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# Smart Production Planning and Control: Do All Planning Environments need to be Smart?

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**Abstract:** As part of Industry 4.0, the concept of smart production planning and control (PPC) is emerging. In this paper we develop a theoretical framework that links the characteristics of a company's planning environment with the need for smart PPC. We show that the potential of smart PPC to improve performance increases with the complexity of the planning environment. The framework is tested in four empirical cases and shows that smart PPC is strongly needed in some planning environments, while in others not. The framework can assist companies in prioritising the areas where smart PPC has the highest potential.



*Keywords:* Production planning and control, Industry 4.0, smart, cases

## 1. INTRODUCTION

The goal of production planning and control (PPC) is to produce what the market demands, in the expected quality, volumes and timing, at minimum cost. Today, a combination of increasing products, volatile market demands, and process complexity is making PPC more challenging (Oluyisola et al., 2020). A key element of operations management is therefore to continuously ensure a good fit between the PPC system and the production, taking into consideration the characteristics of the planning environment with regards to product, market and process characteristics.

With the rapid advances in Industry 4.0, the concept of smart manufacturing is emerging. But standard PPC systems have shown several limitations in their capacity to support the operational requirements of today's dynamic and often turbulent business environment. Regular PPC systems are often slow, relatively static, unwieldy, and do not present an up to date, near real time information about the status of manufacturing operations. Moreover, very few empirical case studies have been reported that specifically focus on the role of PPC in achieving smart manufacturing or how Industry 4.0 can be used to improve PPC (Moeuf et al., 2018, Sun et al., 2019, Ren et al., 2015). It has been suggested that so-called smart PPC has the potential to improve performance by supporting real-time, data-driven and continuous learning and decision support from a more diverse range of data sources than before (Oluyisola et al., 2020) – where the idea is to convert data into knowledge which can be used for PPC. According to (Oluyisola, 2021), smart PPC can be defined as:

*"the integration of emerging technologies and capabilities in the industry 4.0 framework with PPC processes to improve the performance of the production system by enabling real-time, data-driven decision-making and continuous learning with input from a more diverse range of sources."*

Several papers have investigated how emerging technologies can be used for smart PPC (see Bueno et al., 2020 for an overview) – but before we start implementing new technologies, it is necessary to understand in which situations smart PPC has the largest potential to improve performance. The purpose of this paper is therefore to investigate how the characteristics of a company's planning environment impact on the need for smart PPC.

In section 2 the methodology is described, and section 3 provides an overview of the theoretical background. In section 4 we develop a conceptual framework linking product, market and process variables with the need for smart PPC. The framework is subsequently used to analyse four empirical cases in section 5. Section 6 discusses the insights from the study and presents some suggestions for further research.

## 2. METHOD

Previous literature on characterising production planning environments was reviewed and a number of relevant theoretical frameworks were identified. Together with insights from industry, these frameworks were used to identify, define and structure the variables expected to have the largest impact on the need for smart PPC into a theoretical framework. The resulting framework was then used as a tool to logically derive how each variable affects the need for smart PPC. This was done through discussions in the project team, with several iterations. The framework was subsequently used to map and analyse four empirical cases. The cases were selected to represent different planning environment characteristics and PPC 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, workshops, meetings, and formal interviews with production managers and planners, supply chain directors and managers, innovation managers and engineers. The within and cross-case analyses were carried out through several iterations in the project team.


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## 3. THEORETICAL BACKGROUND

The section provides an overview of the topic's theoretical background. It begins with the definition of PPC, Industry 4.0, and the challenges related to the adoption of Industry 4.0 within PPC. Then the planning environment characteristics are introduced that are used in the proposed framework in section 4. And finally, smart, data-driven PPC, which can be considered as the consequence of applying industry 4.0 within PPC, will be assessed at the end of the section.

### *3.1 PPC and Industry 4.0*

PPC can be considered as the required principles and decisions to guarantee the availability of resources needed to satisfy customer demand (Slack et al., 2010). Planning refers to the long-term decisions concerned with future happenings, whilst control is the monitoring of operations and coping with any deviations from the plan for instance through re-planning (Slack et al., 2010). In general, PPC processes determine which products to produce, in which volumes and at what time in order to meet customer demand. Traditionally, planning in production companies is carried out using enterprise resource planning systems (ERP), manufacturing execution system (MES) and advanced planning and scheduling (APS) systems. However, these systems still depend on some human inputs, such as the planning logic and principles, and parameter settings, as well as evaluation of the feasibility of the planning proposals the systems provide (Dannapfel et al., 2019).

