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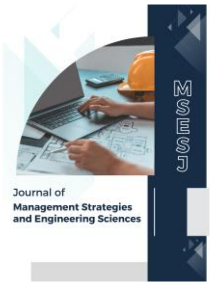


# Smart Production Planning: Presenting a Framework for the Importance and Application of Features of the Production Planning Environment (Case Study: Pharmaceutical Industry)

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**Abstract**

The purpose of this paper was to examine the importance of smart production planning for improving performance, considering the specific features of the planning environment in the pharmaceutical industry. This study uses four empirical case studies in the pharmaceutical industry. These four cases represent four companies producing different products within the pharmaceutical industry for various markets, each with distinct processes. Additionally, along with industry insights, these frameworks were used to identify, define, and structure the variables expected to have the greatest impact on the importance of smart production planning within the theoretical framework. This work was carried out through discussions within the project team and repeated multiple times. The framework was subsequently used to map and analyze the four empirical case studies in the biopharmaceutical pharmaceutical industry. The cases were selected to demonstrate different features of the planning environment and smart production planning approaches, ranging from make-to-stock (MTS) to assemble-to-order (ATO) and make-to-order (MTO). Data was collected through observations and site visits at pharmaceutical manufacturing facilities, workshops, consultations, and formal interviews with production managers, production planners, smart supply chain managers, innovation managers, and production line engineers. Internal and cross-case analyses were performed through several iterations within the pharmaceutical industry team. The fundamental finding is that the potential and importance of smart production planning for improving performance increase with the complexity of the production planning environment. As a result, nine final steps for the design and development of smart production planning importance are presented. The conceptual framework presented is based on the combination of smart production planning, the features of the production planning environment, and the elements of the Fourth Industrial Revolution. The developed framework serves two objectives. First, it provides a tool to structure and describe the planning environment in the pharmaceutical industry, considering product, market, and process features. Insights gained from such a framework regarding the planning environment's features can be useful for smart production purposes. The second contribution of the framework is linking the planning environment's features with smart production planning. The core logic is that the importance of smart production planning for improving performance increases with the intelligence and complexity of the planning environment.

***Keywords:*** *Smart Production Planning, Production Planning Environment, Biopharmaceutical Pharmaceutical Industry*

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## 1. Introduction

The rapid advancement of technology in the era of Industry 4.0 has significantly transformed the landscape of production planning and control (PPC), particularly in industries that rely heavily on efficient production processes, such as the pharmaceutical sector. The increasing complexity of production environments, characterized by ever-evolving customer demands, shorter product life cycles, and global supply chain disruptions, has driven the need for more sophisticated, data-driven approaches to production planning. Smart Production Planning and Control (SPPC), which integrates advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and cloud computing, has emerged as a key solution to address these challenges [1].

The pharmaceutical industry, as a critical component of the healthcare system, faces unique production challenges. The industry's reliance on precise formulations, strict regulatory requirements, and the need for rapid response to market demands make efficient production planning essential [2]. Traditional production planning systems often fall short in meeting the demands of such a complex environment. The limitations of conventional planning methods, including the reliance on manual inputs and the lack of real-time data, have created inefficiencies in production processes, leading to delays, increased costs, and a higher risk of non-compliance with regulatory standards [3]. As a result, there is a growing recognition of the need for smart production planning systems that can leverage the power of Industry 4.0 technologies to optimize production schedules, manage resources more effectively, and ensure compliance with regulatory requirements [4].

Industry 4.0 represents a new paradigm in manufacturing, characterized by the integration of cyber-physical systems, IoT, and AI into production processes [5]. This shift towards digitization has enabled manufacturers to collect and analyze vast amounts of data from production lines in real time, allowing for more informed decision-making and greater flexibility in responding to production challenges [6]. In the context of PPC, this has led to the development of SPPC systems, which utilize data-driven approaches to optimize production planning and control activities.

