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Differentiated production planning and control in food supply chains

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SUMMARY

This PhD thesis reports on an empirical and exploratory investigation of the strategic determination of the principles used to guide production planning and control (PPC) in the food sector. 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 volumes to keep unit costs down. On the other hand, responsiveness has been hailed as one of the most important capabilities needed for firms to achieve competitive advantage – meaning that food producers should be able to respond quickly to changes in the market place as well. However, any efforts to increase responsiveness are thought to increase costs and thus lower efficiency. In addition, food producers' strategy of producing to stock in large volumes is becoming more and more costly. The trend towards 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.

The need for managing products with different characteristics differently is well recognised in both practice and literature. In an attempt to better meet customer requirements, the food sector has over the past couple of decades adopted more market-oriented principles in the way production is planned and controlled - shifting from the dominant MTS approach to applying more make-to-order (MTO) and combined MTO-MTS approaches. In addition, a pack-to-order (PTO) approach may be applicable in situations where the production and packing processes can be decoupled. However, which PPC approach to choose in which situation is still unclear.

Based on the challenges described above, this study investigated how the PPC approaches of food producers can be differentiated to meet the requirements of different situations, and further how a combination of MTS and MTO can enable food producers to meet the demands for both responsiveness and efficiency. Four research questions (RQs) guided the research:

- RQ1: What are the characteristics of food supply chains?
- RQ2: How can PPC be differentiated according to food supply chain characteristics?
- RQ3: What are the potential benefits of differentiated PPC?
- RQ4: What are the tactical and operational challenges of differentiated PPC?

The RQs were addressed through a combination of literature studies and a case study. Following a design science approach, a practical problem was framed based on empirical data. Subsequently, theory and literature were used to develop a conceptual solution, a case study was used to test and refine the concept, before the study's contributions towards substantive theory were formulated based on theoretical reflection following the field testing. The case study was conducted in TINE, Norway's largest producer, distributor and exporter of dairy products. TINE Heimdal, a facility cutting and packing cheese, was selected for detailed analysis and testing of the theoretical concept. The study was mainly conducted in the period 2010-2013, and analyses were performed and solutions developed in close collaboration with company representatives in order to strengthen the trustworthiness of the findings and results.

The purpose of RQ1 was to identify the product, market and production system characteristics of food supply chains since these exert important requirements on the PPC of food producers. In sum, the study found that the market and product characteristics typically require responsiveness from food producers, while producers' production systems are mainly focused on efficiency through exploitation of scale benefits. Thus, there is 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.

In order to answer RQ2, a concept for differentiated PPC was developed, consisting of the following principles:

1) Favourable product and market characteristics like low perishability, high demand predictability and long customer order lead time allowances should be exploited to provide flexibility to the production system
2) PPC approaches should be differentiated according to food supply chain configurations, i.e. product and market combinations
3) Slack resources in the form of inventory, capacity and time should be differentiated to buffer against demand uncertainty

Based on these principles, a framework for differentiated PPC was developed. The framework identifies appropriate PPC approaches and buffering techniques for each supply chain configuration given the most important requirements exerted by the product and market characteristics, see Figure i-1.
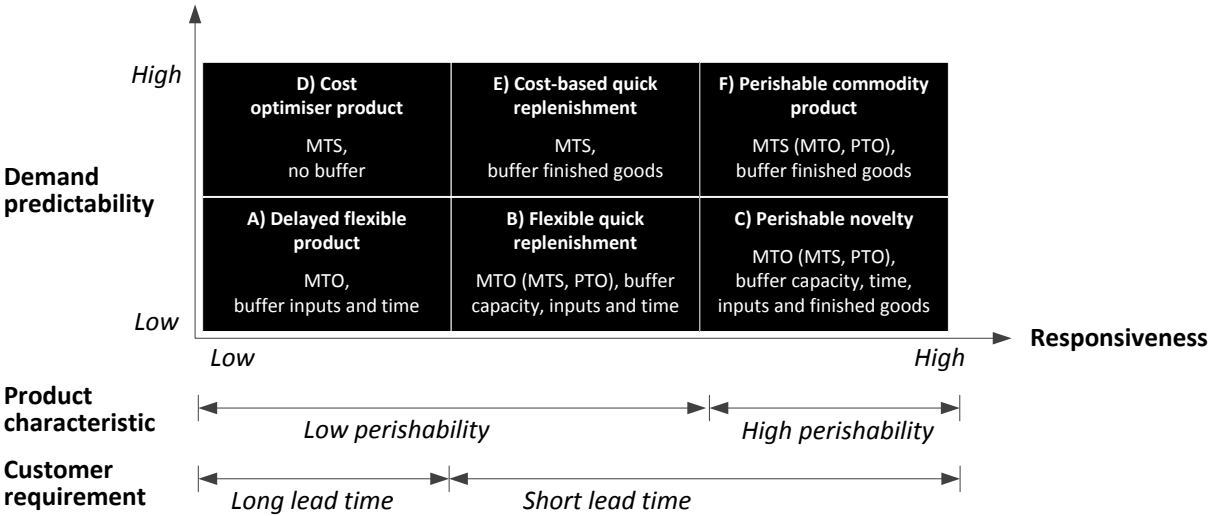
Figure i-1: Framework for differentiated PPC in food production (adapted from Kittipanya-ngam, 2010, p. 110)

The case study of TINE Heimdal was used to illustrate how the concept and framework could be used to design a differentiated PPC system for a food producer – referring to the principles used to guide a company's PPC. In order to identify challenges and improvement potentials, analyses of the facility's PPC performance were carried out. These showed that although the facility is relatively responsive and effective in meeting customer requirements in terms of service levels; this is achieved at the expense of efficiency in production and inventory. The current PPC design is leading to large inventories of finished products, scrapping costs, and

income losses due to price reductions for products with short remaining shelf life. The analyses also found that the facility only to a limited degree differentiates the way products are planned and controlled, where three of the 15 products selected for detailed analysis were planned using an MTO approach and the remaining 12 were MTS.

The concept and framework were used to design a new PPC system for TINE Heimdal. This also required the development of a decision tree for determining a product's demand predictability, which included quantitative and qualitative assessments of product's 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. In the proposed PPC system, it was found 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.