With developments in technology associated with Industry 4.0, there is a trend towards creating self-controlled operations and integrated systems. Industry 4.0 can enable a real-time connection between resources, services, and humans throughout the planning and control of the production phase based on smart technologies such as cyber-physical systems (CPS), the internet of things (IoT), big data analytics (BDA) and machine learning (ML) (Oluyisola et al., 2020, Stock et al., 2018). These integrated systems generate enormous amounts of data – providing opportunities planning, controlling, and re-planning in real-time.

However, the results of some recent studies indicate that many companies are facing challenges in their efforts towards adoption of BDA, ML and the other related smart technologies on their road towards smart PPC (Bean and Davenport, 2019). From the practical point of view, these challenges are related to both intra and interorganizational factors. Intraorganizational factors define the working principles and the control of processes within an organization, while interorganizational factors can constrain or enable a company's adoption of Industry 4.0 technologies for PPC within the supply chain (Oluyisola et al., 2020). Therefore, consideration of such constraints and factors play an important role in selecting and implementing smart technologies towards smart PPC.

### *3.2 Planning environment characteristics*

Planning environment characteristics provide an understanding of the environment in which PPC is conducted and can therefore assist in identifying the PPC contexts where smart PPC is most beneficial. Following the approach of Jonsson and Mattsson (2003), for the purposes of this study we describe planning environments in terms of their product, market and process characteristics. Building on the existing framework of Romsdal (2014), we identified a set of variables which we expect have the largest impact on the need for smart PPC. For our purposes, some variables from the Romsdal framework have been excluded or adjusted, while others have been added, depending on their impact on the need for smart PPC. Demand uncertainty is changed to demand variability because variability can be modelled and, in some ways, controlled thanks to the analysis of data collected from the market. Further, product perishability is excluded since the effect of this characteristic is captured in the inventory management variable. Stock-out rates in retail stores is not included since it does not have a direct effect on PPC. Make-to-order lead time is changed to the more generic term process lead time. The variable plant, processes and technology is replaced by the two variables process flexibility and process complexity since these two help organizations and operations managers decide about the required level of smartness in their PPC. Lastly, supply uncertainty is changed to supply variability since variability can be modelled and, in some ways, controlled.

The revised framework for describing planning environments consists of the following characteristics and variables. **Product characteristics** consist of four product-related variables. *Product complexity* is defined as the number and interrelatedness of product components. *Product variety* is defined as the level of variety demanded by the market. *Product life cycle (PLC)* describes the length of a product's life cycle from launch to termination, including the frequency of new product introduction. *Product volume variability* is the variability related to demand predictability. **Market characteristics** consist of four market-related variables. *Delivery lead time* refers to the time between customer order and delivery, while *delivery lead time variability* refers to variability related to lead time predictability. *Demand variability* describes the predictability of demand. *Inventory management* is defined as the ability to keep inventory of raw materials, work in progress and finished goods, also reflecting product perishability. **Process characteristics** consists of four process-related variables. *Process lead time* is defined as the time between starting and terminating a process. *Process flexibility* refers to the ability to change status within an existing configuration, and *process complexity* refers to the number and interrelatedness of processes. *Supply variability* is defined as the predictability and stability of supply.

Consideration of excessive capacity buffer and safety stock, lack of feedback on the accuracy of resource planning, uncertainties in demand forecasts, periodically running of the production planning process while the demand situation is changing continuously, and adaptability of the PPC within the operational level are only some of the challenges that traditional PPC is faced with them in different levels of decision-making. Smart, data-driven PPC, due to providing and using real-time data, can reduce the uncertainty in the planning and leads to more accurate decisions, reduction of different sources of waste and finally it provides the competitive advantage for the company (Oluyisola et al., 2020).

### *3.3 Smart, data-driven production planning and control*

A recent systematic literature review conducted by Bueno et al. (2020) presents an analytical framework explaining the relationship between PPC, Industry 4.0, performance measurements, and environmental factors. They define smart PPC in terms of smart capabilities, i.e. *"capabilities and resources that leverage the PPC function and its activities toward digitalization, integration, and automation through the exploration of smart technologies, as well as the mechanisms of networking power, applied in smart manufacturing planning and control"*. Thus digitalization, integration of systems, and automation are considered the three drivers of smart capabilities for PPC. Further, the authors identify the required smart capabilities for PPC, identify environmental factors that influence the development of smart capabilities by PPC, and determine some performance measurements as the results of the integration of PPC with Industry 4.0.