One of the key features of SPPC is its ability to integrate real-time data from various sources, such as production machines, supply chain systems, and customer demand forecasts, to create a comprehensive view of the production environment [7]. This integration allows for more accurate production scheduling, improved resource allocation, and enhanced decision-making capabilities [8]. Furthermore, SPPC systems are designed to be adaptive, meaning they can respond to changes in the production environment, such as machine breakdowns or shifts in customer demand, in real time. This flexibility is particularly important in industries like pharmaceuticals, where production processes must adhere to strict regulatory guidelines and any deviations from the plan can result in significant financial and operational consequences [9-11].

The pharmaceutical industry is an ideal candidate for the application of SPPC due to the complexity of its production processes. Pharmaceutical manufacturing involves a high degree of variability, both in terms of the products being produced and the regulatory requirements that must be met [12]. SPPC systems offer the ability to manage this complexity by providing real-time insights into production operations, enabling manufacturers to make informed decisions about how best to allocate resources and optimize production schedules [13]. This, in turn, can lead to improved production efficiency, reduced costs, and a higher level of compliance with regulatory standards.

One of the key drivers behind the adoption of SPPC systems is the increasing availability of data in modern production environments. Advances in sensor technology and IoT have made it possible to collect vast amounts of data from production machines, supply chains, and customer interactions [14]. However, many companies struggle to effectively leverage this data in their production planning processes. According to Bean & Davenport (2019), a significant number of companies are failing in their efforts to become data-driven, largely due to a lack of infrastructure and expertise in data analysis. This is particularly problematic in industries like pharmaceuticals, where the ability to make informed decisions based on real-time data is critical to maintaining compliance with regulatory standards and meeting customer demand [15].

SPPC systems address this challenge by providing a framework for data-driven decision-making in production planning. By integrating data from various sources into a single platform, SPPC systems allow manufacturers to gain a comprehensive view of their production operations, identify inefficiencies, and make more informed decisions about how to optimize their processes [16]. This is particularly important in industries like pharmaceuticals, where the production process is highly regulated, and any deviations from the plan can result in costly delays or product recalls [17]. Furthermore, SPPC systems can help manufacturers manage the complexity of their production environments by providing real-time insights into production operations, allowing them to respond quickly to changes in demand or supply chain disruptions [1].

Challenges and Opportunities in Implementing SPPC

While the benefits of SPPC are clear, implementing these systems in practice presents a number of challenges. One of the primary barriers to adoption is the cost associated with implementing new technologies, particularly in industries like pharmaceuticals, where production processes are already highly specialized and regulated [10]. Additionally, many companies lack the necessary infrastructure to support the integration of data-driven technologies into their production processes [18]. This can make it difficult for manufacturers to fully realize the potential benefits of SPPC, as they may not have the resources or expertise required to implement these systems effectively.

Despite these challenges, there are significant opportunities for companies that are able to successfully implement SPPC systems. By leveraging the power of data and advanced technologies, manufacturers can gain a competitive edge in the market by improving production efficiency, reducing costs, and increasing their ability to respond to changes in customer demand [19]. Furthermore, the use of SPPC systems can help manufacturers improve their compliance with regulatory standards, reducing the risk of costly product recalls or delays in bringing new products to market [12].

In conclusion, the pharmaceutical value chain holds significant importance in the health and treatment system. From another perspective, the rapid advancements in the Fourth Industrial Revolution have the potential to transform smart production planning through the emerging concept of "smart factories and smart production planning." In fact, digitalization and the smartification of the production process are necessities for today's industry. However, there are few empirical case studies that specifically focus on the role of smart production planning based on the features of the production planning environment in the pharmaceutical industry or how Industry 4.0 can be utilized to enhance smart production planning. The rapid advancements in Industry 4.0 provide the potential to transform smart production planning through the emerging concept of smart manufacturing. The purpose of this paper was to examine the importance of smart production planning for improving performance,

## 2. Methodology

Previous literature on the description of smart production planning environments was reviewed, and several relevant theoretical frameworks were identified. Along with industry insights, these frameworks were used to identify, define, and conceptualize the framework expected to have the greatest impact on the need for smart production planning within the theoretical context. The resulting framework will then be utilized as a tool to logically extract how each feature affects the need for smart production planning in the pharmaceutical industry. This work was carried out through discussions within biopharmaceutical industry teams. The conceptual framework was subsequently used to map and analyze four case studies in the biopharmaceutical pharmaceutical industry. The cases were selected to demonstrate different features of the smart production planning environment and smart production planning approaches, ranging from make-to-stock (MTS) to assemble-to-order (ATO) and make-to-order (MTO). Data was collected through observations and site visits at manufacturing companies and research and development workshops in the pharmaceutical industry, consultations, and formal interviews with production managers, production planners, supply chain managers, innovation managers, engineers, and production specialists. Internal and cross-case analyses were conducted through several iterations with the pharmaceutical industry teams.

