1]. DDMRP is a method for modeling, planning, and managing supply chains to protect and promote the flow of relevant information and materials. DDMRP uses strategic decoupling points to drive supply order generation and management throughout a supply chain [1]. Furthermore, using of technologies of I4.0 is a new strategy to achieve supply chain agility and partner integration through automated collection and analysis of enormous data quantities in real-time [4].

In recent years, numerous researchers and practitioners have explored the potential for combining various approaches with I4.0 to deploy a new concept or system. More specifically, several examples highlight the importance of studying the relationship between I4.0 and Lean [5-8], I4.0 and Lean Six Sigma [9,10], I4.0 and supply chain [11-16].

In summary, the literature shows the growing interest in showing the feasibility and the compatibility of the integration between these concepts with I4.0. Given that Lean and Six Sigma are pillars of DDMRP [1] and that there is a dearth of studies on the integration of DDMRP with I4.0 technologies, in this context, the authors consider that the latter can be applied at the process level of DDMRP while taking into accounts its unique characteristics [3].

The primary objective of DDMRP and I4.0 is to enhance performance and adapt to future developments. However, with the emergence and evolution of these two concepts, a research gap has become apparent, particularly regarding their implementation. Additionally, comprehensive studies are scarce to systematically explore the challenges, drivers, and benefits associated with integrating DDMRP and Industry 4.0. Another critical gap is the insufficient attention given to developing a standardized framework for evaluating the performance outcomes of organizations adopting both DDMRP and Industry 4.0 practices. The absence of such a framework hampers the ability to compare and generalize findings across diverse settings. To address this gap, a combination of these concepts seems evident in facing market change and customer demands. The main causes and incentives for undertaking this work are associated with:

- There are limited studies for both production philosophies (DDMRP and I4.0) and the elements of operational performances;
- Understanding the potential for this integration can significantly affect crucial decisions for industrial companies and the parties involved.

This research uses a literature review methodology to explore and identify studies that integrate the implementation of the DDMRP process with I4.0 technology. To do this, a good starting point for this integration is to identify the potential drivers, barriers, tools and benefits, focusing on operational performance perspectives. Derived from the results, it is possible to formulate an integrated conceptual framework that can be utilized by organizations to develop a long-lasting sustainability adoption through the proposed concept of DDMRP 4.0. This new model concept is founded on the DDMRP process, I4.0 technologies, and human resources but does not involve the product as an integration component. As a result, it highlights the interconnections among these constructs and suggests improvements in various aspects. In this sense, two research questions were defined:

RQ1: How can integrating DDMRP and Industry 4.0 be implemented to improve operational performance?

RQ2: What are the drivers, barriers, and benefits associated with creating a conceptual integration framework?

The paper is structured as follows. After a brief introduction, the 2nd explains the research methodology, and the descriptive analysis presents the results accrued from the descriptive analysis and classification of the articles. The 3rd section depicts the study background, namely the concepts of DDMRP and I4.0 technologies. The conceptual framework is developed, and its elements are discussed in the proposal framework section. The following section presents the conclusion and theoretical implications. The paper's final section offers future research opportunities based on the limitations identified.

2. Research Methodology

The current study is based on the literature review (LR) to achieve the research aims and provide a deeper understanding of the paradigm for integrating DDMRP. A literature review of the existing literature was adopted to create a successful conceptual framework for integrating DDMRP and I4.0. LR allows locating and examining articles selected from different databases and sources [17] and analyzing, evaluating, and synthesizing existing studies performed by researchers, scholars, and practitioners [18]. The methodology must be carried out through a structured process to achieve the objective. According to [19] and [20], the main five phases of a literature review were adopted. Table 1 presents the five phases that the LR went through.

Table 1. Literature review phases

Phase	LR phase	Objectives and Methods Used
1	Objective/ Scope Formulation	Defining the scope of research to be within the bounds of integration of DDMRP and industry 4.0
2	Locating Studies	To locate studies, the following criteria were defined: • Duration: 2011-2023 • Electronic databases included Elsevier (sciencedirect.com), Taylor & Francis (T&F) (tandfonline.com), Emerald (emeraldinsight.com), Springer (springerlink.com), IEEE (ieeexplore.ieee.org), Inderscience (inderscience.com), Wiley (onlinelibrary.wiley.com), ISI Web of Science (wokinfo.com), EBSCO (ebscohost.com), Scopus (scopus.com), and Google Scholar (scholar.google.com) were explored. • Keywords: Search strings included (DDMRP) (Demand Driven Material Requirements Planning) (Demand Driven MRP) (Industry 4.0) (I4.0), (Industry 4.0 technologies), (Industry 4.0 tools), (Barriers), (Challenges) (Obstacles), (Drivers), and (Benefits). Boolean operators were employed to combine these search strings (i.e. AND and OR) to identify additional pertinent papers.
3	Study Selection	Published research papers on Industry 4.0 aspects (Technology, digital technology, and tools) and its integration with DDMRP were selected.
4	Analysis & Synthesis	Identifying the drivers, barriers, challenges, and benefits of DDMRP and Industry 4.0 adoption and integration to benefit organizations, practitioners, academics, and researchers.
5	Drawing the conceptual framework	Developing a conceptual framework for DDMRP and Industry 4.0 integration and combination.