The application of advanced data processing, data analytics, data storage, and cloud technologies can be perceived as results of digitalization – where digitalization is a key step to increase the level of automation and leading to smart PPC (Bendul and Blunck, 2019). In most companies PPC is carried out based on inaccurate data (Dombrowski and Dix, 2018). In addition, there are many unanticipated and unforeseen changes during production operations which needs quick responses. After such changes, the planning and controlling phases should be reconsidered and therefore real-time and updated data is required. Applying smart PPC and related technologies can provide access to real-time data based on the current situation and provide PPC decision makers with access to more and qualified data to support and facilitate PPC (Strandhagen et al., 2011).

Building on the concept of smart PPC, Bresler et al. (2020) studied how different types of data from producers and downstream supply chain actors can affect PPC decisions and improve PPC. They proposed a set of principles for data-driven PPC, focusing both on the use of different and new types of data, using data differently for PPC, and how data can enable strategic changes in the way PPC is carried out. For instance, they propose that data on promotional plans and seasonal demand should be shared and transformed into data to be used for PPC, tacit planning knowledge and experience on PPC should be captured and transformed into data for PPC, real-time performance should be captured, measured and used for performance visualization and PPC, and information on sustainability should be captured and visualized to allow for consideration of trade-offs in PPC.

## 4. THEORETICAL FRAMEWORK

The purpose of the paper is to investigate how the characteristics of a company's planning environment impact on the need for smart PPC. To do this, we operationalised product, market and process characteristics into a set of variables. For each variable, we defined a range indicating the importance of smart PPC (low - medium - high). Thus, when a variable is at its lowest setting, smart PPC is of low importance for PPC, while at its highest setting, smart PPC has a large potential to improve PPC. Below, the logic of the importance of smart PPC is described for each variable in the three categories of planning environment characteristics, accompanied with examples of the importance of data in PPC.

***Product characteristics:*** the digitalization of product data, such as bills of materials, products attributes, production flow charts, production recipes, etc., enables a company to collect and make available a great amount of information which can be used for PPC purposes.

- **Product complexity (low – medium – high)**: the higher the complexity, the higher the need for smart PPC. For example, through smart PPC a company can more efficiently collect and store product data, update such data, and enable real-time changes and replanning (such as capacity and material requirements).
- **Product variety (low – medium – high):** the higher the variety, the higher the need for smart PPC. For example, smart PPC can simplify the management of the different products through a more proactive definition and analysis of product families.
- **PLC (long – medium – short):** the shorter the PLC, the higher the need for smart PPC. For example, with regards to product variety, it is beneficial to have access to more and up-to-date data when the product assortment changes frequently so that PPC processes can adapt themselves quickly to a new product mix.
- **Product volume variability (low – medium – high):** the higher the volume variability, the higher the need for smart PPC. For example, it is essential to be able to foresee product volume behaviour over time, and forecasting accuracy relies on the availability of up-to-date demand data and knowing how to exploit this data in PPC in a smart way.

***Market characteristics:*** huge amounts of data can be gathered from the market, including point-of-sale (POS) data and data on promotional activities, seasonal promotions, weather, and population density data. The use of such data can provide input to BDA and ML, leading to better insights into consumer demand.

- **Delivery lead time (long – medium – short):** the shorter the lead time, the higher the need for smart PPC. For example, real-time data on consumer demand can provide more up-to-date and accurate insights for PPC.

- **Delivery lead time variability (low – medium – high):** the higher the variability, the higher the need for smart PPC. For example, the smart use of data on delivery lead times enables planners to better predict the behaviour of the delivery system.
- **Demand variability (low – medium – high):** the higher the variability, the higher the need for smart PPC. For producers, more up-to-date data on consumer demand is an essential input to PPC in order to foresee and manage demand variability.
- **Inventory management (high – medium – low):** the lower the ability to keep inventory, the higher the need for smart PPC. For example, more real time data on remaining shelf life enables more reactive and proactive PPC. This is particularly relevant when inventory levels are low since the risk of stockouts is higher.

***Process characteristics:*** with the use of Industry 4.0 technologies, data from the production system can be captured and combined with external data about factors which can affect the production performance. The use and analysis of such data enables a better understanding of how the production system work.