In the implementation phase of the research, given the need for a systematic method and guide for pharmaceutical manufacturing companies that may seek to develop smart production planning solutions, we will provide key steps such initiatives can follow and elements that should be carefully considered. Here, the "development steps for production planning along with a conceptual framework" propose a sequence indicating which steps should precede others.

Based on the concepts in the research background and theoretical foundations, we operationalized product, market, and process features into a set of production characteristics. For each feature, we defined a range that indicates the importance of smart production planning at three levels (low - medium - high). Therefore, when a feature is at its lowest state, the need for smart production planning is low, while at its highest state, smart production planning holds significant importance for improving performance. The range for each feature and the importance of smart production planning is summarized in Table 4. One is used for a feature at its lowest state, indicating low importance for smart production planning. Two indicates medium importance, and three is used for a feature at its highest state, correlating with high importance for smart production planning.

**Table 1.** Importance of Production Planning Environment Features for Smart Production Planning

| Category | Variable | (3) | (2) | (1) |
|---|---|---|---|---|
| **Product** | Product Flexibility | High | Medium | Low |
| | Product Diversity and Complexity | High | Medium | Low |
| | Product Life Cycle | Low | Medium | High |
| **Market** | Order Time Management | High | Medium | Low |
| | Demand Variability | High | Medium | Low |
| | Inventory Holding Capacity | High | Medium | High |
| **Process** | Process Duration | High | Medium | Low |
| | Process Flexibility | High | Medium | High |
| | Process Complexity | High | Medium | Low |

## 3. Findings

In recent years, due to the importance of biopharmaceuticals and their highly effective role in treating various diseases, research and development of these products have seen significant global growth. Many large companies have invested in this field, generating substantial economic profits for themselves and their home countries. In Iran, many active companies, such as CinnaGen and Biosun Pharmed, have made extensive investments in this area in recent years. Currently, numerous domestic pharmaceutical companies produce and supply biotechnological pharmaceutical products to the country's pharmaceutical market, and it is predicted that the number of these companies will increase in the coming years. Some of these companies include CinnaGen, AryoGen Pharmed, Pouyesh Darou, Samen, Exir, Osveh, Zist Darou Danesh, and Zahravi. Despite the achievements of Iran's biopharmaceutical industry, especially in recent years, limited research has been conducted on this industry. None of the studies have specifically addressed the importance of the need for smart production planning. We selected four case studies from the biopharmaceutical industry where the introduced framework was applied. The four cases represent four companies producing different pharmaceutical products for various markets, each with distinct processes. Consequently, they have different features in their production planning environments and smart production planning approaches.

Pharmaceutical Company (1): This company believes that product quality and safety are the most important principles in biopharmaceutical production. The company has implemented modern systems and equipment, including an environmental management system. It currently has five biopharmaceutical production lines. The market is dominated by large competitors. The company operates multiple production centers divided into five sections, each dedicated to a specific product. The main production strategy is MTS (Make-to-Stock), with smart planning for two key production stages (drug processing and packaging). The production processes are highly smart and automated, with long planning times and short production times. Raw materials, intermediates, and final products are perishable. Inventory levels are determined based on past sales and market demand forecasts.

Pharmaceutical Company (2): This company is involved in the production and marketing of chemical and biological pharmaceutical products. It is a small player in the biopharmaceutical industry. The production strategy is a combination of MTS and MTO (Make-to-Order). Product complexity is moderate, and production is highly smart and automated. MTS is used for a moderate number of pharmaceutical products, with short planning times and few production stages. MTO applies to a wider range of products, following the same basic production stages. The company is also active in the development of cell production technology to serve patients in the field of cell transplantation.

