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Can Differentiated Production Planning and Control enable both Responsiveness and Efficiency in Food Production?

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ABSTRACT

This paper addresses the complex production planning and control (PPC) challenges in food supply chains. The study illustrates how food producers' traditional make-to-stock (MTS) approach is not well suited to meet the trends of increasing product variety, higher demand uncertainty, increasing sales of fresh food products and more demanding customers. The paper proposes a framework for differentiated PPC that combines MTS with make-to-order (MTO). The framework matches products with the most appropriate PPC approaches and buffering techniques depending on market and product characteristics. The core idea is to achieve more volume flexibility in the production system by exploiting favourable product and market characteristics (high demand predictability, long customer order lead time allowances and low product perishability). A case study is used to demonstrate how the framework can enable food producers to achieve efficiency in production, inventory and PPC processes – and simultaneously be responsive to market requirements.

Keywords: food production, planning and control, responsiveness, case study

1 Introduction

Food producers have traditionally focused on offering customers high quality products at low prices, and products are generally made to stock (MTS) to meet customers' delivery lead time expectations as these are typically considerably shorter than production lead times. Since profit margins on food products are generally low, efficiency in production is critical and producers have therefore relied on producing in large batches to keep unit costs down.

Simultaneously, responsiveness has been hailed as one of the most important capabilities needed for firms to achieve competitive advantage (Matson and McFarlane, 1999, Holweg, 2005, Reichhart and Holweg, 2007, Bernardes and Hanna, 2009) – meaning that food producers should be able to respond quickly to changes in the market place as well. However, a common belief in industry has long been that any efforts to increase responsiveness will increase costs and thus lower efficiency (Christopher and Gattorna, 2005).

In addition to reducing responsiveness, food producers' strategy of producing to stock in large volumes is becoming more and more costly. The trend of more product variety, higher demand uncertainty and an increase in the sale of fresh food products with short shelf life means that food producers need large amounts of finished goods inventories to ensure customers find the products they want – resulting in large amounts of waste when products expire in inventory or use of overtime and other costly measures to avoid stock-outs.

In an attempt to better meet customer requirements, the food processing industry has over the past couple of decades adopted more market-oriented approaches to production planning and control (PPC) -

shifting from the traditional MTS approach to applying more make-to-order (MTO) and combined MTO-MTS approaches (Soman, 2005, van Donk, 2001, Van Kampen and Van Donk, 2014). However, which PPC approach to choose in which situation is still unclear - particularly since there are large variations in product and market characteristics. While some of the supply chain characteristics impose critical limitations and challenges on the production system, other characteristics are more favourable and can be exploited to provide flexibility. Thus, by understanding the specific product and market characteristics it would be possible to design a PPC system where the favourable characteristics are exploited and different PPC approaches applied to different product–market combinations, all the while taking the production system constraints into consideration. Such a differentiated approach to PPC could enable companies to respond to different market and product requirements in a more customised manner - thereby achieving both efficiency in production and inventory and responsiveness to customer requirements.

The purpose of this paper is twofold:

1. To demonstrate how the current MTS approach in food production is leading to inefficiencies in production and inventory
2. To illustrate how a differentiated approach that combines MTS with MTO can enable both responsiveness and efficiency

The paper starts by outlining the study's research scope and design. Next, the requirements that food supply chain characteristics impose of food producers are highlighted. These insights are subsequently combined with concepts from literature, resulting in a framework for determination of PPC approaches in food production. A case study is used to illustrate the application of the framework in an empirical setting, before the conclusion section discusses the paper's contributions and outlines some suggestions for further research.

2 Research scope and design

The paper's theoretical base is mainly within operations management, operations strategy, and PPC. The study focuses on food supply chains from a producer perspective, i.e. companies which process intermediate products into consumer or industrial products like packaged meats, baked goods, dairy products, chocolate, etc. The focus is mainly on large industrial food processors where there is a certain maturity and complexity in the PPC processes. Thus, the context is industrialised food production systems dealing with large volumes of standard products, produced in an environment with standardised physical processes and fairly stable lead times.

