Principles and Research Agenda for Sustainable, Data-Driven Food Production Planning and Control

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Abstract. This paper investigates the topics of data, sustainability, and production planning and control in food supply chains from the perspective of industrial food producers. To stay competitive in an industry with low profit margins, strong competition, and sustainability concerns, food producers need new solutions. The capture, digitization, and use of producer and downstream supply chain data enable opportunities for using data in new ways to address the existing challenges. This study proposes some principles for sustainable, data-driven production planning and control (PPC) such as capturing real-time data and tacit knowledge for use in PPC. It then investigates how these principles can impact the sustainability for food producers and the overall supply chain, by giving benefits such as reduced food waste, lower inventory levels, and reduced planning time and effort. Future research topics should address topics such as data availability, use of data in PPC, potential value of data, sustainability trade-offs, and the applications of digital technology in PPC.

Keywords: Food industry, Production planning and control, Sustainability

1 Introduction

Previous studies have highlighted a need to increase sustainability and reduce food waste in food supply chains [1, 2], and companies need to investigate novel ways of increasing sustainability. A major contributor to food waste is an imbalance in supply and demand [3, 4], where for instance unsold inventories of perishable products produced in advance of customer orders are scrapped in large amounts in all stages of the supply chain [5]. Data and information sharing in supply chains has long been widely heralded for the potential to better match supply and demand [6-8]– leading many companies to invest heavily in information technologies to manage data and information [9, 10]. Further, advanced concepts and models for supply chain collaboration and information sharing have been developed, such as efficient consumer response, and collaborative planning, forecasting and replenishment [11, 12]. Yet, after over 30 years of research and development, few companies actually share information and proliferation of both technologies and models for supply chain information sharing remains limited [13, 14]. Simultaneously, the rise of digital technologies has a potential to transform the way data is used, both to improve current operations and innovate how processes in supply chains are carried out [15, 16].

This paper investigates data sharing in food supply chains from the perspective of industrial food producers. Based on the assumption that data from downstream actors is available, the purpose of the paper is to propose a set of principles for how such external data can be used and combined with internal data to change the way food production is planned and controlled – with an ultimate aim of reducing food waste and increasing sustainability. The result is a research agenda that outlines issues and ideas for how to achieve sustainable, data-driven planning and control of food production.

2 Theoretical Background

2.1 Sustainability and Food Supply Chains

In addition to the overriding necessity to be economically viable, society now expect firms to balance their financial, environmental, and social goals [17]. For environmental aspects, since planning and control includes managing resources, the consumption of resources such as water, energy, and materials are relevant. Also, along with food waste, other wastes and pollution can be created during manufacturing such as greenhouse gas emissions, waste-water, or other non-food production waste including hazardous waste, food losses, and packaging material waste [18]. Social metrics that relate directly to PPC are more difficult to identify, but PPC utilizes human personnel, so job satisfaction is as an important aspect to consider [19]. Furthermore, the food industry has distinguishing characteristics that set it apart from other industrial sectors. Food is perishable, so there are product-dependent constraints on inventory holding time as well as handling and storage environment requirements. Industrial food production seeks maximize efficiency and minimize long change-over and set-up times. Production is sequence dependent, with certain colors, flavors, and allergens produced after others to shorten the changeovers as well. Demand of some food products is dependent on seasons, holidays, and promotions. Food supply chains consist of many actors, including raw material suppliers, producers, wholesalers, retailers, and consumers [20].

2.2 Planning and Control of Production and Supply Chains

PPC can follow a variety of strategies, from engineer-to-order to make-to-stock (MTS) strategies; the difference is how much planning and production is based on customer orders or forecasts. For MTS, production is based on forecasts which are made using methods that include moving average, exponential smoothing, and algorithms accounting for trend and seasonality. After forecasting, production planning is done periodically at different aggregation levels (by time or groups of products) and must also be integrated with the inventory distribution needs at various stages of the supply chain. Plans are typically created using enterprise resource planning (ERP) and advanced planning and scheduling (APS) software systems, but these plans are not integrated and optimized across supply chain actors [21].

However, it is becoming increasing necessary for manufacturing firms compete not just individually with other firms, but as a supply chains since a lot of the profitability is derived through proper planning and control of the activities of the extended supply chain [22]. Supply chain planning and control takes into account the needs of multiple supply chain actors together. This is important as many benefits, such as reduced bullwhip, can be gained by thinking about how to optimize the whole system and not just the processes of one actor. [23] presented the Principles for Intelligent, Demand-Driven Control as a step towards realizing more demand-driven supply chain relationships. These principles include capturing and using real-time data for decision-making and performance measurement, sharing data across the supply chain, and moving the customer-order-decoupling-point (CODP) toward less-forecast based and more order-based approaches such as make-to-order (MTO).