Pharmaceutical Company (3): A large company developing and selling various types of biopharmaceutical products, categorized into several product families. The company is considered an active player in the biopharmaceutical industry, with multiple smart production centers. All stages of production, from raw material selection to processing and packaging, are subject to strict quality control. The company produces a wide range of 20 different biopharmaceutical products. Product complexity is very high, with a high degree of product customization and long production planning times. The main production strategy is MTO combined with ATO (Assemble-to-Order).

Pharmaceutical Company (4): A large manufacturer and one of the leading players in the pharmaceutical market, with significant export activity. The company has a biopharmaceutical product production line and a biological vaccine production line. It operates in three key areas: research and development, pharmaceutical raw material production, and quality control. The company produces a wide range of biopharmaceutical products for different sectors. Product and process complexity is low. The production strategy is a combination of MTS and MTO. The company operates in a GMP (Good Manufacturing Practice) environment with modern equipment in the pharmaceutical industry.

The theoretical framework related to the features of the production planning environment and the need for smart production planning was used to analyze the four case studies in the biopharmaceutical industry. The findings are summarized below. For each case, the importance of smart production planning for each feature of the production environment was analyzed, and the results were expressed in terms of a score (1 to 3). A score of one indicates low importance of smart production planning for improving performance. A score of two indicates medium importance, while a score of three suggests that smart production planning is expected to improve performance significantly.

**Table 2.** Importance of Smart Production Planning Elements in the Case Study of Four Pharmaceutical Companies

| Elements of Smart Production Planning | Company (4) | Company (3) | Company (2) | Company (1) |
|---|---|---|---|---|
| **Real-time Data Management** | | | | |
| Data Analysis in Production | 2 | 3 | 2 | 3 |
| Data Security in Production | 3 | 3 | 3 | 3 |
| Production Data Extraction | 2 | 2 | 2 | 3 |
| **Dynamic Production Planning** | | | | |
| Virtual Data Mining | 2 | 3 | 3 | 2 |
| Dynamic Scheduling | 3 | 3 | 3 | 3 |
| Dynamic Learning | 3 | 1 | 1 | 3 |
| **Autonomous Production Control and Learning** | | | | |
| Self-Optimization in Production | 3 | 3 | 2 | 3 |
| Data Quality Inspection | 3 | 3 | 1 | 3 |
| Virtual and Augmented Reality | 3 | 3 | 1 | 3 |
| **Total Score** | 24 | 22 | 18 | 26 |

From Table 2, it is clear that the first pharmaceutical company scored the highest (26 points), indicating the greatest need for smart production planning elements. The fourth company ranks second, with 24 points. This company operates a smart production planning environment with three critical elements: production data security, dynamic scheduling capability, and self-optimization in production. On the other hand, the second company scored the lowest with 18 points, indicating minimal importance for smart production planning, particularly in terms of virtual reality and augmented reality, and data quality inspection. Therefore, the need for smart production planning in the second case is very low.

**Table 3.** Summar y of Production Planning Environment Features and the Importance of Smart Production Planning

| Category | Variable | Company (4) | Company (3) | Company (2) | Company (1) |
|---|---|---|---|---|---|
| **Product** | Product Flexibility | 2 | 3 | 2 | 2 |
| | Product Complexity | 3 | 3 | 2 | 3 |
| | Product Life Cycle | 2 | 2 | 2 | 2 |
| **Market** | Order Time Management | 2 | 3 | 2 | 3 |
| | Demand Variability | 3 | 3 | 3 | 3 |
| | Inventory Holding Capacity | 3 | 1 | 1 | 3 |
| **Process** | Process Time | 3 | 2 | 2 | 3 |
| | Process Flexibility | 2 | 3 | 1 | 3 |
| | Process Complexity | 2 | 3 | 1 | 3 |
| **Total Score** | | **22** | **23** | **16** | **25** |

From Table 3, we can see that the first pharmaceutical company scored the highest (22 points) in terms of the need for smart production planning. The high product diversity, short delivery time requirements, high demand variability, limited inventory holding capacity due to perishability, long process times, and low process flexibility all indicate that the planning environment's features significantly increase the complexity of smart production planning. Consequently, smart production planning has great potential to improve performance.