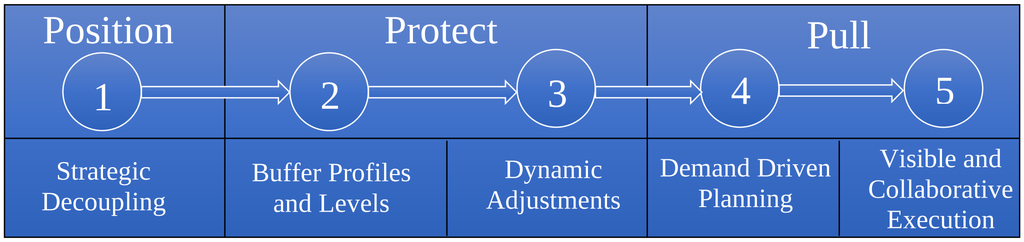

Fig. 1 DDMRP components [1]

The initial search was conducted using the following keywords: DDMRP, Demand Driven Material Requirements Planning, Demand Driven MRP, industry 4.0, I4.0, and digital technologies of industry 4.0. A large number of articles on DDMRP and Industry 4.0 were found in the database, but when the search was filtered through different combinations of keywords on DDMRP and I4.0, these numbers were reduced significantly.

3. Literature Review

3.1. Demand Driven MRP

DDMRP is an innovative multi-echelon material and inventory planning and execution solution. It involves strategically positioning decoupling points within the product structure and supply chain to absorb variability and shorten lead time. [1]. DDMRP allows an organization to converge closely to actual market requirements to promote the relevant actions at the production planning and execution level [1]. As DDMRP is a recent innovative production control system [21], the state of the art in the field is relatively scarce [22]. Figure 1 shows the three main DDMRP components of the process considered in this research. These steps are interconnected: from position to protect and to pull. Each step is represented by inputs and outputs. The inputs are the key parameters, and the outputs consist of the outcomes and KPIs.

Here are the detailed steps in the process:

3.1.1. Strategic Decoupling

Determine the positions of decoupling points within the supply chain to establish autonomy between processes or entities. These decoupling points serve as the key means to mitigate the bullwhip effect, minimize variability, and streamline lead times.

3.1.2. Buffer Profiles and Levels

Establish the target inventory level contained at those decoupling points (buffers). Buffer sizing acts like a shock absorber, helping to deal with changes in both supply and demand. Its goal is to reduce or eliminate the bullwhip effect. The buffer size is determined by adding up three calculated zones: red, yellow, and green.

3.1.3. Dynamic Adjustments

Dynamic adjustments mean that the level of protection can go up or down depending on how things are running, changes in the market or events we expect or know will happen in the future. This part of the DDMRP process helps stabilize the supply chain and smooth operations for all variabilities over a specific period. There are two types of dynamic adjustment: recalculated adjustment and Planned Adjustment Factors (PAF).

3.1.4. Demand-Driven Planning

Generating supply orders is done by applying the net flow equation (NFE). Planning involves creating supply orders such as purchase orders, manufacturing orders, and stock transfer orders. This is done by assessing current inventory, orders that have not been received, and qualified sales order demand.

3.1.5. Visible and Collaborative Execution

The DDMRP system's handling of active supply orders is managed in this step. During this phase, DDMRP execution centers on the present and anticipated inventory positions within the DDMRP model. Collaborate with supply chain partners using the replenishment zones/triggers to execute the plan. The purpose of this section is not to discuss each component of the DDMRP process in detail but to present a brief definition of DDMRP steps. Some recent comprehensive reviews can be found in the previous study of this work and Azzamouri et al. (2021) [24].

DDMRP process is based on the parameterization of the key parameters of each step. Nevertheless, the review of the literature underscores certain crucial concerns linked to key parameters that may influence the application and effectiveness of the system [22- 26]. In their studies, the authors present some issues related to the parameterization of the DDMRP process. Some of the input parameters are tactical or strategic decision tools allowing an optimal use of the method, which will be treated in this paper.

3.2. Industry 4.0 Technologies

Industry 4.0 refers to the next step of the industrial revolution that can increase a transformation in the production flow and communication between machines and humans through suppliers, producers, and customers [28]. The production system uses several I4.0 technologies to produce small batches of products and increase the volume and flexibility of production [14, 29, 30]. The authors [29] show that firms can use the I4.0 concept to reduce costs, increase the volume of supply, and performance improvements.

According to [31], the main pillars of I4.0 can be divided into nine groups of technologies: Big Data and analytics, Autonomous Robots, Simulation, Horizontal and Vertical System Integration, the Industrial Internet of Things, Cyber-Security, Additive Manufacturing, Augmented Reality and the Cloud Computing. Integration and application of all these technologies transform and improve traditional manufacturing systems [32]. According to [33], I4.0 can be classified into three main kinds of integration: vertical integration, horizontal integration, and end-to-end engineering. Moeuf et al. (2018) [2] also supported this point of view, where the author highlighted the vertical integration to controlling the shop floor using Enterprise Resource Planning (ERP) change and integration of new pieces of software. Other authors [14] and [34] underline that the implementation of I4.0 should be operated on an integration of horizontal and vertical processes of manufacturing systems to improve efficiency and responsiveness. The integration and direct effects of digital technologies of I4.0 have been extensively studied in academic research in manufacturing systems. Therefore, assessing the production system by introducing digital solutions and I4.0 technologies is essential. In the study by [35-37], it was found that I4.0 has the potential to enhance supply chain management structures and manufacturing processes. I4.0 optimizes the production process by reducing lead time and error rate and improving efficiency [38]. This section aims not to provide an in-depth examination of I4.0 technologies but rather to provide a brief overview. In work [3], the authors provided comprehensive reviews of recent I4.0 technologies, where they examined the design principles, tools, pillars, and critical features of this industry in detail.