RQ3 investigated the potential benefits of a differentiation approach to PPC. The proposed PPC system was not implemented as part of the study and effects could therefore not be measured. Expected benefits were instead substantiated by combining insights from literature and the case study. The expected benefits were grouped into six categories; improved quality, higher speed, better dependability, higher flexibility, reduced costs, and improved performance of the PPC function.

Most of the literature on PPC focuses on solutions for a single type of production environment, e.g. MTO or MTS. The concept for differentiated PPC is based on combining MTO and MTS in the same production system, and RQ4 investigated the additional challenges this imposes on the tactical and operational planning and control levels. The study used literature and insights from the case study to highlight and discuss some of the most critical decisions and challenges in such hybrid production environments. The key question in this respect is how to deal with MTO items in the MTS schedule, particularly with regards to planning methods and techniques for accommodating the uncertainty related to the volume and timing of MTO items. The discussion concluded that the traditional material requirements planning (MRP) method is likely to continue to be the backbone of PPC in the food sector, but that MRP combined with a workload control (WLC) planning method could be a potential solution for handling combined MTO-MTS production on the tactical and operational levels.

The core mission of any design science initiative is to develop general knowledge that professionals can draw upon to design solutions to their specific challenges and problems. In order to survive in tomorrow's business environments, managers must find solutions that can help them deal with the continuously increasing product variety and demand uncertainty. Advances in production technology are enabling the efficient production of more variants and smaller batch sizes. Simultaneously, we see that rapid advances in information and communication technology (ICT) are providing great opportunities for exploiting large amounts of data in the PPC task. In this respect this study was both relevant and timely since it demonstrated how a differentiation approach to PPC can enable and exploit these developments and thereby make food producers both efficient and responsive.

SAMMENDRAG

Denne ph.d.-avhandlingen er sluttrapporten fra en empirisk og eksplorativ studie av prinsippene som brukes i planlegging og styring av matproduksjon. Matprodusenter har tradisjonelt konkurrert på å tilby kundene gode produkter til lave priser. Produktene er tradisjonelt produsert til lager basert på prognoser ettersom produksjonsledetiden oftest er betydelig lengre enn kundenes krav til leveringsledetid. Ettersom fortjenestemarginene på matvarer er små, har produsentene vært avhengige av å produsere effektivt og i store volum for å opprettholde lønnsomheten. På den andre siden framheves nå responsevne som en av de viktigste egenskapene for å skape og opprettholde konkurransefortrinn. For matprodusenter betyr dette at de må kunne reagere stadig raskere på endringer i markedet – samtidig som investeringer i økt responsevne anes å redusere kostnadseffektiviteten. I tillegg ser vi at strategien med produksjon til lager i store volum blir mer og mer kostbar og risikabel. Økende produktvariasjon, større usikkerhet i etterspørsel og en stadig større andel av ferske matvarer med kort holdbarhet gjør at det kreves større og større lager av ferdigvarer for å sikre tilgjengelighet av produktene kundene etterspør – med tilhørende risiko for at produkter går ut på dato mens de ligger på lager eller bruk av overtid eller andre kostnadsdrivende initiativer for å kunne levere det kundene etterspør.

Behovet for å planlegge og styre produkter med ulike karakteristika på ulike måter er velkjent både i praksis og vitenskapelig litteratur. For å møte kundenes krav har for eksempel matprodusenter i løpet av de siste par tiårene adoptert mer markedsorienterte produksjonsplanleggingsprinsipper gjennom også å produsere varer på ordre og å kombinere lagerproduksjon med ordreproduksjon. I tillegg kan pakking på ordre være et alternativ i situasjoner hvor produksjons- og pakkeprosessen kan kobles fra hverandre. Hvilket planleggingsprinsipp man bør velge i ulike situasjoner er imidlertid fortsatt uklart.

Med utgangspunkt i utfordringene beskrevet ovenfor undersøkte denne studien hvordan man kan differensiere planleggingsprinsippene i matproduksjon i henhold til hva som er mest hensiktsmessig i ulike situasjoner, og videre hvordan en kombinasjon av lagerproduksjon og ordreproduksjon kan gjøre matprodusenter i stand til å møte kravene til både responsevne og effektivitet. Studien tok utgangspunkt i fire forskningsspørsmål:

1. Hva karakteriserer verdikjeden for mat?
2. Hvordan kan prinsippene for produksjonsplanlegging differensieres i henhold til verdikjedens karakteristika?
3. Hva er de potensielle fordelene ved differensiert produksjonsplanlegging?
4. Hva er de taktiske og operasjonelle konsekvensene av differensiert produksjonsplanlegging?

Forskningsspørsmålene ble adressert gjennom en kombinasjon av litteraturstudier og et casestudium. Studien ble designet innenfor 'Design Science'-paradigmet - hvor et praktisk problem ble identifisert og formulert ut fra empiriske data. Deretter ble teori og vitenskapelig litteratur brukt for å utvikle en konseptuell løsning og et casestudium brukt for å teste og videreutvikle konseptet før studiens teoretiske bidrag ble formulert gjennom refleksjon i etterkant av testingen. Casestudiet ble gjennomført i TINE, Norges største produsent, distributør og eksportør av meieriprodukter. TINEs pakkerianlegg for ost på Heimdal sør for Trondheim ble plukket ut for detaljert analyse og testing av konseptet. Studien ble hovedsakelig gjennomført

i perioden 2010-2013, og analysene ble gjennomført og løsningene utviklet i tett samarbeid med bedriftens ansatte for å styrke påliteligheten av resultatene og de nye løsningene.

Hensikten med forskningsspørsmål 1 var å identifisere nøkkelkarakteristika ved matverdikjeden med hensyn til produkt, marked og produksjonssystem ettersom disse utgjør rammebetingelser matprodusenter må forholde seg til i planlegging og styring. I sum ble det funnet at produkt- og markedskarakteristikaene krever høy responsevne fra matprodusenter, mens produksjonssystemet i størst grad er fokusert på utnyttelse av storskalafordeler. Det er dermed dårlig samsvar mellom kravene som følger av de eksterne faktorene ved produkt og marked og produksjonssystemets evne til å møte disse på en ressurs- og kostnadseffektiv måte.