The second company scored 16 points, indicating a simple production planning environment with two key variables—short delivery times and high demand variability—creating pressure for smart production planning. Therefore, the need for smart production planning in the second case is very limited.

The third company, with a score of 21, indicates a moderately complex planning environment, under which smart production planning is implemented in the pharmaceutical industry. Product, market, and process features are at least moderately important. Hence, the importance of smart production planning is medium.

The fourth company scored 22 points, indicating moderate to high importance for smart production planning in its production environment. The most challenging variables include high product diversity, large volume variability, short delivery time requirements, high demand variability, and limited inventory holding capacity. Therefore, the need for smart production planning is very high.

The adoption of smart technologies in recent decades has increased dramatically due to the growing availability and affordability of computational power. Generally, companies adopt technologies in two ways: either they are pressured by industry peers through market trends, or a business need leads to a search for a technological solution. In either case, the full potential value of a technology is realized only when there is alignment between the technology, strategy, company processes (both production and support), and its planning environment. With the significant hype around Industry 4.0, it can be said that technology-driven pressure has been the primary driver of most recent research and applications.

The primary task of smart production and operations management in the production system is to convert product ideas into final products. It also involves smart production planning and control activities within manufacturing systems, which lead to a wide range of topics and research themes. For example: value creation elements in smart production planning, resource organization, optimized production scheduling, smart production planning and control, and smart logistics. In this paper, based on previous sections, we present a conceptual framework built upon relevant studies, covering five key topics: value creation mechanisms in smart production, capacity planning, production planning, scheduling, and smart logistics. Our proposed review framework for smart production planning in the production planning environment of the pharmaceutical industry is shown in Figure 1.