- **Process lead time (short – medium – long):** the longer the lead time, the higher the need for smart PPC. For example, when process lead times are long, more data is necessary to have a clear and real-time overview of the entire process and its potential variability.
- **Process flexibility (high – medium – low):** the lower the flexibility, the higher the need for smart PPC. For example, when a process is rigid and setup times are long, more data is useful to assess possible constraints and limitations on the production system. Oppositely, a flexible process can more easily be adapted to changes in the planning environment, reducing the need for smart PPC.
- **Process complexity (low – medium – high):** the higher the complexity, the higher the need for smart PPC. For example, high process complexity requires availability of more accurate, detailed and real time data about the process for the use in PPC.
- **Supply variability (low – medium – high):** the higher the variability, the higher the need for smart PPC. For example, if supply is highly variable, up-to-date data from suppliers is essential in order to foresee and manage variability through the planning of purchasing, inventory and production.

The range of each variable and the importance of smart PPC are summarised in Table 1. One star (*) is used for the variable at its lowest setting, indicating a low importance of smart PPC. Two stars (**) indicates medium importance of smart PPC, and three stars (***) is used for the variable at its highest setting, associated with a high importance of smart PPC.

**Table 1. Planning environment characteristics' importance for smart PPC**

| | | Importance of smart PPC | | |
|---|---|---|---|---|
| Category | Variable | * | ** | *** |
| Product | Product complexity | Low | Medium | High |
| | Product variety | Low | Medium | High |
| | PLC | Long | Medium | Short |
| | Product volume variability | Low | Medium | High |
| Market | Delivery lead time | Long | Medium | Short |
| | Delivery lead time variability | Low | Medium | High |
| | Demand variability | Low | Medium | High |
| | Inventory management | High | Medium | Low |
| Process | Process lead time | Short | Medium | Long |
| | Process flexibility | High | Medium | Low |
| | Process complexity | Low | Medium | High |
| | Supply variability | Low | Medium | High |

## 5. CASES

The following paragraphs illustrate the four empirical cases we selected where the here introduced framework was used. The four cases represent four companies producing different products for different markets, with distinctive processes. Consequently, they have different planning environment characteristics and PPC approaches.

Case A is medium-sized producer of nuts, sugar confectionery and chocolate. The market is dominated by large competitors. The company has one production facility, and this is divided into three sections, one for each product type. The production strategy is mainly MTS, with separate planning of the two main production steps of processing and packing. The production processes are highly integrated and automated, and setup times are long, while production lead times are short. Both raw materials, intermediates and finished products are perishable. Demand variation is high due to effects of seasonal demand, frequent promotional campaigns, and production introductions several times a year.

Case B is a small producer of natural mineral water in plastic and glass bottles. The production strategy is a combination of MTS and MTO. The product complexity is low, and production is highly integrated and automated, with short lead times. MTS is applied for a limited number of products where set up times are short and the number of production steps low. MTO is applied for a wider variety of products, and these go through the same main production steps, but with longer set up times than for the MTS variants.

Case C is a large company that develops, produces and sells several variants of baling machines to agriculture and industry, classified into three product families. The company is considered as a small player in the larger agricultural equipment and systems industry and has one production facility. The product complexity is very high, there is a high level of product customization, and production lead times are long. The main production strategy is MTO combined with ATO.

Case D is a large producer of plastic pipe systems and a member of one of Europe's leading conglomerates in the market, with considerable export. The company produces a wide range of quality pipe systems for different sectors. The complexity of the products and production processes is low. The production strategy is a combination of MTS and MTO. A key challenge for the company is to reduce inventory level.

The theoretical framework linking planning environment characteristics with the need for smart PPC in Table 1 was used to analyse four empirical cases. The findings are summarised in Table 2. For each case, the importance of smart PPC per variable was analysed and the result expressed as stars. One star (*) indicates that the setting of the variable in the company means that smart PPC does not have much potential to improve performance in the company. Two stars (**) indicates a medium importance of smart PPC, and three stars (***) indicates that smart PPC can be expected to bring performance improvements. The total number of stars per case is shown in the bottom row.