The research was performed as part of a PhD project following a design science approach, where an exploratory and pragmatic approach was used to design a solution to a practical problem identified in industry. The study consisted of four stages;

1. *Identification and framing of problem* – based on a literature study and insights from practice (see Romsdal et al., 2011)
2. *Design of initial solution* – where original frameworks were successive modified based on empirical and theoretical insights to form a concept and framework for differentiated PPC in food production (see e.g. Romsdal et al., 2012)
3. *Solution refinement* – where a case study demonstrated the applicability of the framework and provided feedback to the design stage
4. *Development of substantive theory* – where the theoretical relevance of findings from the field study were discussed

This paper mainly reports on stage 3 of the project – the case study of TINE, Norway's largest dairy and production network. A case study was used to diagnose the current state and subsequently design, apply and evaluate a solution. Case data was collected from company databases (product data, forecast accuracy, service levels, inventory levels, sales data, market activities, etc.) and through interviews, observations and workshops covering topics like market and company strategies, and planning and forecasting processes. The data collection took place over a period of two years, and historic data from 2011 was used in the analyses and as a basis for development of new solutions. Company representatives were closely involved in research design, analyses, solution development and reflections on findings in order to strengthen the trustworthiness of the findings and results.

3 Food supply chain characteristics and requirements for food producers

In order to understand the environment within which food producers operate, an analysis of the characteristics of food supply chains is appropriate. **Error! Reference source not found.** summarises the key product, market and production system characteristics that are thought to have an impact on the way food producers plan and control their production to meet customer requirements.

Table 1.

Food supply chain characteristics (based on Romsdal et al., 2011)

Area	*Description*
Product	*Perishability and shelf life;* high perishability, with shelf life constraints for raw materials, intermediates and finished products. *Complexity and variety;* mainly divergent product structure, with varying complexity. High and increasing variety, particularly for promotions. High percentage of slow-moving items. *Product life cycle (PLC);* decreasing, with high failure rates for new products. *Volume;* high volume, with increasing volume variability in downstream processes.
Market	*Delivery lead time;* varies by product. Customers generally demand and receive frequent deliveries and short response times. Demand mainly met from finished goods inventory. *Demand uncertainty;* varying and increasing, largely caused by high and increasing frequency of promotional activities. Strong presence of bullwhip effect. *Inventory management;* limited ability to keep stock. Periodic ordering. High and stable stock-out rates. Cost of lost sales often higher than inventory carrying costs.
Production system	*Production lead time;* product dependent, but generally long lead times and low degree of postponement. *Plant, processes and technology;* adapted to low product variety and large production volumes. Mainly integrated and continuous production process on capital-intensive equipment with long set-up times and high set-up costs. *Supply uncertainty;* some uncertainty, mainly caused by seasonality, demand amplification and economy of scale thinking, but generally high reliability for raw materials.

In sum, the market and product characteristics require food producers to be flexible and responsive in order to meet demands for frequent deliveries and short response times, and simultaneously cope with product perishability and increasing product variety. Despite these requirements, the production system is designed for economies of scale, favouring large production volumes and low product variety – thereby limiting producers' flexibility and market responsiveness. Thus, there appears to be a lack of strategic fit between the external requirements stemming from product and market characteristics and the capabilities of the production system to enable the required level of responsiveness and efficiency. This indicates that the principles currently used to plan and control production are mainly determined by the production system's internal requirement for cost efficiency and not by the external requirements for customer responsiveness and supplying high quality products in an increasing number of variants.

4 Framework for production planning and control in food production

This chapter briefly introduces food production and PPC in the food sector, before a framework for differentiated PPC in food production is presented.

4.1 Introduction to food production

The typical steps in a food production system are receipt of inputs (raw materials, ingredients, packaging materials, etc.), processing/mixing, packing (which is often integrated with cutting and labelling), and delivery. Typically there are three stock points; raw materials before processing, unpacked bulk products between the processing and packing stage, and end products packed in consumer packaging (Méndez and Cerdá, 2002, van Dam et al., 1993). The number of product variants increases with each production step, where a moderate number of raw materials and other inputs are converted into a broad variety of finished products through a divergent product structure (Crama et al., 2001).

The packing process is of particular importance since this is often the point in the process where the product becomes customer specific, i.e. sized, packed and labelled for a specific market or customer. This means that the risk of obsolescence is usually lower for the inventory of unpacked bulk products since these can be used for several different variants of finished goods. Further, processing and packing lead times are critical since MTO is impossible if lead times exceed customers' delivery lead time expectations. Another aspect is perishability, where the shelf life of several processed and packaged products is based on the packing date. This means that before packing, the risk of obsolescence is lower since the bulk item can be assigned to different customers, markets or finished goods items before product deterioration becomes an issue.