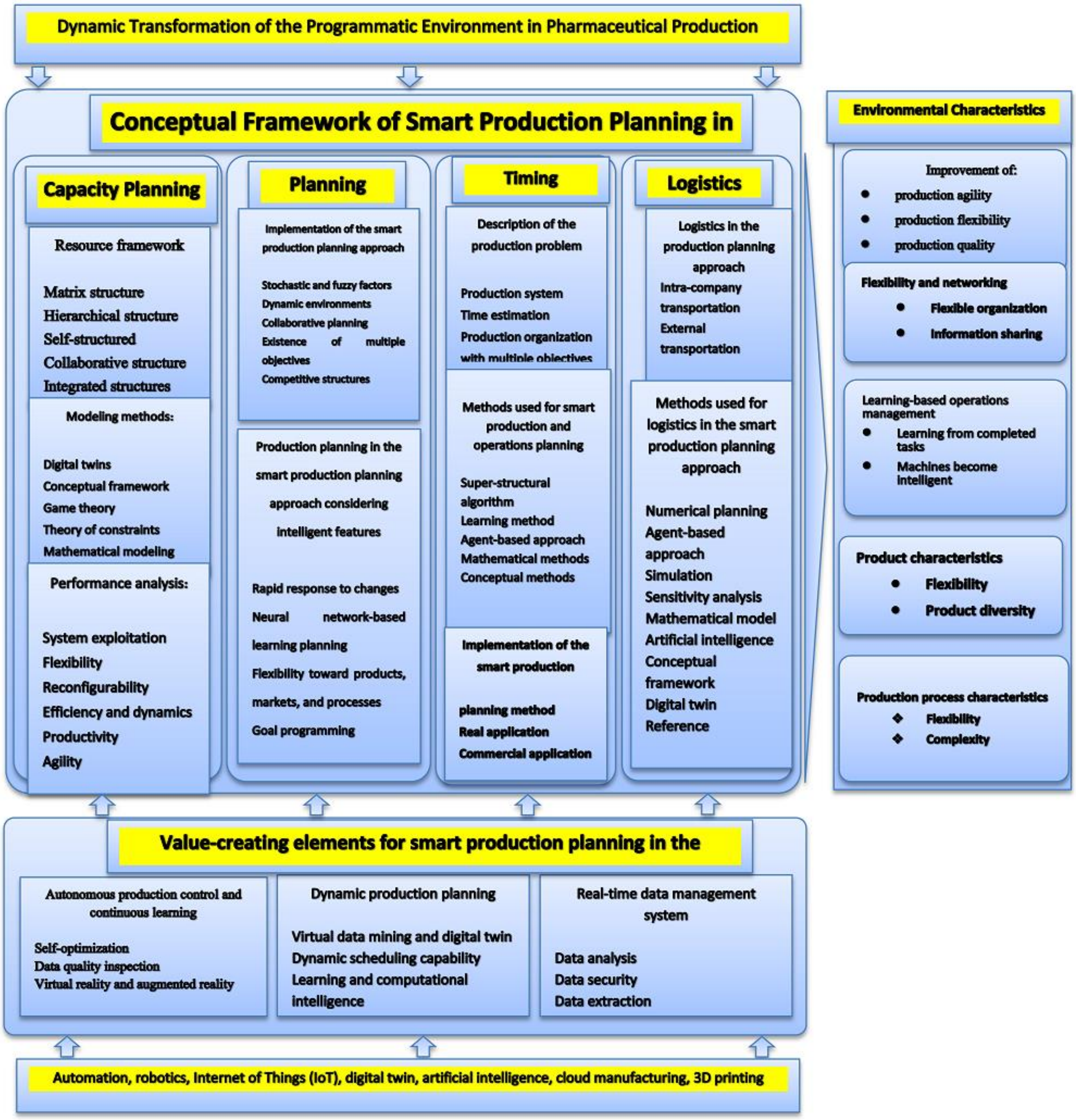


**Figure 1.** Conceptual Framework of Smart Production Planning Based on the Production Planning Environment in the Biopharmaceutical Industry

For smart production planning (and related terms within Industry 4.0), while many authors have discussed the potential impact, expectations, industry implementation experiences, and adopted strategies, there is currently no clear conceptual or developmental guide for designing and developing a smart production planning and control system. There are gaps in the conceptual frameworks, particularly regarding how smart production planning and production environment features relate to lower-level elements, data structures, the adaptation of appropriate algorithms, and so on. This is necessary to support the development of smart production planning systems that meet the short-term, medium-term, and long-term needs of a production planning system. This is particularly important for smaller pharmaceutical companies with limited research and development budgets, and now for larger pharmaceutical companies during global economic crises.

At present, no comprehensive research has provided a design and development framework for a smart production planning system. However, we attempt to address this gap by discussing the design principles for smart production planning solutions and demonstrating the use of a 9-step method for designing and developing smart production planning solutions. These nine steps are as follows:

**Step 1:** Preliminary study: Determining the goals and priorities based on the compatibility of the smart production planning environment variables in the pharmaceutical industry.

**Step 2:** Identifying gaps in the field of smart production planning based on the characteristics of the production planning environment in the pharmaceutical industry.

**Step 3:** Defining system requirements: Evaluating issues and identifying performance indicators of smart production planning.

**Step 4:** Identifying gaps in the field of smart production planning elements based on the characteristics of the production planning environment in the pharmaceutical industry.

**Step 5:** Identifying data sources, analyzing and selecting appropriate algorithms related to smart production planning.

**Step 6:** Designing a smart production planning system and integrating data with existing systems and technologies in the smart manufacturing industry.

**Step 7:** Presenting long-term development methods, continuous innovation, and compatibility with smart production planning in the pharmaceutical industry.

**Step 8:** Solving with mathematical models using multi-objective algorithms and defining the conceptual approach for smart production planning.

**Step 9:** Testing, validating, and implementing the mathematical model, summarizing, and providing IT suggestions for further actions.

In recent decades, the adoption of smart technologies has increased dramatically due to the growing availability and affordability of computing power. Generally, companies adopt technology in two ways: either a company (or its leadership) is pressured by industry peers through a market trend, or a business need leads to the search for a technological solution. In either case, the potential value of technology is fully realized only when there is alignment between the requirements and application of the technology, the company's strategy, its processes—both production and support—and its planning environment. With the massive hype surrounding Industry 4.0, it can be said that technological pressure has driven most recent research and applications.