For å besvare forskningsspørsmål 2 ble det utviklet et konsept for differensiert produksjonsplanlegging bestående av følgende prinsipper:

1) Gunstige produkt- og markedskarakteristika som lang holdbarhet, høy forutsigbarhet i etterspørsel og kunder som tillater lang ledetid bør utnyttes for å gi høyere fleksibilitet i produksjonssystemet
2) Planleggingsprinsipper bør differensieres i henhold til verdikjedekonfigurasjoner, dvs. kombinasjoner av produkt- og marketskarakteristika
3) Bruken av ekstra lager, kapasitet og tid bør differensieres for å bufre mot usikkerhet i etterspørsel

Basert på disse prinsippene ble det utviklet et rammeverk for differensiert produksjonsplanlegging. Rammeverket identifiserer de mest hensiktsmessige planleggingsprinsippene og bufferteknikkene for hver verdikjedekonfigurasjon, gitt de viktigste kravene som de aktuelle produkt- og markedskarakteristikaene stiller til produsenten; se Figur i-2.
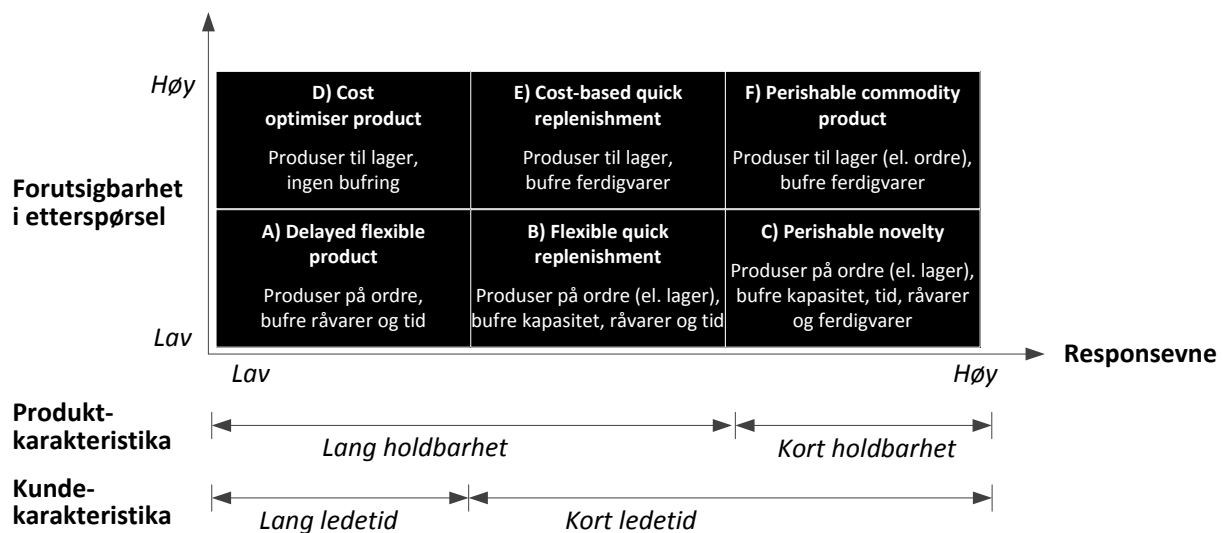
Figur i-2: **Rammeverk for differensiert produksjonsplanlegging i matproduksjon (videreutviklet fra Kittipanya-ngam, 2010, p. 110)**

Casestudiet av TINE Heimdal ble brukt for å illustrere hvordan konseptet og rammeverket kan brukes for å designe et differensiert produksjonsplanleggingssystem for en matprodusent. For å identifisere utfordringer og forbedringspotensial ble ytelsen til anleggets produksjonsplanleggingssystem analysert. Konklusjonen ble at selv om anlegget er relativt effektivt med hensyn til å møte kundenes krav til leveringspresisjon, så oppnås denne ytelsen på bekostning

av effektivitet i produksjon og lager. Dagens planlegging medfører blant annet behov for store ferdigvarelager for å bufre mot usikkerhet i etterspørsel, kostnader knyttet til produkter som går ut på dato, og inntektstap knyttet til at produkter med kort gjenværende holdbarhet selges til reduserte priser. Analysene viste også at anlegget i liten grad differensierer prinsippene for produksjonsplanlegging, hvor kun tre av de 15 produktene som ble plukket ut for detaljert analyse ble produsert på ordre, mens de resterende 12 ble produsert til lager.

Konseptet og rammeverket ble brukt til å designe et nytt produksjonsplanleggingssystem for TINE Heimdal. Som en del av dette ble det også utviklet et beslutningstre bestående av kvalitative og kvantitative vurderinger av forutsigbarheten til et matprodukts etterspørsel, inkludert vurdering av produktets innovasjonsgrad, fase i livssyklusen, bekreftelse av hvilke butikker som vil selge produktet, historisk prognosenøyaktighet, og følsomhet overfor andre eksterne faktorer som vær og sesonger. Redesignet av produksjonsplanleggingssystemet resulterte i at åtte av de 15 analyserte produktene burde produseres på ordre i situasjoner med ordinært salg, mens planleggingen av ytterligere tre produkter burde endres fra lagerproduksjon til ordreproduksjon i perioder hvor de er utsatt for markedsaktiviteter.

Forskningsspørsmål 3 undersøkte de potensielle fordelene ved differensiert produksjonsplanlegging. Det nye planleggingssystemet ble ikke implementert som en del av studien og effektene kunne dermed ikke måles. De potensielle fordelene ble isteden underbygget ved hjelp av innsikt fra litteratur og casestudiet. Fordelene ble gruppert i seks kategorier; bedre kvalitet, større hurtighet, høyere pålitelighet, økt fleksibilitet, lavere kostnader og bedre ytelse i planleggingsfunksjonen.

Det meste av litteraturen innenfor produksjonsplanlegging og -styring fokuserer på løsninger for én type produksjonsmiljø, dvs. enten lagerproduksjon eller ordreproduksjon. I konseptet for differensiert planlegging kombineres lager- og ordreproduksjon i samme produksjonssystem, og forskningsspørsmål 4 diskuterte noen av utfordringene dette medfører for taktisk og operativ planlegging og styring. Innsikt fra litteraturen og casestudiet ble brukt for å kaste lys over og diskutere noen av de viktigste beslutningene og utfordringene i slike hybride produksjonsmiljø. Nøkkelspørsmålet i denne sammenhengen er hvilke planleggingsmetoder og -teknikker som kan brukes for å håndtere usikkerheten knyttet til volum og timingen av innkommende ordrer for de ordrestyrte produktene. Diskusjonen konkluderte med at den tradisjonelle materialbehovsplanleggingsmetoden (material requirements planning, MRP) sannsynligvis vil fortsette å være den viktigste planleggingsmetoden innenfor matproduksjon, men at denne i kombinasjon med 'Workload Control' (WLC) kan være en hensiktsmessig løsning for å håndtere kombinert ordreproduksjon og lagerproduksjon på taktisk og operativt nivå.