4.2 Production planning and control in food production

PPC can be defined as the principles, procedures and decisions that are required to ensure availability of materials and other variable resources needed to supply the goods and services which fulfil customers' demands (Slack et al., 2007, Bertrand et al., 1990). The design of a PPC system thus includes specification of the principles used to operate and coordinate operations on a day-to-day basis. A central concept in this respect is the customer order decoupling point (CODP). This point represents a strategic stock holding point in the production process and expresses how production interacts with the market; are production activities triggered by customer orders (e.g. MTO) or by forecasts (e.g. MTS)? The CODP thus decouples forecast-driven activities (upstream of the CODP) from activities driven by a specific customer order (the CODP and downstream), in other words it differentiates between decisions made under certainty and decisions made under uncertainty of customer demand (Wikner and Rudberg, 2005).

In literature and practice, the determination of PPC approaches, i.e. whether a product is to be made to order or to stock, is often done on an SKU level using simplistic rules like ABC classification or variations thereof (Soman et al., 2004, van Kampen et al., 2012). The MTS-MTO decision in food production has mostly been based on volume, where high volume items are produced to stock and low volume items to order (Soman et al., 2004). However, due to tenders, export, promotional activities and other orders which have special packaging or other customer-specific features, MTO might also be relevant for high-volume orders since these are associated with considerable uncertainty of timing, variants and volume (Soman et al., 2004). Thus, volume may not be the best determinant for PPC approaches in food production (van Kampen and van Donk, 2011).

Also, the fact that the largest variant explosion in food production is usually found in the packing stage means that there is potential for using postponement. An MTO approach can reduce the effect of demand uncertainty since less of the production is based on speculation and forecast accuracy is increased since forecasts can be aggregated in the upstream processes (Slack et al., 2007). An assemble-to-order (ATO) approach in the form of pack-to-order (PTO) can therefore be relevant, for instance in cases where the processing and packing processes can be decoupled and intermediate products can be stored in front of the packing process. In such a PTO approach, processing would for instance be based on forecasts, while packing, cutting and labelling would be done to order.

Figure 1 illustrates the three most relevant PPC approaches in the food sector.

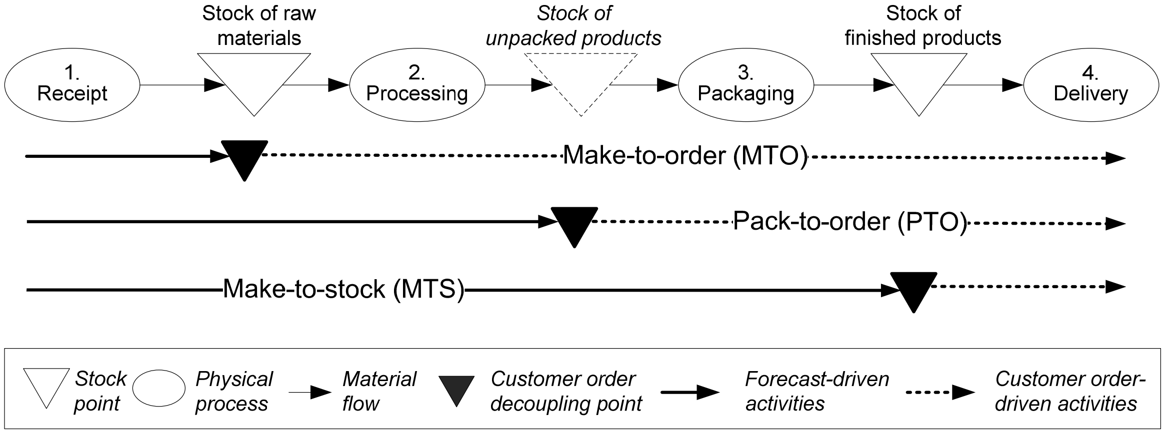

Figure 1. Relevant PPC approaches in food production (based on Olhager, 2003, Hoekstra and Romme, 1992)

Although all three PPC approaches are relevant in food production, on a facility level the decision most often comes down to; which production activities should be based on forecasts and which should be triggered by customer orders? For simplicity, the decision can therefore be reduced to a choice between MTO, where all processes are triggered by an order, and MTS, where all processes are performed to forecast.