Table 2. Literature review of the relation of DDMRP-I4.0

Article	Authors	Year	Reference	Main contributions
Industry 4.0 Technologies on Demand Driven Material Requirement Planning: Theoretical Background and Impacts	El Marzougui *et al.*	2023	[25]	This study attempts to present the theoretical background impacts of I4.0 technologies on DDMRP parameters.
Integration Model for Demand-Driven Material Requirement Planning and Industry 4.0	El Marzougui *et al.*	2022	[3]	The paper proposes and develops an integration model based on three levels: 1) principles and goals, 2) process and tools, and 3) Pillars.
Transformation the logistics to digital logistics: Theoretical approach	PEKARČÍKOVÁ, Miriam, , *et al.*	2020	[39]	The purpose of this article was to deal with the transformation of the Supply Chain, including the integration of customers using the DDMRP methodology in connection with Industry 4.0.
Digital Supply Chains Key Facilitator to Industry 4.0 and New Business Models, Leveraging S/4 HANA and Beyond	Götz G. Wehberg	2020	[40]	This book introduces a practical guide to digital supply chain modeling, bringing important solutions, practical tools, and technologies together with the latest concepts and tools, such as DDMRP.
Demand-driven material requirements planning. Some methodical and practical comments	PEKARČÍKOVÁ, Miriam, , *et al.*	2019	[41]	The publication aims to extend the knowledge of demand-driven supply logistics using the DDMRP in connection with the context of Industry 4.0 and verify the processed theoretical knowledge in a case study.
Why DDMRP Is a Necessary Condition For Industry 4.0 To Deliver on the Promise	Patrick Rigoni	2019	[42]	This article indicates the importance of DDMRP for Industry 4.0 to get a correct and accurate demand signal linked directly to true customer demand.
Why becoming demand-driven is crucial for a successful digital transformation	Patrick Rigoni	2019	[43]	This paper examines the idea that companies must restructure and manage their supply chains with demand-driven concepts so that they can digitize and transform their processes.
Analysing the possibility of dealing with uncertainty in ERP/MRP con-trolled environment with Demand Driven MRP	Battissacco, V. E., & Espôsto, K. F.	2018.	[44]	This paper contributes to increasing the knowledge of DDMRP and discusses its adoption to deal with uncertainty in SMEs in the context of Industry 4.0.

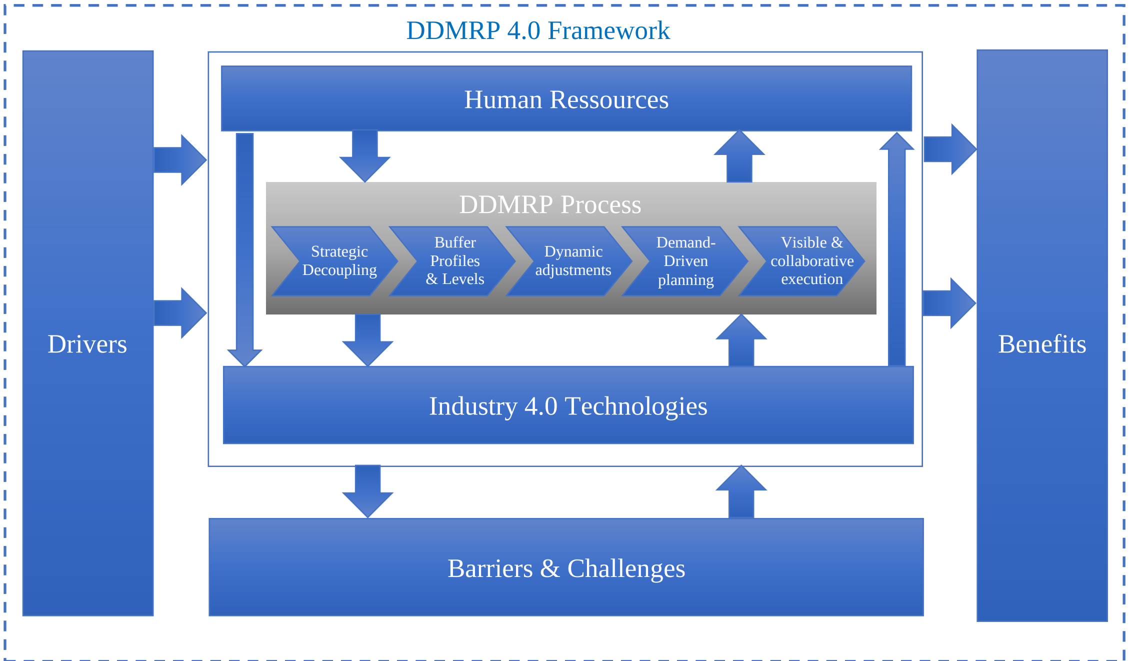

Fig. 2 Conceptual framework of DDMRP and I4.0 integration (Proposed by authors)

3.3. DDMRP and Industry 4.0 Integration

Literature regarding the link between DDMRP processes and I4.0 is limited (Table 2). Very few studies are dedicated to integrating DDMRP and Industry 4.0 [3, 25]. The main point of interest for this study is to investigate the relationships between DDMRP and I4.0. The most significant study is that of El Marzougui et al. [3], which proposes a new concept of DDMRP4.0. According to this study, this new model is based on three aspects of integration: principles, tools, and pillars. From an operational performance point of view, the DDMRP4.0 model aims to examine its implications and optimizations in terms of added value.

As the relationship between DDMRP and I4.0 is still in its infancy [3], the result of this process was only a few articles published. During the literature review stage, special attention was given to a paper that proposed that the content is pertinent to the perspective of current research goals. Finally, eight papers have been selected for their contribution to the relationship between DDMRP and I4.0 and how they intersect with each other when both methods are integrated.

4. Proposal Conceptual Framework of DDMRP and I4.0 Integration

From the literature review, there are a limited number of studies about DDMRP-I4.0 integration and a lack of an integrated conceptual framework describing how organizations should manage the process of DDMRP implementation in combination with I4.0 to establish a positive contribution to operational performance and generate value for customers and stakeholders. Due to this knowledge gap, the authors carried out a literature review to identify relevant research in the field of DDMRP-I4.0 to propose a conceptual framework integration of the DDMRP4.0 based on the combination of the integration model and theoretical elements (Figure 2).