Hovedoppgaven i ethvert 'Design Science'-prosjekt er å utvikle ny kunnskap som praktikere kan bruke for å designe løsninger på sine spesifikke problemer og utfordringer. For å overleve i morgendagens konkurransesituasjon må dagens bedrifter blant annet finne løsninger som kan hjelpe dem med å håndtere stadig økende produktvariasjon og usikkerhet i etterspørsel. Den tekniske utviklingen av produksjonsutstyr gjør det mulig å produsere stadig flere varianter i kortere serier. Samtidig gjør framskritt innenfor informasjons- og kommunikasjonsteknologi (IKT) at vi har stadig mer informasjon tilgjengelig som kan brukes til planlegging og styring. I så henseende var denne studien både relevant og tidsriktig ved at den demonstrerte hvordan en differensiering av produksjonsplanleggingsprinsipper kan understøtte og utnytte disse nyvinningene for å gjøre matprodusenter både effektive og responsive.

ACRONYMS AND ABBREVIATIONS

APS   Advanced planning system
ATO   Assemble to order
BOM   Bill of materials
CIMO   Context, Intervention, Mechanism, Outcome
CODP   Customer order decoupling point
COLT   Customer order lead time
CONWIP   Constant Work-In-Process
CPFR   Collaborative planning, forecasting and replenishment
ECR   Efficient consumer response
EOQ   Economic order quantity
ERP   Enterprise resource planning
ETO   Engineer to order
FIFO   First-in first-out
HORECA   Hotel, restaurant and catering
ICT   Information and communication technology
JIT   Just-in-time
MPC   Manufacturing planning and control (used interchangeably with PPC)
MPS   Master production scheduling
MRP   Material requirements planning
MRPII   Manufacturing resource planning
MTO   Make to order
MTS   Make to stock
NAA   Norwegian Agricultural Authority
NOK   Norwegian kroner
NPD   New product development
OM   Operations management
OR   Operations research
OPP   Order penetration point
PLC   Product life cycle
POLCA   Paired cell overlapping loops of cards with authorisation
PPC   Production planning and control (used interchangeably with MPC)
PTO   Pack to order (similar to ATO)
RFID   Radio Frequency Identification
RQ   Research question
SC   Supply chain
SCM   Supply chain management
SKU   Stock keeping unit
TOC   Theory of constraints
UHT   Ultra-high temperature
VMI   Vendor managed inventory
WLC   Workload control
XML   Extensible markup language

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1 INTRODUCTION

Food is essential to all humans and the food sector is a cornerstone for economic growth and wealth around the world, having shaped the emergence, development and persistence of human civilisations throughout the ages (Godfray et al., 2010b). Simultaneously, the continuing population and consumption growth means that a global food crisis is looming, leading to a need to change the way food is produced, stored, processed, distributed and accessed (Godfray et al., 2010a). An important way to increase food supply and decrease the environmental impact of current food production is to reduce waste (Godfray et al., 2010b, Parfitt et al., 2010, Mena et al., 2011, Godfray et al., 2010a). Currently, food is wasted in all stages of the food supply chain - and food producers are major contributors to this waste (Godfray et al., 2010b). Thus, food producers have a responsibility to manage their operations as effectively and efficiently[1] as possible in order to maximise the amount of edible output from the limited raw materials (Parfitt et al., 2010, Mena et al., 2011, Godfray et al., 2010a), from both a moral, environmental and economic perspective (Mena et al., 2011). And in this situation, turning to academics within the field of Operations Management (OM) for assistance and inspiration would be appropriate.

Although OM is an applied field with a distinct managerial character, research within OM is in general thought to provide limited guidance to OM practitioners. Or as de Treville et al. (2008, p. 15) put it:

> *'In the field of operations management ..., it is not clear whether much if anything would change in practice if the entire group of academics suddenly disappeared.'*

This quote is an indication of a gap between theory and practice and a reflection of practitioners' continuing dissatisfaction with OM research – where researchers for decades have been accused of following rather than leading business practice (Holmström and Romme, 2012, Westbrook, 1995, Chopra et al., 2004).

Against this background, this PhD thesis reports on an empirical and explorative study which, in addition to making a theoretical contribution, aims to demonstrate that OM research can in fact contribute to solving some of the practical challenges facing food producers. In an attempt to narrow the gap between theory and practice, practical relevance and realism were guiding stars for the study's scope, objectives, and research questions, as well as the research methods used to achieve the objectives.

This chapter starts by presenting some of the practical challenges that motivated the research, followed by an outline of the research challenges and opportunities underpinning the study. This then provides input to the study's objectives, research questions and scope. The chapter concludes with an outline of the structure of the thesis.

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[1] In this thesis, effectiveness is used to describe something that is adequate to accomplish a purpose; producing the intended or expected result (http://dictionary.reference.com/browse/effectiveness). Efficiency is used to describe the ability to accomplish a job with minimum expenditure of time and effort (http://dictionary.reference.com/browse/efficiency).

1.1 Practical challenges in food supply chains

Food supply chains deal with perishable goods, where rapid product and raw material deterioration significantly affects product quality and safety. Food producers deal with a very heterogeneous group of products, with different degrees of perishability, supply uncertainty and production lead times, supplied to different customers, in differing quantities and at different frequencies in markets with varying degrees of demand uncertainty. Thus, both demand and supply in food supply chains are becoming more heterogeneous and dynamic (Trienekens et al., 2012). Traditionally, food producers in industrialised countries have paid great attention to quality, food safety and meeting customer demand (Parfitt et al., 2010), and like industry in general producers have focused on efficiency and economies of scale to keep costs and prices down (van Donk et al., 2008, Verdouw and Wolfert, 2010).