4.3 Framework for differentiated production planning and control in food production

The need for managing products with different characteristics differently is well recognised in both practice and literature. The concept of supply chain fit was popularised by Fisher's conceptual article matching supply chain strategies for production and buffer inventories with product characteristics (Fisher, 1997). Other examples of similar differentiation include postponement (Christopher and Towill, 2002), leagile (Naylor et al., 1999, Bruce and Daly, 2004), matching PCL with different pipeline strategies (Aitken et al., 2005), and varying supply chain planning approaches with different needs for execution flexibility and information sharing (Kaipia, 2007).

Kittipanya-ngam (2010) makes an interesting extension to Fisher's framework in the food production setting. She shows how different combinations of product and market characteristics cluster in six food supply chain operating environments, each exerting different primary requirements on food producers. These insights can be used as a starting point for identifying the appropriate PPC approaches for each configuration on a product-by-product basis.

Based on the previous subsections, the following principles are set forward with regards to PPC in food production:

1. Favourable product and market characteristics should be exploited to provide flexibility to the production system
2. PPC approaches should be differentiated according to product and market characteristics
3. Slack resources in the form of inventory, capacity and time should be differentiated to buffer against demand uncertainty

Based on these principles, the most appropriate PPC approaches and buffering techniques can be identified for each supply chain configurations, resulting in the framework in Figure 2 (for more detals, see Romsdal, 2014).

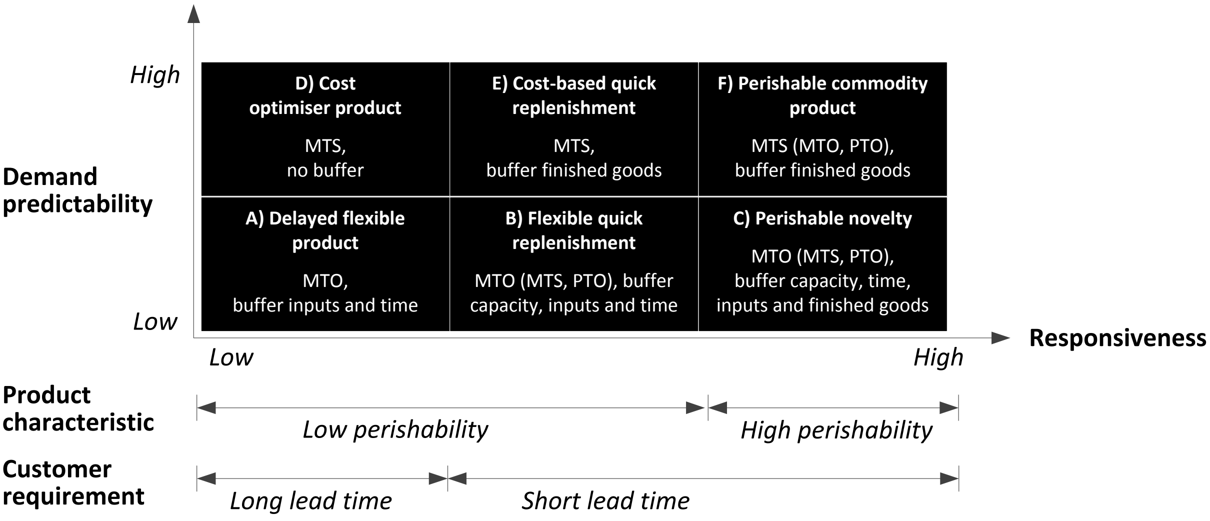

Figure 2. Framework for differentiated PPC in food production (adapted from Kittipanya-ngam, 2010, Romsdal et al., 2012)

5 Application of framework for differentiated production planning and control

This section starts with an introduction to PPC in the case company and the case facility, followed by an analysis of the performance of the current PPC design. Next, the framework from section 0 is applied to the case company and the expected benefits outlined.

5.1 Introduction to case facility

The case study focuses on TINE, Norway's largest food producer, distributor and exporter of dairy products. The case facility TINE Heimdal is part of TINE's network of approx. 40 production and warehousing facilities in Norway which produce and pack/bottle approx. 840 variants of milk and milk-based drinks, cheeses, butters, yoghurts and desserts.