However, to the best of the authors' knowledge, no structured and complete strategy for integration has been found, except El Marzougui et al. (2022) [3] tried in their study to introduce an integrated model for DDMRP-I4.0. This model aims to represent the three levels of integration between DDMRP and I4.0. They showed in their model that this new approach could be integrated into a new single concept of DDMRP4.0.

Based on some principles and common characteristics between the two concepts, they are complementarity and synergetic strategies because both approaches are based on the concept of flow [1,2,5], real-time [1,45,46], productivity [1,2,45] and flexibility [1,39,47], etc. Consequently, pillars, tools, processes, and principles from the two concepts have been combined under the integrated model to impact operational performances positively [3].

Based on the literature review of DDMRP and I4.0, organizations require a framework that includes the identification of barriers, drivers, challenges, and benefits to encourage the implementation of the DDMRP and I4.0 approach to improve their operational performance. The conceptual framework follows a typical deployment approach from drivers as input to the benefits, where strategies and processes are translated into operational performances. The framework starts with the reasons that push companies to adopt the integrated conceptual framework referred to as the drivers of the integration. The core of the conceptual framework, which combines the DDMRP process, I4.0 technologies, and human resources, is located at the center and supports the integration and implementation of DDMRP4.0. The barriers and challenges for the DDMRP-I4.0 integration are the constraints that restrict the organizational pursuits to improve operational performance. Last, the benefits of the integration serve as output.

4.1. DDMRP4.0 Framework

Based on the theoretical elements, the authors presented a conceptual framework of DDMRP and I4.0 that guides professionals in adopting the DDMRP4.0 strategy in their organizations. The proposed framework can be used as a pilot project framework and extended after its execution. The presented framework provides the connection between DDMRP and I4.0 at every component of the DDMRP process. At this stage, the authors have thought about combining them depending on the strategic goals in mind to achieve and improve operational performance.

This section presents the conceptual framework's operative part and describes its elements. El Hamdi [48] considers three main core components: process, tools and people to implement any kind of integration approach. One of the important aspects highlighted in this framework is the need for collaboration between the personnel with DDMRP knowledge and the I4.0 technologies. Therefore, this integration involves the amalgamation of components of the DDMRP process and technology of I4.0 with important investment in skills and knowledge of human resources.

However, Human Resources (HR) is considered simultaneously a barrier and a driver. Adding to that aspect, specific skills and a higher level of education will be needed, especially for I4.0 [49,50]. The authors have seen throughout the process the drivers and obstacles related to this integration that this integration strategy could not be done without the involvement of the human aspect. Consequently, people are the engine of performance and the key to the success of each technology implementation project [51]. These technologies cannot resolve the tasks except with human capacities, which can predefine their rules [52].

The authors consider that the integration will be done through the DDMRP process. They will proceed to introduce the different potential tools in the DDMRP implementation process, i.e. see how I4.0 technologies can be integrated horizontally into the DDMRP implementation process. For this, they will analyze the relationship between the tools of the two concepts. This integration strategy aimed to create new concepts or tools to extend the benefits of DDMRP-I4.0 and return to DDMRP's more successful method. The authors obtained new integrated tools, DDMRP4.0, that are more intelligent, digitalized and connected.

Using the proposed core of the conceptual framework, the current study investigates the links between established constructs (DDMRP, I4.0, and HR) according to the six arrows describing the relationships between them.

As shown in figure 3, the framework illustrates that the DDMRP process, I4.0 technologies and human resources are interrelated with each other. The six relationships in the framework tools are described as follows, where the collaboration opportunities for DDMRP, I4.0, and HR are identified.

a) DDMRP could complement Industry 4.0 implementations, as it can streamline the processes necessary for facilitating the implementation of Industry 4.0.
b) Industry 4.0 technologies can support and improve the applicability of the DDMRP process; that is, Industry 4.0 technologies support and may complement the DDMRP process. The selection of the appropriate I4.0 technologies will significantly affect the applicability of the DDMRP.
c) DDMRP will provide new knowledge and skills for human resources, influencing their decision-making and enhancing their abilities in supply chain planning and execution.
d) Human resources should use and adopt the new knowledge of DDMRP through training and education to implement and utilize the methodology effectively in supply chain planning and execution.
e) Industry 4.0 technologies offer human resources access to vast amounts of data, enabling more informed decision-making and opportunities for upskilling and reskilling through training and education programs.
f) Human resources play a critical role in adopting and supervising Industry 4.0 technologies, and their involvement can positively impact the selection and evolution of appropriate technologies.

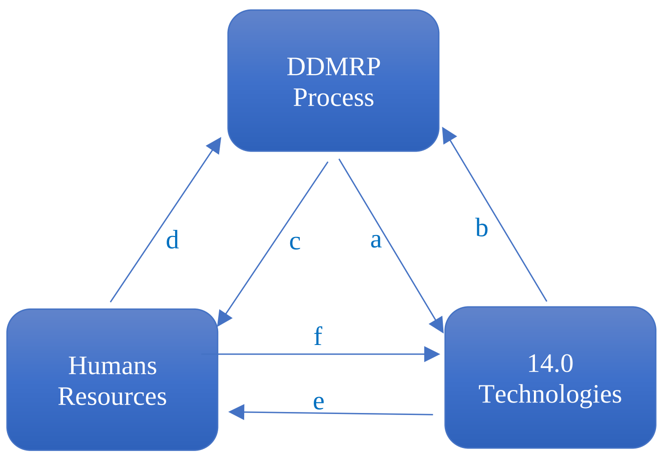

Fig. 3 DDMRP4.0 integration framework

Table 3. Impact of Industry 4.0 technologies on the DDMRP process (Proposed by authors)