Production lead times in the food sector tend to be much longer than customers' delivery lead time expectations, and this means that producers have mostly used finished goods inventories to meet customer requirements for responsiveness. The result of the traditional ways of managing production and inventory include large amounts of waste when the amounts produced exceed demand since products expire in inventory (Gustavsson et al., 2011). Conversely, in situations where demand is higher than expected, producers commonly use overtime and other costly measures to avoid stock-outs and loss of goodwill.

The need for differentiating products and managing products with different characteristics differently is well recognised in both practice and literature. In 1997, Marshall Fisher's (1997) seminal article titled 'What is the right supply chain for your product?' was published in Harvard Business Review. In the article, he conceptually matched different product demand characteristics with what he called the 'right' supply chain strategies – recommending that companies that deal mainly with functional products with predictable demand follow a physical efficiency strategy, while innovative products with unpredictable demand should be associated with a market responsiveness strategy. Supply chain strategy was thus an 'either or' question between efficiency and responsiveness.

Although attractive in its simplicity, the pratical value of Fisher's article in today's business environment can be questioned. Although the framework provided companies with a valuable tool for determining supply chain and market interaction strategies, it was derived from yesterday's stable and supplier-driven competitive environments where the focus was on standardisation, mass production and economies of scale (Christopher and Holweg, 2011). Today's business environment is however characterised by turbulence, increasing uncertainty and a variety of external requirements that are creating a new reality for companies (Christopher and Holweg, 2011). In today's environment, it is no longer sufficient for producers to be either efficient or responsive since customers are demanding that suppliers deliver high quality products at low prices (thus requiring internal cost efficiency) and simultaneously want suppliers to be responsive in providing them with the products they want as timely as possible (Holweg, 2005).

Another trend that is affecting food producers is the market requirements for more product variety, delivered more frequently and in smaller batches within shorter and shorter lead times (Reichhart and Holweg, 2007). These developments are creating severe operational problems for companies that apply traditional push or forecast-based strategies as these require large amounts of finished goods inventories to ensure customers find the specifications they are looking for (Reichhart and Holweg, 2007). Further, more frequent and intensive use of cam-

paigns and other market activities are leading to more fragmented demand and increasing demand variability (Huchzermeier and Iyer, 2010). Thus, in an OM perspective, the inherent product and market characteristics make food supply chains more complex and harder to manage than many other supply chains (Ahumada and Villalobos, 2009, Crama et al., 2001, Rajurkar and Jain, 2011).

The traditional approach of using only one strategy to manage production and the company's interaction with the market does not exploit the fact that there are significant differences in the product and market characteristics of food supply chains. It would for instance make sense for a food product with a production lead time of one day and shelf life of 11 days to be managed differently from a product with a production lead time of 15 months and shelf life of three months. Yet consumers expect both products to be available in grocery stores at all times, and retailers and wholesalers expect the delivery lead time of these products to be identical. Similarly, there is also some variation in the requirements wholesalers and retailers exert on food producers. While some customers demand same day delivery, others are willing to wait several weeks or even months. In addition, although some products have a short shelf life and should not spend any time in inventory at all, others have lower perishability and can be stored in inventory for weeks or months without any reduction in product quality. Also, although demand can be variable, not all demand is unpredictable. For strong brands with high turnover, demand can in fact be very predictable.

From the above, we see that there is a need for food producers to manage, plan and control their operations in a different manner in order to meet the evolving market requirements and stay competitive. It appears that the dominant 'one size fits all' approach does not effectively enable the capabilities this requires. Thus, instead of selecting between efficiency and responsiveness, companies are now forced to compete on both simultaneously (Hvolby et al., 2001) – for as Bernardes and Hanna (2009, p. 30-31) put it:

> *'...responsiveness may be one of the most important capabilities needed for firms to achieve competitive advantage'.*

Although responsiveness has the simple and sensible business logic of providing customers with the products they want as timely as possible (Holweg, 2005), the question of how food producers can meet the need for simultaneous responsiveness and efficiency in an effective and efficient manner remains open.

1.2 Research challenges and opportunities

Food production is similar to process production, showing a higher complexity than discrete production (Crama et al., 2001). In the short term, food producers tend to aim for production economics to keep costs and prices down. This means that supply chain design to a large extent has been determined by the characteristics of the production system (van Donk et al., 2008, Verdouw and Wolfert, 2010, van Wezel et al., 2006). However, existing configuration literature maintains that product and market characteristics should determine a company's competitive priorities rather than the characteristics of the production system (Reichhart and Holweg, 2007). From a capabilities perspective, one would therefore expect food producers over time to have adapted the capabilities of their supply chains to the external requirements following from product and market characteristics. The fact that this is still not the case indicates that there may be a lack of strategic fit between the external requirements placed upon food producers and the strategies they use to guide the design of their production system.

A production system as a whole should not only focus on costs and cost efficiency but also show high flexibility with respect to reacting to changing market conditions, fluctuating demand forecasts and actual demand (Bertrand et al., 1990). As mentioned, the need for differentiating products and managing them differently is well recognised in both practice and literature. The concept of supply chain fit was popularised by Fisher's conceptual article, which was based on matching supply chain strategy with product characteristics. The framework had its roots in the operations and production strategy literature, and already three decades earlier, Skinner called for better integration between production and corporate strategy (Skinner, 1969). Since then, the link between supply chain fit and company performance has been confirmed in a number of studies, most recently by Wagner et al. (2012). Thus, there seems to be a general agreement in literature that different types of products should be treated differently in terms of the processes needed to produce those products.

A common belief in industry has long been that increasing product diversity leads to increases in overall production costs (Christopher and Gattorna, 2005). However, aligning strategies and processes to market requirements has been suggested as a way of achieving service improvements to customers at less cost (Christopher and Gattorna, 2005). This is also reflected in the view that matching customer requirement with product characteristics and ensuring delivery should be one of the greatest concerns for the management (Li and O'Brien, 2001, Aitken et al., 2003, Holweg, 2005, Demeter et al., 2006, Payne and Peters, 2004). 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 make-to-stock (MTS) approach to applying more make-to-order (MTO) and combined MTO-MTS approaches (Soman, 2005, van Donk, 2001). 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 are applied to different product–market combinations, all the while taking the constraints of the production system into consideration. Such a differentiated approach to PPC could in this manner enable the company to respond to different market and product requirements in a more customised manner.