TINE Heimdal is one of three TINE facilities that cut and pack bulk cheese into finished end products with low to medium perishability. The facility receives bulk cheese in 10 and 20 kg blocks from TINE's cheese factories, and these are sized (cut, sliced or grated), packed and labelled into 83 finished product variants on one of 14 highly automated production lines. Production technology, equipment and processes are designed for high production volume and low product variety, with large batch sizes and a low degree of postponement. Production lead times vary from 1-4 days depending on the required cool-down time for products after processing. Orders are mainly filled from inventory and delivery lead time to national customers is fairly stable at one day, while export customers accept lead times of weeks or months. Demand uncertainty varies between products and is generally increasing.

TINE's Heimdal's current PPC approach is mainly MTS, with MTO for export orders. TINE's centralised PPC function plans inventory and production volumes per packing facility, while local production supervisors perform the daily sequencing and timing of production based on available capacity. A 104-week forecast is generated by sophisticated forecasting software and this is manually adjusted by the central production planner to arrive at the weekly production plan for each facility.

5.2 Analysis of current production planning and control design

The performance of a company depends on how the company has designed its PPC system, as well as a number of external conditions and circumstances. In order to identify key PPC challenges and improvement potentials, a number of quantitative and qualitative analyses were performed with regards to demand uncertainty, service level and delivery reliability, inventory turnover, capacity utilisation and qualitative aspects of the PPC system.

In some cases, performance data could be extracted directly from TINE's ICT systems. However, most of the analyses required collecting, structuring and cleansing large amounts of data. In order to keep the amount of data at a manageable level, 15 of the facility's 83 product variants were selected for detailed analysis, ensuring that they captured key variations with regards to product, market and production system characteristics (process type, volume, forecast accuracy, shelf life, markets and newly launched products). Some of the key findings are summarised in Table 2.

Table 2.

Summary of PPC performance analyses

Indicator	*SKU 1*	*SKU 7*	*Avg. 15 SKUs*	*Comment*
Service level (%)[*]				
Average	98,6	99,5	97,4	Customer requirement 97,5
Variation	77-100	90-100	20-100	Average all 83 SKUs 95,8
Forecast accuracy (%), average	63	72	63	
Inventory				
Turnover rate (month)	3,9	5,6	4,6	Variation 1,4-8,1
Scrapping	N/A	N/A	N/A	Income loss from discounts not recorded
Production efficiency				
Overtime (OT), all products	Weekend OT every 3,5 weeks + weekdays (weekday OT data missing)			
Capacity utilization	51-154 %, unevenly distributed over weekdays			

The analyses concluded that although the facility's average service level was slightly below wholesalers' requirement, the facility appears relatively responsive and effective in meeting market requirements. However, this is achieved in a PPC environment characterised by relatively low and varying forecast accuracy, resulting in large variations in service levels. Since TINE uses an MTS approach for the majority of its products, good estimates of future demand are essential. The fairly low and varying forecast accuracy means that large inventories are used to buffer against demand uncertainty – leading to high inventory carrying costs and some scrapping costs for expired products. In addition, there are considerable income losses associated with the frequently used policy of offering customers price reductions for products with short remaining shelf life. In order to meet higher than forecasted demand, overtime was frequently used, as well as moving products between TINE facilities, causing disturbances to PPC at other facilities. In sum, it can be concluded that although the company's current MTS approach

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[*] Measured as orders filled from facility

appears effective in meeting customer requirements in terms of service levels, this comes at the expense of efficiency in production, inventory and PPC performance.

5.3 Application of framework

The concept for differentiated PPC is based on matching supply chain configurations with the most appropriate PPC approaches, i.e. MTS or MTO. The framework provides the dimensions of product and market characteristics which need to be mapped to identify to which configuration each product belongs. Each of the 15 reference products were therefore mapped according to three dimensions; product perishability, customer order lead time allowance, and demand predictability.

Product perishability was easily determined since all products have a fixed shelf life which starts counting when packing commences. All 15 reference products were considered to have low perishability, with three having a shelf life of 275 days, and the remaining 12 a shelf life of 91 days.