DDMRP Process/ Sub-process	**DDMRP Parameters**	**I4.0 Technologies**	**I4.0 Contribution to DDMRP Parameters**
Position (Strategic Inventory Positioning)	Six positioning factors : 1. Customer tolerance time 2. Market potential lead time 3. Sales order visibility horizon 4. External variability (Demand & Supply) 5. Inventory leverage and flexibility 6. Critical operation protection	- Radio Frequency Identification (RFID) ; - Internet of Things (IoT) ; - Big data analytics (BDA) ; - Cloud Computing (CC) ; - Artificial intelligence (AI) and Machine Learning (ML) - Cyber-physical systems (CPSs)	- New technologies **(BDA**) can provide a large dataset about customers and help to extract and analyze the relevant data; - Automatic data collection **(Robotic)**, sharing data of six positioning factors in real-time **(IoT);** - The six factors should be used as input for a semi-automatic positioning to help consultants with decision-making of optimized positions using **AI** and **ML;** - Identifying the state's physical locations of the products **(RFID)** ; - Real-time and automatic data collection from machines **(CSP),** critical operation and limited capacity can be identified through **Smart Sensors** to protect them; - Storage of relevant information on demand variability and supply variability **(CC)**
Protect (Buffer Profiles and Levels & Dynamic Adjustments)	- Decoupled Lead Time (DTL) - Average Daily Usage (ADU) - Minimum Order Quantity (MOQ) - Variability Category or Factor (VF) - Lead Time Category or Factor (LTF) - Internal Variability - Planned Adjustment Factor (PAF) - Seasonal Demand	- Cyber-physical systems (CPSs) ; - Big data analytics (BDA) ; - Robotic stations on the automated production line ; - Cloud computing technologies ; - Artificial intelligence and machine learning - Radio Frequency Identification (RFID); - Augmented Reality (AR) & Smart Human Interfaces (SHI)	- Help to extract and analyze the relevant data by **IoT** - Sharing databases (ADU, DTL) and software with customers and suppliers**(IoT)** - Establish the optimal levels of inventory based on the current market conditions - Collecting data automatically to measure key parameters in real-time - Automatic and real-time calculation of buffer levels - Cyber-physical systems **(CPSs)** visualize and control the performance of buffers in real time - Machine learning allows for accuracy and real-time visibility of parameter settings
Pull (Demand Driven Planning & Visible and Collaborative Execution)	- Net Flow Equation (NFE) - On-hand inventory - Qualified sales order demand - Order spike horizon and - Order spike threshold	- Radio Frequency Identification (RFID); - Internet of Things (IoT) - Cyber-physical systems (CPSs) ; - Artificial intelligence and machine learning - Big data analytics (BDA) ; - Digital automation with smart sensors ; - Additive manufacturing (AM) - Augmented Reality (AR) and Smart Human Interfaces (SHI	- Controlling inventory in real-time and traceability **(RFID)** - Cyber-physical systems **(CPSs)** visualize and control planning and execution in real-time - Planners can control and visualize the planning and execution in real-time - Planners manage processes of priority more efficiently and effectively. - Collecting data automatically and measuring the KPI in real time - Synchronization of operation of planning and control with the capacity and scheduling **(IoT**) - real-time information sharing for visible and collaborative execution

Many reasons support the proposed integration tools; DDMRP4.0 provides organizations with tools to accelerate the flow of materials and information. The common and fundamental principle between the two approaches accelerates the flow [1,2,5]. These approaches need qualified people to supervise and run the organisation's material and information flow. Therefore, qualifications and skills are important aspects of implementing and sustaining this integration. For it, specific training is needed in specific skills, such as the Demand Driven Planner Professional (DDPP) and the Demand Driven Leader Professional (DDLP) certificate.

To maximize the value and cost-effectiveness of implementation, companies should carefully choose appropriate Industry 4.0 technologies based on their business principles and leverage the fundamental principles of DDMRP to determine the most advantageous criteria, such as flow, current demand, and decoupling points, to derive maximum benefit from DDMRP and Industry 4.0. Therefore, I4.0 can support a quicker and more effective DDMRP process and improvement by providing better suitable tools and technologies [25], such as IoT, CSP, DB, and AI. Optimized production and planning processes are essential for successfully implementing Industry 4.0 technologies. To effectively adopt these technologies, companies may need to implement DDMRP first. Thus, DDMRP could be considered a necessary condition for facilitating the implementation of Industry 4.0 technologies.

The supply chain heavily relies on various tools and technologies, and it is important to incorporate them into the DDMRP process. However, trade-offs must be made when selecting which Industry 4.0 tools to use for optimal DDMRP operations. The DDMRP process has three fundamental building blocks: position, protect, and pull. An analysis was conducted to examine how Industry 4.0 technology can affect each of these blocks within the DDMRP process.

The authors investigated the potential benefits of incorporating Industry 4.0 technologies into the position, protect, and pull stages of the DDMRP process to enhance its effectiveness. They found that integrating these technologies into various blocks of the DDMRP process can improve its different parameters.

Several I4.0 technologies can potentially complement the DDMRP process and enhance its effectiveness, including big data analytics, radio frequency identification, cyber-physical systems, Internet of Things, cloud computing, artificial intelligence, and machine learning. El Marzougui 2023 [25] carried out a study that highlighted some positive effects of I4.0 on DDMRP. To support this integration, Table 3 provides a list of Industry 4.0 technologies that can be used in various stages of the DDMRP process to improve its parameters and overall value.