As mentioned, the increasing product variety is making the PPC task more complicated and resource demanding since a larger number of products with different characteristics must be planned and controlled. On the other hand, the amount of data available to PPC decision makers is exploding – with developments in ICT providing unprecedented opportunities for data capture and analysis. This presents an opportunity to re-design PPC systems so that companies can take advantage of the access to more and better data to support, facilitate and to a larger degree automate the PPC task, and thus free up resources to focus on for instance surveillance and status monitoring (Strandhagen et al., 2011). A critical issue in this respect is to determine the principles on which the PPC system will be based, and to identify the products on which PPC resources should focus the most, in other words find the 'focus box' for PPC that will enable an increase in both the efficiency and effectiveness of the PPC function.

As mentioned, existing configuration literature focuses on matching product and market characteristics with supply chain design and strategy. However, many of the existing taxonomies and typologies can be claimed to have limited applicability in the food sector since they fail to

take the unique characteristics of food products into consideration. Already in 2001, van der Vorst et al. (2001) noted the difficulty in applying Fisher's 1997-framework to food producers. On the one hand, the majority of food products have fairly long life cycles and low contribution margins – characteristics associated with Fisher's functional products. On the other hand, the products are also associated with volatile and unpredictable demand, large product variety, and retailers demanding frequent and responsive deliveries at short notice – characteristics of innovative products in Fisher's framework. So for food producers the question of which strategy to aim for and whether there is one 'right' strategy for a company as a whole remains open.

The need for more research to develop methodologies and frameworks for strategy formulation as well as suitable planning and scheduling systems in food supply chains was also noted in a recent literature review by Rajurkar and Jain (2011). Although some work has been done on specifying hierarchical frameworks and guidelines for planning and control in food production (see e.g. van Donk, 2001, Soman et al., 2004, Soman, 2005, van Wezel et al., 2006), there is still a need for further refinement and extension of these for PPC purposes and investigation of how combined MTO-MTS approaches could work in practice.

From the above, a number of relevant questions for further research can be derived, including; should food producers aim for an efficiency or responsiveness strategy? And indeed; is there one single 'right' strategy for a company as a whole? And further; which PPC approach should be chosen in which situation? And more broadly; how can PPC be differentiated to provide a better strategic fit between the external requirements and the capabilities of food producers' production system, thus enabling food producers to meet the requirements in an effective and efficient manner?

1.3 Research objectives and questions

The problems and challenges described in the previous sections are typical problems that food production managers face on a day-to-day basis and for which there are no off-the-shelf solutions available. There is therefore a need for research which generates knowledge that managers can use to initiate appropriate interventions. The overall scientific goal of this study is therefore to:

- Contribute to increased understanding of how differentiated PPC can enable food producers to meet external product and market requirements in an effective and efficient manner

In order to attain this goal, a number of measurable objectives were defined to guide the research. Objective 1 addresses the need to establish an in-depth understanding of the empirical context for the research by mapping and analysing how the characteristics of food supply chains impact on food producers and how production is planned and controlled. Objective 2 focuses on the need to develop a concept and a framework which can be used to design a differentiation approach to PPC, while objective 3 aims to illustrate through an in-depth case study how the concept and framework can be operationalized. Objective 4 targets the need for research that not only focuses on creating new knowledge but that also aims to address a relevant and current practical problem in industry. The four objectives are summarised in Table 1-1.

Table 1-1: Research objectives

Objective	Description
1	Identify challenges of current PPC in the food sector
2	Develop a concept and framework for differentiated PPC in the food sector
3	Conduct a case study to identify relevant PPC challenges, develop new solutions and investigate the potential benefits of differentiated PPC
4	Provide guidance to industry on a relevant and current problem

Four research questions (RQ) were formulated to guide the research based on the scientific goal and the four objectives, see Table 1-2.

Table 1-2: Research questions (RQ)

Number	Research question
RQ1	What are the characteristics of food supply chains?
RQ2	How can PPC be differentiated according to food supply chain characteristics?
RQ3	What are the potential benefits of differentiated PPC?
RQ4	What are the tactical and operational challenges of differentiated PPC?

In order to contribute to closing the gap between practice and theory, the PhD study has a dual purpose by aiming to contribute both to knowledge creation and to solving a relevant and interesting problem in practice. Given this purpose, the study was designed and conducted under the design science paradigm. Design science is a stream of research which uses analysis and explanation to specify interventions that can transform present practices and improve the effectiveness of organisations (Denyer et al., 2008). In other words, design science research studies are driven by real-world problems and aim to develop general and prescriptive knowledge to support the design of solutions to practical industrial problems such as the ones described above (van Aken and Romme, 2009). More details about the study's research methodology are found in chapter 2.

1.4 Research scope

This section briefly introduces and defines some of the key theoretical terms and concepts upon which the PhD study is based (these are further explored in chapters 3 and 5). In addition, some clarifications with regards to supply chain actors and processes are appropriate, as well as some comments on issues and aspects which are outside the scope of the study.

1.4.1 Key theoretical perspectives

The practical industry problems described in the previous sections fall within the OM domain and are at the heart of the functional area of operations. OM is here understood as the activity of managing the resources involved in the conversion and delivery of an organisation's goods and services through the creation, design and coordination of business operations (Slack et al., 2007, Holmström and Romme, 2012).

Further, an organisation's operations strategy determines the role, objectives and activities of the operations function. In other words, operations strategy is concerned with effectiveness, i.e. doing the right thing, while OM is concerned with efficiency, i.e. doing things right.

One of the key decision areas in operations strategy is PPC, which in literature is also referred to as manufacturing planning and control (MPC)[2]. In this thesis, the term PPC system is used similarly to the MPC framework of Vollmann et al. (2005) – where the system comprises the principles, procedures and decisions which 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 the PPC system thus specifies the principles used to operate and coordinate operations on a day-to-day basis. The PPC system is further set within a production system, understood as a system of independent productions that each consist of a set of conditions and actions (Simon, 1996). Although the productions are independent, together they form a complex system which needs to be coordinated in order for the organisation to achieve its overall objectives.