Customer order lead time allowance was also easily determined since the facility only has two main types of customers. National customers (wholesalers and others) allow a lead time of maximum one day, while international customers allow several weeks or months. Thus, of the 15 reference products, the three export products were classified as having long lead time allowance, and the remaining 12 short lead time allowance.

The third dimension, demand predictability, was not easily determined. To analyse predictability, a decision tree had to be developed in order to evaluate the most important quantitative and qualitative factors which are thought to impact on demand predictability in TINE. The factors were identified based on theory and experience, and involved close cooperation with experts from different parts of TINE, including central and local PPC, sales, marketing, ICT, and managers at the strategic, tactical and operational levels. The decision tree included assessment of product life cycle stage, degree of innovation, confirmation of assortment listing in retail stores, historic forecast accuracy during market activities, and sensitivity to external factors like weather conditions and seasonality. For each factor, data requirements were determined, analyses performed, cut-off limits set, and findings interpreted in collaboration with key TINE personnel (for more detals, see Romsdal, 2014).

5.4 New solutions for production planning and control

Once the configurations of the 15 reference products had been identified, the framework in Figure 2 was used to determine the appropriate PPC approach(es) and buffering techniques for each product. The result was that eight of the 15 products should be MTO in ordinary planning situations, while during periods of market activities an additional three should be switched from MTS to MTO; see Figure 3.

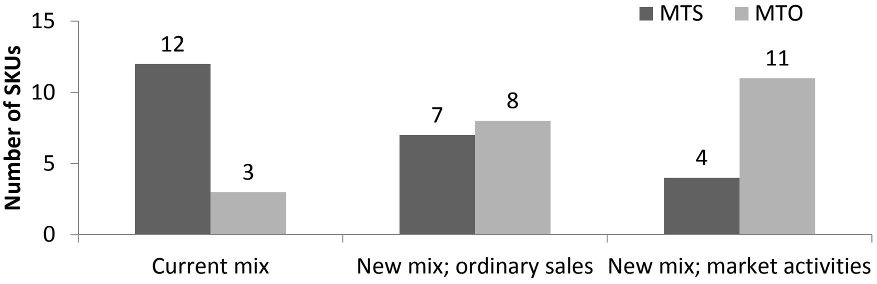

Figure 3. Current and proposed mix of MTO and MTS, reference products

5.5 Expected benefits

The proposed PPC system was not implemented as part of the study and effects could therefore not be measured. Expected benefits were instead substantiated through a combination of logic reasoning, insights from literature and the case study, and joint reflections with case company representatives. A combination of quantitative measures and collaborative evaluation and interpretation of the case study and the proposed solutions were used to reflect on the problem from several angles and explore rival explanations. The anticipated effects were structured into six categories.

Quality is about consistent performance to customers' expectations. The proposed solution is expected to improve or at least maintain service levels. For market activities, the increased focus and follow-up of products with low demand predictability is likely to lead to earlier detection of unexpected changes in demand. Further, the MTO approach with associated capacity buffering is expected to enable shorter response times in the production system. A reduction in the number of stock outs for MTS items is expected since PPC resources will be freed up to focus on improving inventory management for finished goods. Further, the proposed solution is expected to lead to better product quality since MTO products will have more days of shelf life remaining when sold to customers because packing is postponed.

Speed is about doing things fast, related to the time it takes from a customer places an order till he or she receives the product. Production response times are expected to become shorter since planning with slack resources in terms of capacity enables the production system to respond quicker to demand signals and not have to wait until the product is next scheduled for production. The inventory turnover rate is expected to increase, particularly for items which will become MTO since these will no longer have any finished goods inventory.

Dependability is about doing things on time like delivering a customer's order when it is needed or promised. Delivery reliability is expected to improve as production response times become shorter and service levels increase and become more stable. Due date adherence for MTO products is expected to improve since dates can be set depending on overall capacity and resource availability on a longer horizon. Re-planning frequencies might increase with the introduction of more MTO production, but an associated redesign and formalisation of TINE’s PPC system is expected to introduce more predictability and clearer policies for how MTO items should be incorporated into the MTS schedules and improve plan stability. The proposed solution is also expected to reduce the number of disruptions to PPC at other facilities since there will be fewer out of stock situations at TINE Heimdal.