From the perspective of pharmaceutical industry experts, several challenges must be addressed as the industry transitions toward smart production planning, including the following:

**Table 4.** Challenges in Transitioning to Smart Production Planning

| Challenges | Description |
|---|---|
| Data Value | Data and digitalization are essential parts of smart production planning, but the value of data sharing and utilization is not fully recognized. Supply chain actors face difficulties agreeing on the distribution of costs and risks related to data collection, storage, processing, and sharing. |
| Data Sharing | The exact data useful for smart production planning is still unknown. Challenges include over-collection, insufficient data, relevant data, and incompatible data formats. |
| Cost of Smart Technology | High initial investment and hidden costs, such as maintenance, upgrades, and the need for higher-skilled personnel, may deter companies from investing in smart production planning technologies. |
| Infrastructure | Realizing the potential benefits of smart production planning requires infrastructure investment, such as data collection on production lines and automation. Challenges include integrating and implementing various technologies. |
| Resistance to Smart Technology | Organizations may have heavily invested in traditional information systems like ERP and MES. Further investigation is required to demonstrate the benefits of adopting and integrating more digital technologies. |

## 4. Discussion and Conclusion

The results of this study highlight the significant impact of Smart Production Planning and Control (SPPC) on optimizing pharmaceutical production environments. Through the integration of real-time data, adaptive scheduling, and automation, SPPC systems have demonstrated the ability to address the complexities associated with pharmaceutical production, including regulatory compliance, product variability, and the need for rapid responses to market demands. The findings align with previous studies that have shown the potential of SPPC in improving production efficiency, reducing costs, and enhancing operational flexibility [1, 9-11]. Moreover, the results indicate that companies utilizing SPPC systems experience greater agility in their production processes, allowing them to quickly adapt to changes in demand and supply chain disruptions.

One of the key outcomes of this research is the confirmation that SPPC systems contribute to the reduction of production delays and operational costs by optimizing resource allocation and minimizing waste. This finding is supported by the work of Bean and Davenport (2019), who emphasized the importance of data-driven decision-making in improving operational performance [15]. By providing real-time insights into production operations, SPPC systems enable managers to make informed decisions regarding resource allocation, production scheduling, and quality control. This leads to more efficient production processes and, ultimately, cost savings for pharmaceutical manufacturers. Additionally, the ability of SPPC systems to manage real-time data allows for more accurate forecasting and demand planning, further reducing the risk of stockouts or overproduction [6].

Another important result of this study is the role of automation in enhancing the flexibility and responsiveness of pharmaceutical production. The automation capabilities of SPPC systems enable pharmaceutical manufacturers to automate routine tasks, such as production scheduling and inventory management, allowing for a more dynamic and responsive production process [8]. This is particularly important in the pharmaceutical industry, where production processes are often subject to sudden changes in demand due to factors such as regulatory approvals, market conditions, and public health crises. The findings align with the work of Oluyisola et al. (2022), who demonstrated that automation in SPPC systems allows for greater agility in production processes, enabling manufacturers to quickly respond to changes in the production environment without sacrificing efficiency or quality [10].

The study also highlights the role of SPPC systems in ensuring regulatory compliance in the pharmaceutical industry. Compliance with regulatory standards is a critical concern for pharmaceutical manufacturers, as any deviations from the production plan can result in costly delays or product recalls [12]. SPPC systems address this issue by providing real-time monitoring and control of production processes, ensuring that all production activities are carried out in accordance with regulatory requirements. This finding is consistent with previous research by Jahed and Tavakoli Moghadam (2020), who noted that the ability of SPPC systems to monitor production processes in real time allows for greater transparency and accountability in the production process, reducing the risk of regulatory non-compliance [2].