The OM phenomenon investigated in this research is responsiveness, which has been recognised 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). There is however inconsistency and ambiguity in the use of the construct in literature and therefore a clarification concerning its use is required. In this thesis, the definition of Bernardes and Hanna (2009) is used, where responsiveness is understood as a performance-related concept that expresses the business level performance capability and the system's behaviour or outcome. Responsiveness is consequently defined as the propensity for purposeful and timely behaviour change in the presence of modulating stimuli, e.g. a customer order or other market signals (Bernardes and Hanna, 2009).

At the lower level of abstraction, responsiveness can be viewed as the company's ability to act on market knowledge – i.e. customer responsiveness. Customer responsiveness is thus defined as the business level performance capability of a system to react on market knowledge to rapidly address modifications in customers' expectations (Bernardes and Hanna, 2009). Customer responsiveness refers to the organisation's reactive capability in relation to the market, i.e. coping with changes imposed by external forces, as opposed to being proactive in controlling uncertainty by seizing initiatives and opportunities to modify the external environment.

The reactive capability of customer responsiveness can further be expressed in terms of flexibility. Flexibility within the scope of this research is the enabling ability to change status within the existing configuration. Thus, flexibility is understood as the operating characteristic which enables operations to absorb disturbances and variability, while responsiveness indicates how well the system behaves with regards to market changes.

Responsiveness has further been linked to different types of internal and external flexibility. This thesis addresses external flexibility by looking at the external factors which require responsiveness and how internal PPC can enable this responsiveness. Slack (2005) defines four types of external flexibility: product, mix, volume and delivery (for more on responsiveness and flexibility; see sub-section 3.1.4). The thesis mainly addresses volume flexibility referring to the company's ability to change the level of aggregated input (Slack, 2005) since this flexi-

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[2] In this thesis, production and PPC are used interchangeably with manufacturing and MPC respectively

bility type enables the production system to deliver the requested product variants, in the quantities required and within the customers' order lead time expectations – i.e. meet customer demand. Mix flexibility refers to the company's ability to change the range of products made within a given time period (Slack, 2005) and this is indirectly addressed since considerations are made on the level of stock keeping units (SKU), fitting different market and product combinations with the appropriate strategy in different situations. Also, the scope is on how PPC can provide flexibility to handle the mix as specified by incoming orders within the existing capacity.

The need for external flexibility has been linked to a number of different types of variability, e.g. supply, process, demand, workforce and equipment (Beckman and Rosenfield, 2008). Since the focus of the research is on customer responsiveness, the type of variability addressed is demand variability and how an organisation's PPC system can be designed to meet demand variability under different circumstances.

Over the past decades, companies have been facing more and more uncertainty which has had to be accommodated or buffered against within the constraints of the company's production system (Bernardes and Hanna, 2009). Changes in customer requirements have pushed food producers to adopt more market-oriented strategies (Soman et al., 2004, Crama et al., 2001), and a central concept in this respect is the customer order decoupling point (CODP). This point represents a principal design parameter in a company's PPC system and expresses how production interacts with the market; are production activities triggered by customer orders (e.g. MTO) or by forecasts (e.g. MTS)? An MTO approach does therefore not necessarily contain any kind of customer specification of the product itself or its production process.

PPC is considered at the strategic level where the principles for the PPC system are designed. In addition, some of the implications for PPC at the tactical and operational levels are discussed. MTO and MTS are in this thesis referred to as different PPC approaches and have traditionally been viewed as extreme philosophies, entirely distinct and incompatible with the other. However, as product lines and customer bases have grown in diversity, some companies have come to realise that a combination of the two may be an appropriate solution (Federgruen and Katalan, 1999, Soman et al., 2004, van Donk, 2001), and this situation is in this thesis referred to as differentiated PPC.

1.4.2 Supply chain actors and processes

The study focuses on food supply chains from a producer perspective. A food producer is here defined as a company which processes intermediate products into consumer or industrial products; e.g. packaged meats, baked goods, dairy products, chocolate, etc. This is different from companies which produce intermediate products from natural materials, e.g. mills, abattoirs, and sugar refineries. The results of the study may be of interest also to these types of producers but they are not the main focus of the study.

Although the food sector also consists of a large number of small and medium sized companies producing food specialities and catering to niche markets, this study focuses 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 study further takes the perspective of a food production company with limited resources that produces a variety of product variants in a limited number of facilities on a limited number of production lines. At the core of the differentiation approach under investigation is the fact that each planning unit, i.e. factory, can manufacture products using both an MTO and an MTS approach – and that an individual product can be MTO or MTS depending on its product and market characteristics. In a situation with unlimited resources, facilities or production lines could be set up to deal with the MTO and MTS items separately. However, for most companies this is neither practical nor financially feasible – and thus this study looks at how a company can differentiate the way products are managed by differentiating the way production is planned and controlled using the equipment, resources and facilities currently available.

In the supply chain perspective, suppliers in this study includes farmers and companies which produce intermediate food products, ingredients, packaging material, and other production inputs. Downstream in the supply chain, customers are defined as professional actors who buy food products from food producers, e.g. wholesalers, retailers, restaurants and hotels.

In terms of supply chain processes, the scope is limited to the planning and control of production processes. Although PPC will also have an impact on how inventory is planned and controlled, inventory is not the main focus of the study.

A number of aspects related to products and production technologies are considered fixed and therefore constitute parameters within which analyses are performed and new solutions developed. Such aspects include internal physical flexibility (physical production processes, machinery, routings and other physical operations), product perishability and shelf life, production capacity, supply chain structure, number of facilities, product variants produced at each facility, and distribution channels.