**Table 2. Cross-case summary of planning environment characteristics and importance of smart PPC**

| | | Case | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| Category | Variable | Importance of smart PPC | | | |
| Product | Product complexity | * | * | *** | * |
| | Product variety | *** | * | *** | *** |
| | PLC | ** | * | ** | ** |
| | Volume variability | ** | ** | ** | *** |
| Market | Delivery lead time | *** | *** | ** | *** |
| | Delivery lead time variability | * | * | *** | ** |
| | Demand variability | *** | *** | *** | *** |
| | Inventory management | *** | ** | ** | *** |
| Process | Process lead time | *** | * | *** | ** |
| | Process flexibility | *** | * | ** | ** |
| | Process complexity | ** | * | *** | * |
| | Supply variability | ** | * | ** | * |
| | Totals (out of 36) | 28 | 18 | 30 | 26 |

From the table, we can see that **Case A** obtained 28 out of a potential 36 stars. The company's large product variety, short delivery lead time requirements from customers, high demand variability, limited ability to keep inventory due to perishability, long process lead times, and low process flexibility indicate that the many of the characteristics of the planning environment severely complicate PPC and thus that smart PPC has a high potential to improve performance. **Case B** obtained 18 stars out of 36. The company has a fairly simple planning environment, where the two most challenging variables that push for smart PPC are short delivery lead time requirements from customers and high demand variability. Thus, the need for smart PPC in case B is fairly limited. **Case C** is the company with the highest number of stars (30 out of 36), reflecting the complicated planning environment under which PPC is conducted. Both product, market and process characteristics are at their least favourable or medium setting. Thus, the potential for smart PPC is very high. **Case D** obtained 26 stars, indicating a medium to high complexity in the planning environment. The most challenging variables are high product variety, high volume variability, short delivery lead time requirements, high demand variability and limited ability to keep inventory. Thus, the potential for smart PPC is high. The cross-case analysis shows that the relevance of smart PPC is high in three of the cases (Case A, Case C and Case D) and less relevant in Case B. This coincides with the companies' present interest in Industry 4.0 as well, where Case A, Case C and Case D are expressing a stronger interest than Case B in investigating the potential of Industry 4.0 technologies for PPC.

## 6. DISCUSSION AND CONCLUSIONS

There are great expectations both in industry and academia around the potential of Industry 4.0 to transform and improve operations. A plethora of technologies are emerging, and many companies are struggling to decide which technologies to invest in. The purpose of this paper was therefore to investigate the potential of smart PPC to improve performance, given the specific characteristics of a company's planning environment.

The developed framework in section 4 serves two purposes. It firstly provides a tool to structure and describe a company's planning environment with regards to product, market and process characteristics. The insights from such a mapping of planning environment characteristics can be useful also for other purposes, e.g. for identifying the need for efficiency vs. responsiveness (Romsdal, 2014), for identifying production planning and control methods (Jonsson and Mattsson, 2003), and in supply chain design decisions (Pagh and Cooper, 1998).

The second contribution of the framework is the linking of planning environment characteristics with smart PPC. The underlying logic is that the potential of smart PPC to improve performance increases with the complexity of the planning environment. The highest setting for each of the variables represent key challenges for PPC in general – and thus the potential for utilising Industry 4.0 technologies for smart PPC is high. Thus, a company can use the framework to firstly identify the most challenging aspects of its planning environment, secondly to prioritise the areas where smart PPC has the highest potential, and finally to select the Industry 4.0 technologies that can enable the required level of PPC smartness.

Data is an essential part of smart PPC, and some examples of how data can enable smart PPC were provided in section 4. Building on the concept of data-driven PPC, Industry 4.0 technologies can enable capturing new types of data from a company's operations and the supply chain, which can be combined with existing data for use in PPC, thus providing more complete and real-time data sets. Further, data can be used in new ways in PPC, e.g. by digitising tacit planning knowledge, using artificial intelligence to support decision making and automate PPC processes and decisions. And finally, data can enable strategic PPC changes, such as integrating sustainability measurements in performance management systems and enabling more order-based PPC approaches to meet the demand for more low-volume product variants and customised products.

The multiple case study demonstrated the applicability of the framework. We found that the companies with the most challenging planning environments were also the ones who are already demonstrating the most interest in investigating the potential of smart PPC. The cases also illustrate that smart PPC is not needed in all planning environments. And similarly, that a company does not necessarily need to exploit all the capabilities of smart PPC to improve performance.

The framework helps to priories areas for smart PPC but does not assist in identifying which specific technologies that could enable smart PPC. The next step for the study is therefore to identify specific technologies that can enable smart PPC for each planning environment characteristic, and investigate how this affects performance, i.e. how smart PPC can overcome the least favourable setting for each variable. A quantification of expected benefits can then assist in evaluating the return on investment for specific technologies in specific planning environments. A limitation of the study is the low number of cases and limited data sets, and future studies could extend the analysis with a broader survey and structural equation modelling to identify some specific relations between planning environment characteristics and the needs for smart PPC.

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