Furthermore, the results indicate that the integration of big data and advanced analytics in SPPC systems significantly improves production decision-making. By analyzing large volumes of data collected from various stages of the production process, SPPC systems provide valuable insights into production performance, enabling manufacturers to identify inefficiencies and implement corrective actions [5]). This capability is particularly important in the pharmaceutical industry, where production processes are often highly complex and involve multiple stakeholders. The findings of this study support the work of Kusiak (2017), who emphasized the importance of big data in enabling smart manufacturing systems to optimize production processes and improve decision-making [14].

The study's results also show that SPPC systems play a key role in improving supply chain management in the pharmaceutical industry. The integration of real-time data from production and supply chain systems enables pharmaceutical manufacturers to better coordinate their production activities with suppliers and distributors, ensuring that materials are available when needed and that finished products are delivered to market in a timely manner [19]. This finding aligns with the research conducted by Romsdal et al. (2021), who highlighted the importance of smart production planning in managing supply chain relationships and ensuring the efficient flow of goods throughout the supply chain [16].

While this study provides valuable insights into the role of SPPC systems in optimizing pharmaceutical production, there are several limitations that must be acknowledged. First, the study relies on case studies from a limited number of pharmaceutical companies, which may not be representative of the entire industry. As a result, the findings may not be generalizable to all pharmaceutical manufacturers, particularly those operating in different regulatory environments or with different production processes. Additionally, the study focuses primarily on the technical aspects of SPPC systems, such as data integration and automation, without considering the potential organizational and cultural challenges associated with implementing these systems. Future research should explore these aspects to provide a more comprehensive understanding of the factors that influence the successful implementation of SPPC systems.

Another limitation is the lack of longitudinal data, which makes it difficult to assess the long-term impact of SPPC systems on production performance. While the study demonstrates the short-term benefits of SPPC, such as improved production efficiency and cost savings, it is unclear whether these benefits can be sustained over time. Future research should consider conducting longitudinal studies to examine the long-term effects of SPPC on production performance, particularly in terms of regulatory compliance and market responsiveness.

There are several avenues for future research that could build on the findings of this study. First, researchers should consider expanding the scope of the study to include a larger and more diverse sample of pharmaceutical companies, including those operating in different geographical regions and regulatory environments. This would provide a more comprehensive understanding of the factors that influence the adoption and implementation of SPPC systems in different contexts.

Additionally, future research should explore the organizational and cultural factors that impact the successful implementation of SPPC systems. While this study focuses primarily on the technical aspects of SPPC, it is important to consider the human and organizational elements that can influence the adoption of new technologies. For example, future research could examine how organizational culture, leadership, and employee engagement affect the implementation of SPPC systems in pharmaceutical manufacturing.

Finally, future studies should investigate the potential for integrating SPPC systems with other emerging technologies, such as blockchain and AI-driven quality control systems. These technologies have the potential to further enhance the capabilities of SPPC systems, particularly in areas such as supply chain transparency and predictive maintenance. Research in this area could provide valuable insights into how pharmaceutical manufacturers can leverage these technologies to create more efficient and resilient production systems.

For pharmaceutical manufacturers looking to implement SPPC systems, there are several practical considerations that should be taken into account. First, companies should invest in building the necessary infrastructure to support the integration of real-time data and automation into their production processes. This may require upgrading existing production equipment or investing in new technologies, such as IoT sensors and cloud computing platforms, to enable seamless data flow across the production environment.

Second, manufacturers should prioritize training and development programs for their employees to ensure that they have the skills and knowledge needed to operate and maintain SPPC systems. This may involve providing specialized training in areas such as data analysis, automation, and regulatory compliance, as well as fostering a culture of continuous learning and innovation within the organization.

Finally, pharmaceutical companies should adopt a phased approach to the implementation of SPPC systems, starting with pilot projects in specific production areas before scaling up to full implementation. This allows companies to test the effectiveness of SPPC systems in a controlled environment, identify any potential challenges, and make adjustments as needed before rolling out the system across the entire production facility. By taking a gradual and strategic approach to implementation, pharmaceutical manufacturers can minimize the risk of disruption and ensure a smoother transition to smart production planning.

## Authors' Contributions

Authors equally contributed to this article.

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## Declaration of Interest

The authors report no conflict of interest.

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## Ethical Considerations

All procedures performed in this study were under the ethical standards.

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