Flexibility is about the ability to change an operation in some way, e.g. what, how or when. The main scope of the study was on volume flexibility, and the proposed PPC solution is expected to increase volume flexibility since favourable characteristics can be exploited to provide more volume flexibility. The slack capacity provides flexibility in production with regards to timing, variants and volume.

Cost is about doing things cheaply and is a universally attractive objective which influences the cost of the company's products and services. Cost savings are expected through increased efficiency of PPC resources in the proposed solution. Further, lower inventory carrying costs are expected, as well as reduced costs for disposal of expired products and less value loss from selling obsolete or excess inventory at reduced prices or as animal feed.

In addition, improvements in the *performance of PPC function* are expected. The implementation of the new PPC solution should include a review and redesign of the PPC function and processes – which should lead to simplification, formalisation, standardisation and validation of PPC processes. In addition, the new PPC system should automate a number of PPC tasks, thus reducing the risk of human errors and freeing up central and local resources to focus on more value-adding activities.

6 Conclusions

The case study presented in this paper is a reflection of the growing awareness in industry and academia of how the trends of increasing product variety, demand variability and number of fresh food products are significantly increasing the complexity of the PPC task. In today's competitive environment it is no longer sufficient to be cost effective and offer high quality products. Customers are increasingly demanding shorter response times, higher service levels, new product variants and customised products – thus requiring a high degree of responsiveness from food producers. As such, the paper highlights an important strategic PPC issue which many companies are currently failing to recognise. One reason for this may be found in the widespread adoption of enterprise resource planning (ERP) systems. These systems are encouraging companies to apply MTS practices and thus ignore the impact differences in product and market characteristics have on their operations (Vitasek et al., 2003). In this respect, the proposed framework provides a scientifically founded basis for the strategic determination of the principles that should guide the design of PPC systems in the food sector.

The main theoretical contributions of the paper include increased understanding of the PPC challenges facing food producers. The paper also contributes to explaining the adverse effects of the mismatch between external requirements and internal capabilities of food production systems. The framework and the case study demonstrate that the question of efficiency and responsiveness is not an either-or issue but rather a question of matching different configurations with the appropriate degree of responsiveness and efficiency. In this way, differentiated PPC can enable companies to achieve efficiency in production, inventory and PPC processes, and responsiveness to customer and product requirements simultaneously.

In terms of practical implications, a number of tactical and operational issues remain to be solved before the proposed differentiated PPC solution can be implemented in practice, e.g. how to deal with MTO items in the MTS schedule in such hybrid production environments. Also, since an MTO approach is impossible for many products due to long production lead times, efforts should be made to reduce lead times to increase the applicability of the concept.

The concept of PPC differentiation has some weaknesses that limit its applicability. Firstly, it only addresses downstream uncertainty and thus provides little support for food producers who may also be facing high supply uncertainty. Secondly, the concept is based on assessment on an SKU level and therefore does not consider interdependencies between products. Thirdly, an important prerequisite for the use of postponement strategies like MTO is the ability to decouple the production processes, as well as having production or packing lead times that do not exceed customer order lead time expectations.

Despite these shortcomings, the concept of managing products differently based on their product and market characteristics is widely supported in literature (see e.g. Fisher, 1997, Soman, 2005, Van Kampen and Van Donk, 2014). Thus, even in contexts where an MTO approach is not feasible, the approach of analysing market and product characteristics on a product level can still be used to provide a better understanding of the key requirements exerted upon food producers. This insight can then be used to focus PPC resources on the products which are the most difficult to plan and control, for instance initiating closer monitoring of products with low demand predictability, working with customers to improve forecasting accuracy, working with operations to enable greater flexibility in the physical production processes, etc. The concept of linking configurations with different strategies and approaches can also be useful for other purposes, e.g. inventory management, distribution strategies, forecasting techniques, and supply chain information sharing and collaboration models.

The case study was used to illustrate how a differentiated approach combining MTS with MTO can be used in practice to enable simultaneous responsiveness and efficiency. Although the redesigned PPC system has not yet been implemented, the work has sparked a lot of interest among practitioners – showing that the topic is both timely and relevant. Simultaneously, technology providers are continuously working to develop production equipment that enable quicker changeovers and smaller batch sizes. Thus, in order for producers to reap the full benefits of these new opportunities, now is the time to investigate how new approaches to PPC can enable and support the growing flexibility in the physical production processes.

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