2.3 Digital Technology

Traditionally, planning and control was carried out through the use of ERP and APS systems for planning, using input static and historical data and optimization parameters to plan production. However, these systems still heavily rely on human input for updating parameters and providing accurate and complete data. To make production "smarter", there is a growing trend to use Industry 4.0 methods such as artificial intelligence (AI) to address a wide variety of industrial challenges. AI is a broad category of learning-based algorithms that have the potential to find patterns in data that humans cannot and use these underlying patterns to make suggestions in, for example, the planning and control of food production. There is research being done to apply AI to PPC, with application areas such as product family and layout optimization, identifying the right control strategy, and predicting supply chain disruptions [24, 25].In order to use digital technology, the data must be collected and digitized. RFID and networked sensors can collect and transmit data in real-time to give a picture of the current state various points in the supply chain, from production to inventory [26]. While there is not yet a consensus among practitioners about how or whether all data has value and what specific data has value, it is believed that real-time process-monitoring data is useful in forecasting and production situations [16], and data such as remaining shelf life has been shown to improve alignment of supply and demand [27].

3 Method

This is a conceptual paper that explores the use of data to improve PPC. In the theoretical background, we outlined key concepts and trends that are expected to have an impact on PPC in the food sector. Through the illustrative example of a food producer, we highlight current practices and challenges to show the industry need and desire for data-driven PPC. These are then used in the following chapter to develop a set of principles for sustainable, data-driven PPC by considering the challenges of current food PPC, what different types of data are useful to PPC, what new data and technology are now available, and how the data should be used within existing or new processes. We then discuss their potential impact on sustainability because, while the principles do have specific elements of sustainable practice, the sustainability implications of all the principles are not immediately obvious. Finally, the literature, principles and discussions are synthesized into an agenda for further research.

4 Brynild – An Illustration of Food PPC Challenges

Brynild Gruppen is a medium-sized Norwegian food producer with nearly 200 employees and an annual revenue of EUR 70 mill. The company's factory produces 46 variants of sugar confectionery products, 44 chocolate variants and 50 nut variants. The Norwegian market for confectionery and snack products is dominated by large international actors and Brynild Gruppen has a market share of approx. 14 %. Their main customers are the four Norwegian wholesaler – retailer dyads that control 100 % of the retail market, with wholesalers requiring a 98 % service level. Consumer demand for snacks and confectionery products is highly seasonal and affected by promotional activities and product introductions, which makes demand forecasting difficult.

Brynild Gruppen's production strategy is mainly MTS for standard products, with build-up of inventory of seasonal products months in advance. The products typically have a shelf-life of 6-18 months, and products that approach or pass their industry-standard sell-by date are sold at reduced prices through alternative sales channels or scrapped. Brynild Gruppen has limited access to data from the supply chain beyond orders from wholesalers, an annual joint planning with retailers regarding timing and product variants for promotional activities and product launches, and the opportunity to buy aggregated sales data from a national grocery database. The company's seasonal products are sold on buy-back agreements, where customers in some cases have been credited up to 35 % for unsold goods at season end. Thus, Brynild Gruppen carries a large portion of the risk associated with seasonal products, while having little or no insight into actual consumer demand or influence over inventory levels in retail stores. This complicates demand forecasting and production planning and limits the company's ability to quickly respond to changes in demand. The consequences include both lost income and scrapping of unsold products in several supply chain stages. To improve sustainability and supply chain performance, Brynild Gruppen has initiated an innovation research project together with their largest customer, one other food producer, two ICT system providers and three research institutions. One of the purposes is to explore how data from downstream actors in the supply chain can be used in PPC – and thereby create a smart, transparent and sustainable food supply chain.

5 Principles for Sustainable, Data-Driven PPC

In this section, we firstly adapt the existing principles for intelligent, demand-driven supply chains [23] to the PPC context (see Table 1). Secondly, we discuss how the application of the proposed principles can impact on sustainability in a food context, outlining effects for both food producers and for downstream supply chain actors.

Table 1. Principles for sustainable, data-driven PPC

P1	Promotional plans from producer/brand owner and downstream actors should be transformed into data to be used for PPC
P2	Historic demand data on seasonal products from the producer/brand owner and downstream actors should be transformed into data to be used for PPC

P3	Real-time data on demand and inventory levels from retailers and wholesalers should be transformed into data to be used for PPC
P4	Real-time data on finished goods and WIP inventory levels should be captured at the producer and used for PPC
P5	Tacit planning knowledge and experience on production planning should be captured and transformed into data to be used for PPC
P6	Tacit knowledge of production processes and machines/production lines should be captured and used for PPC
P7	Real-time performance data (including sustainability performance) should be captured, measured, and used for performance visualization and PPC
P8	Plans should be adjusted based on updated data from the producer and downstream supply chain
P9	AI and learning-based analytics should be applied to generate new insights for PPC
P10	The proportion of automated PPC processes should be increased to minimize planning time and reduce repetitive tasks for human planners, freeing up human planners for more complex PPC tasks
P11	The CODP should be continuously evaluated, exploring potential for more order-based or hybrid production strategies (both across product range and over time/seasons)
P12	Sustainability trade-offs should be considered in PPC and visualized to support human decision-making