By integrating I4.0 technologies, DDMRP will undergo a profound transformation and changes whereby interconnected steps organize themselves in this new process integration tool, thus forming a connection with new human resource skills. Building on the conceptual framework proposed in this analyzed study, important attributes were expressed and were affected by different stages of this new concept. The first attribute of this new concept of DDMRP4.0 is the digitalization using the main technologies such as Big Data analytics, the Internet of Things (IoT), and cyber-physical systems.

Digitalization is an important element of DDMRP4.0 that will bring synchronization, visibility, traceability, and collaboration of all steps of the DDMRP process to connect different elements of a network and to make their components smarter and faster for accurate decisions. The second attribute identified is automating strategic inventory positioning and parameter setting.

This includes the calculation of buffer levels adaptiveness automatically to external and internal environments and the creation of intelligent planning and control systems using Artificial Intelligence and Machine Learning. The third attribute is a smooth and solid integration of I4.0 technologies and human resources with the DDMRP process. This integration provides a strong foundation for a new system.

The last attribute is real-time data and connection between the DDMRP process, I4.0 technologies, and human factors through smart technologies such as IOT, ML, CPS, DB, etc. This attribute allows getting an accuracy of the data at the required time. Therefore, this characteristic allows consultants, managers, and planners to monitor continuously these choices concerning factors of positing buffers, parameters of calculating level buffers, and their adjustments.

By contrast, integrating DDMRP and I4.0 presents a difficult process, considering the lack of an integrated framework and limited studies about this integration. It is important to note that integration of DDMRP-4.0 implementation in firms cannot be done in a very short time or one go; rather, it is a gradual transition.

4.2. Drivers

Drivers are key opportunities that motivate and encourage organizations to move towards the DDMRP-I4.0 integration strategy. A comprehensive understanding of the drivers for effective integration of DDMRP and I4.0 is the key to overcoming the perceived barriers. It is also important for organizations to evaluate them for the reason that these drivers could influence the expected outcome of integration. Table 4 provides a summary of the drivers that were identified and a description of each of them.

Table 4. Drivers of DDMRP and Industry 4.0

DDMRP Drivers	References	I4.0 Drivers	References
Return-On-Investment (ROI): DDMRP protects and promotes the flow of relevant material and information. DDMRP reduces Working Capital use	[1,53,54]	**Cost saving and financial performance:** I4.0 reduces human resources costs, inventory management and operating costs; increases sales volumes and cost savings.	[2,11,14,29,38, 55]
Compressing lead-time: DDMRP proposes a new lead-time with buffer placement that can reduce and improve delivery time.	[1,56,57]	**Efficiency production process**: Reduction of lead time, Reduction of the error rate, Improvement of efficiency, Ensuring reliable operation (less downtime), reduction of risks and energy consumption.	[38,58,59]
Consumer demand: DDMRP synchronizes effort with the market as it operates based on actual demand rather than forecasts. It utilizes a transparent execution system, enabling planners to respond in real time.	[1,57]	**Consumer expectations:** I4.0 will be able to respond to specific customer requirements and adapt faster to customers' needs and requirements	[30,59,60]
Support and take advantage of well-known concept initiatives: DDMRP is built on strong core concepts: MRP, DRP, TOC, Six Sigma and Lean, and it uses their principles in its approach. DDMRP is seen as an extension of these concepts.	[1,26,61]	**Market competition and time-to-market:** I4.0 will be able to respond to time and competition of the market (compliance with market conditions)	[2,14,62]
Variability management: Control and absorption of variability in a highly volatile environment through the use of buffers that prevent the bullwhip effect and avoid bimodal distribution of inventory in the supply chain system.	[1,54,56]	**Productivity pressures:** I4.0 helps to improve industrial productivity by improving corporate efficiency and procedures, reducing lead times, increasing the level of automation	[33,59,63,64]
Adjustment and dynamic of inventory: DDMRP integrates dynamic adjustment in the buffers to avoid bimodal distribution of the inventory.	[1,26, 56, 57, 65, 66, 67, 68]	**Technological innovation opportunity**: I4.0 increases innovation capacity in product and service design.	[38,59]
Service level: DDMRP improves customer service by satisfying customer needs, requirements, and expectations (inventory, quantity, product, lead time, etc.).	[1,26,54,57,68]	**Customer Satisfaction:** I4.0 allows to be more customer-oriented, which assumes increasing customer satisfaction and customer experiences	[28,59]
Simplicity and visibility for human resources: DDMRP provides an easy methodology that allows planners to react easily through a planning priority concept.	[1,26]	**Human Factors**: I4.0 provides tools to support human decision-making, reduce human errors and time;	[59,69]

Although these characteristics relate to the key drivers of DDMRP and I4.0 separately, they are insufficient for a holistic understanding of DDMRP4.0 as a unifying and integrating paradigm. Therefore, to provide an integrated approach for the analysis of DDMRP4.0, those fundamental characteristics can be grouped under specific dimensions based on their similarity, complementarity, and closeness. This grouping can serve as a summary of the similar characteristics and their implications for DDMRP4.0. However, there is a lack of comprehensive studies in the literature that have identified the key drivers and barriers for DDMRP 4.0. Therefore, the authors have gathered and presented them in this study, providing the main drivers and implications of these closely related concepts (Table 5).

Table 5. Drivers of DDMRP and Industry 4.0

DDMRP 4.0 Drivers dimension	Characteristics
Customers orientation	- Companies can enhance customer satisfaction by tailoring their products or services to meet specific customer needs and expectations and adapting to fluctuations in demand.
Return-On-Investment	- The financial return is important for investors by reducing production costs, supply chain costs, inventory levels, and waste. - The attractiveness of new concepts to investors is closely tied to their potential for generating a good return.
Human Factors/ aspects	- Acquire new skills and qualifications through the use of technologies and concepts. - Facilitate and support decision-making.
Efficiency Process	- Process efficiency through unified and optimized processes. - Businesses can improve their productivity and effectiveness by optimizing their processes and eliminating waste and unnecessary activities.
Solid concepts foundation	- Built and based on a robust foundation of well-established and effective tools, technologies, methods, and concepts.
Technological and innovative pressure	- Development and implementation of intelligent concepts and technologies can enable companies to accelerate their pace of innovation and technological advancement.

Table 6. Barriers and challenges of DDMRP and Industry 4.0

DDMRP Barriers & Challenges	References	I4.0 Barriers & Challenges	References
Difficulty in positioning the buffers: this procedure is subjective and relies on the judgment of the planner and the experience of the consultant to determine the placement of strategic buffers, considering six factors	[53, 57,71]	**Lack of adaptation and standard processes:** lack of properly optimized processes, not flexible structure, and not support fast flow; Lack of understanding of the process importance of I4.0	[30,38,72]
Buffers profiles and levels process: calculation of buffers levels does not include the supply variability factor, management variability, operational variability	[23]	**Financial investment limitation**: Limited access to financial resources. A high amount of capital investment is needed to implement the I4.0 tools and technologies.	[13,38, 73,74, 75, 76,77]
Settings & Adjustments: numerous parameters can be acquired through the subjective selection of factors: LT percentage, variability percentage, buffer profiles, PAF (planned adjustment factor) for seasonality, and the frequency of dynamic buffer re-adjustment…The DDMRP methodology does not define these parameters. Consequently, the DDMRP process is not stabilized.	[22,24,26, 54,57,71]	**Unclear benefit**: Lack of a clear comprehension of the I4.0 technologies' economic benefits.	[38, 55, 78,79]
		Integration and Incompatible technology: need for technological integration and compatibility between old and new technologies ;	[55,72, 80]
Lack of experience of employees with the parameters the DDMRP processes based on the statement that they are some subjective aspects	[57]	**Resistance to change:** Lack of open innovation and flexible organizational culture. Employees' resistance to new technologies, innovation and practices.	[12,38,78, 81]
		Shortage of skills and qualifications labor /lack of expertise: the employees do not have the competencies and digital skills required in the future; several enterprises are not yet prepared for I4.0.	[29,30,72,82, 83,84,85]
Immaturity of DDMRP: DDMRP is not tested and evaluated in different, complex environments and all industrial contexts (complex BOM, different sectors, different contexts, different types of demand response)	[24]	**Fear of failure of I4.0 technologies**: lack of understanding and fear of the new technologies.	[38,86,87, 88]

Table 7. Barriers of DDMRP 4.0 (Proposed by authors)

DDMRP 4.0 barriers dimension	Characteristics
Parameterization level	Lack of guide for setting parameters and adjustments.
Technologies and tools implementation and integration	Lack of standardization of technological integration.
Awareness and readiness	Lack of awareness and knowledge of readiness.
Financial resources and investment	Shortage of financial resources and fear of investment in new concepts.
Novel philosophy and methodology	Immaturity of novel philosophy and methodology.
Skills and qualification	Shortage of skills and qualifications of employees about new concepts and new technologies.
Resistance to change	Resistance to change related to new concepts and technologies, such as lack of understanding, attachment to usual practices, fear of the unknown, or concern about potential negative consequences.
Data management and security	Ineffective management and security of collected data refer to situations where data is not being properly managed or protected. This can occur when data is not organized, labeled, or stored in a way that makes it easy to access and use, leading to potential problems or risks.

4.3. Barriers and Challenges

In this section, the authors identified and examined the kinds of barriers that hindered the implementation of the integration of DDMRP4.0. The identification of barriers is crucial for organizations to reduce them and make the most of the benefits without much issue [70]. The inhibiting factors will help organizations implement a robust integration strategy. This study identified the barriers from the collected literature, as seen in Table 6. The authors do not argue that the identified barriers represented an exhaustive list.

The analysis revealed that additional barriers are hindering the adoption of the DDMRP approach, such as:

- Lack of DDMRP knowledge /awareness: DDMRP is a novel concept; limited scientific research is available, and its applicability is insufficient.
- Low readiness level for implementing DDMRP: Many organizations have not fully embraced this new methodology due to a lack of preparedness or resources to support its implementation.

The authors follow the same principle of grouping similar characteristics to identify the main barriers to the implementation of DDMRP4.0 (Table 7)

4.4. Benefits of the integration of DDMRP and I4.0

DDMRP and I4.0 are two beneficial approaches for the whole supply chain partners: customers, organizations, and suppliers. However, there is a lack of precise framework literature that identifies the benefits of an integrated conceptual framework. Instead, the literature mostly focuses on performance indicators related to a single approach of either DDMRP or I4.0. The performance benefits of implementing DDMRP are proven in numerous cases. Many studies and authors have shown that implementing the DDMRP affect significantly and positively the firm's performance: enhanced customer services, reduction in lead time, minimization of overall supply chain expenses, right sizes inventory, simple and intuitive, better synchronization of the whole supply chain [1,26,53,56,57,65,68]. Likewise, the I4.0 increases productivity [33] and flexibility [47], reduces manufacturing lead time [47], reduces the level of inventory [27, 47], etc. Therefore, when implemented together rather than separately, I4.0 will support DDMRP in overcoming its barriers and vice versa. This integration must positively impact the barriers and challenges identified for both approaches. The authors confirmed some important barriers but could be managed within a strong integration management process that fosters collaboration between these constructs.