The principles presented above are aimed at improving PPC and subsequently sustainability. In the following paragraphs, we discuss the potential impacts the principles can have in a food supply chain context, both for producers and downstream stages. The use of data on promotional plans (P1) and seasonal demand (P2) in PPC will enable better alignment of supply and demand in the supply chain – subsequently decreasing food waste from overproduction and reducing lost sales due to stockouts. Any reduction of food waste will also reduce the expenditure of raw materials and other resources. Using real-time data in PPC (P3, P4, P7, P8) will also better align supply and demand, as well as increase food producers' responsiveness and flexibility to changes in the supply chain. This can allow for lower inventory levels, which in turn can increase inventory turnover and increase the days of remaining shelf life available in the downstream stages of the supply chain. This again reduces the risk of food waste of expired products in wholesale, retail and consumer households.

In particular, real-time data on demand and inventory levels (P3) of new products would allow a producer to adjust production volumes to early sales data, giving them time to ramp up production to avoid lost sales of a popular item or halt production to avoid food waste of a failed launch. Additionally, more real-time monitoring of performance (P7) on parameters such as inventory levels and product quality (e.g. temperature, humidity and remaining shelf life) through RFID and networked sensors can reduce food waste from quality degradation. However, while adjusting plans based on real-time data (P8) will improve the quality of the plans, it also requires an increase of planning cost through the increase of time and resources needed for the adjustments. Applying AI and learning-based analytics (P9) on PPC-relevant data can provide new and valuable insights, thereby reducing planning effort, time and cost. Automation of planning processes (P10) will also reduce the amount of repetitive planning tasks, thus leading to higher levels of job satisfaction for planners. The transformation of tacit knowledge to digital data (P5, P6) has the potential to improve PPC. Standardized knowledge can be used to improve production and planning processes – increasing speed, quality, efficiency, flexibility, etc.

However, it is unclear how these principles could affect social sustainability. Digitizing tacit knowledge may make training easier but could also make planners feel less valuable and contribute to loss of deep experiential knowledge once algorithms replace human decision making. Any reconsideration of CODP towards more order-based production (P11) could reduce the risk of food waste due to overproduction. However, more order-based strategies such as MTO could be applicable for non-standard products (such as planned promotions) as the customer lead time expectations for standard products is typically considerably shorter than production lead time. Thus, hybrid approaches could be considered to ensure the high service level requirements are still met.

Considering all the above principles are expected to have impacts on sustainability, some indicators should be used to measure positive and negative effects (P12). Although food waste is an important indicator, it can be hard to measure and therefore other indicators should be included, such as inventory levels and remaining shelf life. It is not clear how different types of data can be used in PPC to achieve the potential benefits, nor is it clear if there are trade-offs, e.g. between financial and environmental sustainability, that should be considered in the application of the principles.

6 Towards a Research Agenda

In order to achieve the principles for sustainable, data-driven PPC discussed in the previous chapter in the food supply chain context, research is needed in some key areas. The topic of data availability is an underlying premise. Studies are needed to investigate which data would be useful for PPC, which data is currently available, which data is not captured, and how to capture and share data. In addition, how to use such data in PCC, including the development of logic and algorithms. Further, investigating how data can be utilized to improve existing processes and also how processes should be changed to better align supply and demand and thereby realize potential benefits. The full potential value of data also warrants further investigation. While food supply chain actors are interested in implementing new methods and technologies, wholesalers and retailers are likely to be hesitant to share data if all the benefits go to the producer. Therefore, studies into how the shared data can improve performance and identifying the possible benefits for producers and their downstream supply chain partners is needed.

Key data mentioned in the principles also includes real-time data and tacit knowledge. Neither of these data types has been extensively studied in relation to PPC, so the capture and use of these data types in PPC should be investigated, both conceptually and empirically. In addition, while potential sustainability implications of the principles were outlined in chapter 5, several key questions remain. One relevant topic is how sustainability trade-offs can be accounted for in PPC, both in automated and human decision-making. Finally, in order to utilize new methods and technology to exploit the data, there is need for further study in how digital technology can be used in PPC.

7 Conclusion

This paper has illustrated how food producers can increase supply chain sustainability through data-driven PPC. Our proposed set of principles can be used by actors in the food supply chain to guide future collaboration and information sharing initiatives. However, the research agenda shows that more studies are needed before the principles can be implemented and the sustainability effects achieved. We believe there are great possibilities for increasing the application of data and technology in PPC to increase sustainability. While this study has limitations including the lack of validation of the principles and generalizability (which could be remedied through more rigorous methodology such as a structured literature review, multiple case studies, or a survey), this research has shown that there are great possibilities for increasing the application of data and technology in PPC to increase sustainability.

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