This study focuses clearly on the opportunities and drivers, meaning that the barriers might be overcome by integrating DDMRP4.0. The authors believe that the combination of the two approaches will overcome certain barriers for both approaches, namely the lack of experience of employees, lack of DDMRP knowledge /awareness, shortage of skills and qualifications labor, and lack of expertise. It should be noted that the certified people DDPP and DDLP conduct the role of the human resource of support for the DDMRP approach, who can direct and manage the DDMRP process. Furthermore, I4.0 requires specific skills such as AI, human–robot collaboration, cybersecurity, digital twin, intelligent material, and IoT [23]. Consequently, these new skills will promote and contribute to positive outcomes of coordination and collaboration in the DDMRP process.

On the other hand, the main reasons for using the DDMRP philosophy are protecting and promoting the flow of relevant materials and information by reducing variabilities [1] and using decoupling points and actual demand. Advanced technologies of I4.0 can assist DDMRP in accelerating the flow by synchronizing it in real time. Therefore, the planning and production process becomes more unified and standardized by applying DDMRP principles and techniques, which will help implement I4.0 technologies and facilitate the adaptation of human factors.

Moreover, the analysis showed the emerging role of integration strategy in a sustainable environment that allows adapting to the requirements of the environment. The combination of DDMRP and I4.0 has positive environmental consequences; DDMRP reduces inventory [26,53,65,68] and is based on the statement that it produces only what it can and will sell [1].

As a result, less inventory means less production, less waste, less consumption, and less pollution. Likewise, I4.0 reduces waste in this context, and this integration contributes to environmental sustainability. Consequently, the benefits of integrating the two approaches, DDMRP and I4.0, could have a more important, positive impact on an organization's performance.

By processing this integration strategy, companies gain many that exceed the barriers and challenges.

Table 8 illustrates the identified performance benefits reported in the literature review. However, the studies have only focused on operational performance metrics.

5. Conclusion and Theoretical Implications

The main contribution of this study is a theoretical proposal for a conceptual framework that can be validated using a case study to investigate the proposition. This study explored the concept of DDMRP4.0 integration and its conceptual framework adoption in an organization. By adopting a literature review method, the process of integrated conceptual framework begins with the identification of drivers, barriers, and benefits of DDMRP and I4.0 integration. This research discusses the term "DDMRP4.0" to highlight the relationships between the DDMRP process and Industry 4.0, explore the applicability and effects of I4.0 context on the DDMRP and vice versa, and identify the most important technologies of I4.0 that could shape the foundation of DDMRP4.0 without forgetting the key role of human resources in this strategy of integration.

The findings of the current study have many theoretical implications. The results of this study may help firm decision-makers and practitioners address the highlighted barriers, overcome barriers, and foster drivers and motivations to obtain the expected results, paving the way for the successful implementation of DDMRP4.0. Another important implication is how this integration strategy will affect management practices and philosophy workers and what challenges can be identified at the human resources level. The authors present this study as a cornerstone for future research, serving as a robust foundation. It offers a starting point for researchers and practitioners to build upon, providing valuable supporting data for practical applications. The authors suggest that the conceptual framework proposed in this study can be a beneficial starting point for managers, consultants, and practitioners engaged in DDMRP digitalization projects, potentially complementing research on developing the DDMRP4.0 concept.

Finally, more research is required to guide practitioners in implementing this new concept. Therefore, proposing Critical Success Factors (CSF) is an important task and should be treated to facilitate a successful implementation of DDMRP within the I4.0 context and allow organizations to maximize their benefits. To bolster the conceptual framework to overcome several barriers, a limited list of comprehensive critical success factors has been defined for the effective implementation:

- Performing a readiness evaluation to identify prospects for simple and efficient implementation in the DDMRP process, Industry 4.0 technologies, and human resources.
- Invest, qualify, and educate human resources on required skills such as data analytics, smart sensors, AI, ML, and robotics to adapt the competencies to the new methods.
- A good implication and understanding of the DDMRP process and industry 4.0 technologies.
- Sharing information, communication, and commitment of top management support to allocate the necessary resource.
- Coordination and simulation between strategy formulation and implementation to avoid project failure of integration.
- Data protection and best management to ensure a secure and efficient integration process.

Table 8. Perception of potential benefits of DDMRP4.0 integration (Proposed by authors)

DDMRP 4.0 benefits dimension	Characteristics
Real-time visibility and traceability	Accurate and real-time visibility and traceability of parameters setting.
Highly dynamic adjustment	Be more adjustment dynamic of buffers.
Synchronization and strong process	A strong process which promotes and protects the flow of information Synchronization of DDMRP components and stage
Increase and high flexibility	React quickly to demand changes by ensuring the right products' availability at the right time.
Agility	High agility between the DDMRP process and components.
Speed communication and coordination	Speeding feedback and sharing communication between supply chain partners.
Customer satisfaction	Improve and perfect customer service level by meeting the customers' requirements.

5.1. Limitations and Future Research

The study is limited by the data from the literature, as this area is nascent. Therefore, there is a lack of academic literature regarding DDMRP and I4.0 integration. A more in-depth study would yield more data, leading to several new research questions. New models and frameworks are needed to test the paper's contribution's accuracy and usefulness to shape the concept of DDMRP4.0 further, which is an integral philosophy of future production planning and inventory control processes. It will be useful to identify, test, and select specific tools and technologies of I4.0 to implement this integration DDMRP4.0. Then, new artificial intelligence models and algorithms will be developed to support and optimize the DDMRP method.

Finally, using multi-criteria decision-making techniques, such as the Analytic Hierarchy Process (AHP), is important to determine the most suitable set of drivers, barriers, critical factors, and benefits. This prioritization or weight allocation can be applied to validate and implement DDMRP4.0 in real-world manufacturing environments.

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