1.5 Thesis structure

Figure 1-1 shows how the research questions are linked with the different stages of the study and the eight main chapters of the thesis.
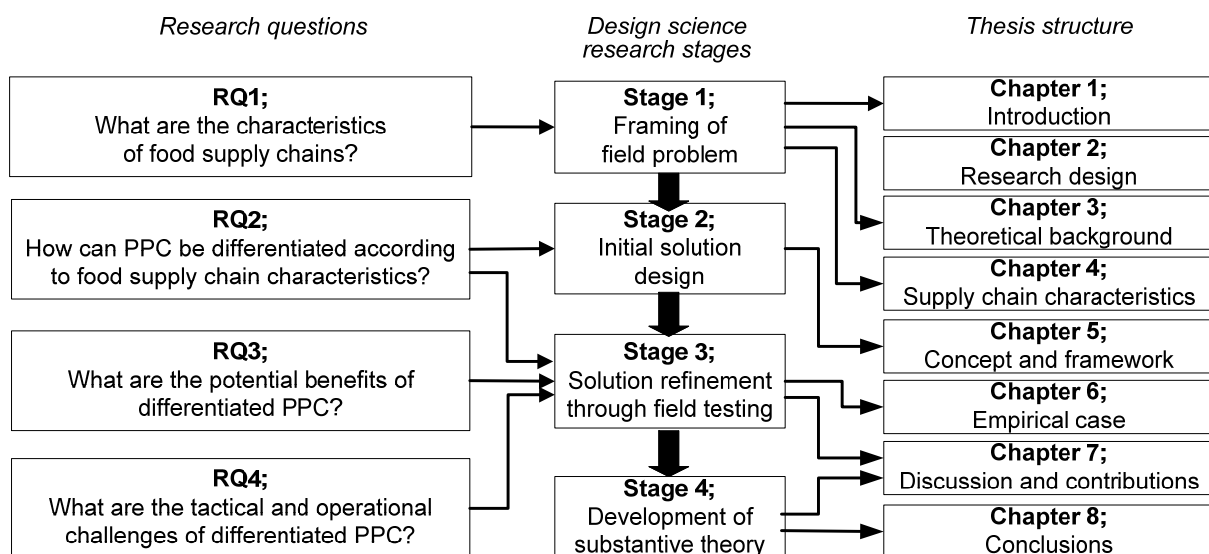
Figure 1-1: Relationship between research questions, research stages and thesis structure

RQ1 is the starting point for the study and investigates the characteristics of food supply chains to provide a better understanding of both the empirical context and the requirements facing food producers. This question is addressed in stage 1 of the study where the field problem is identified, framed and defined based on empirical insights from previous studies and a mapping and analysis of the characteristics of food supply chains. The theoretical background for the problem is elaborated in chapter 3. The answers to RQ1 can be found in chapter 4, and these are further confirmed through the case study presented in chapter 6.

RQ2 investigates how PPC can be differentiated. This question is explored in the study's stage 2, where an initial solution design is developed based on a systematic review of literature, combined with theoretical and empirical insights. The concept and the associated framework are described in chapter 5.

The concept and framework from chapter 5 is subsequently tested in the case study, both analysing the field problem in more detail and developing a new solution for differentiated PPC. Chapter 6 describes the case company, the analysis of planning and control, and the proposed solutions.

RQ3 is investigated in stage 3 of the study, where the case study provides empirical insights which are combined with insights from literature to substantiate potential benefits of the proposed concept and framework from stage 2. The findings with regards to benefits are presented in sub-section 6.3.3 and discussed in chapter 7.

RQ4 is also part of stage 3 and focuses on the tactical and operational challenges of the differentiation concept developed in stage 2. The question is addressed through a literature study, inspired by insights from the case study. The findings are presented and discussed in section 7.4.

In stage 4, the theoretical and empirical insights from the previous stages are synthesised into a number of contribution towards substantive theory. In chapter 7, the study's theoretical relevance and contributions are discussed, linking them to the theoretical discourse. A summary of the study's insights and contributions is outlined in chapter 8, together with some implications for practice and suggestions for further research.

2 RESEARCH METHODOLOGY

Research can be described as a voyage of discovery, where knowledge is searched for through objective and systematic methods for finding solutions to a problem. A study's research methodology describes the way that the research problem has been systematically approached, thus explicating the steps that have been adopted and the logic behind the selection of the methods and techniques for collecting and analysing data and establishing relationships (Kothari, 1990).

In order for others to evaluate the research conducted in this PhD study, this chapter describes the choices which have been made with regards to research methodology. The chapter starts by outlining key developments and the paradigm that inspired the study's research strategy. Then, the details of the specific research design are described in terms of methods and techniques for data collection and analysis. The chapter concludes with a table that links the study's research questions with the different stages of the study, the data types and the methods for analysis.

2.1 Research strategy

Before the study's specific research design is outlined in the next section, a description of some of the developments and concepts with guided the study's research strategy is appropriate. A brief overview of the history of OM research is provided as well as a general introduction to the design science paradigm and abductive reasoning approach used to build arguments in the study.

2.1.1 History of research methodology in OM

The problems that OM practitioners and researchers are typically concerned with first came into focus following the Industrial Revolution and the rise in popularity of the ideas of Frederick Taylor and Scientific Management (Taylor, 1911, 2006). At that time, managers of large businesses faced practical coordination problems of unprecedented scope, and organising, measuring and managing production became the topics of treatises published by professionals from business and industry (Chopra et al., 2004).

World War II saw the emergence of Operations Research (OR) – a field dominated by mathematicians concerned with efficient allocation and control of industrial resources. The management issues of a tactical nature stemming from Taylor's time were ideally suited for the positivist methodologies that had been developed up to that point (Chopra et al., 2004). For decades, OM's research focus was on mathematical analysis, algorithms and modelling techniques for optimisation of well-defined tactical problems.

With improvements in the cost and speed of computing from the 1970s and onwards, the industry sector envisaged great contributions from academia. However, academia did not live up to the promises made to industry, leading practitioners to question the value and relevance of research results which were unable to keep pace with the quickly evolving business challenges and practice (Chopra et al., 2004). The positivist methods that had dominated OM research for decades may have been well suited for solving the relatively well-defined and tactical issues of the past with quantitative research methods. However, in the more modern business environments these approaches were found to have little benefit for practitioners facing

complex, dynamic managerial problems (Karlsson, 2009, Näslund, 2002). Thus, from the early 1980s there have been calls for more empirical research methods in OM (Barratt et al., 2011), and in the 1990s, a refocusing of OM research back to using theory to inform current practice was attempted, shifting focus from tactical execution to more managerial issues (Chopra et al., 2004).

The success of the reorientation of research questions and methods can be questioned as the increase in the application of more non-positivist methods like case studies and action research has only been slow and fairly limited (see for instance reviews of research methods by Mentzer and Kahn, 1995, Reichhart and Holweg, 2006, Sachan and Datta, 2005, Barratt et al., 2011). Thus, despite being an applied field with a managerial character, OM research is still though to provide limited guidance to OM practitioners, with academia in general following rather than leading business practice (Holmström and Romme, 2012, Westbrook, 1995, Chopra et al., 2004).

From the above, it appears that there is still a need to shift OM research from a predominant orientation on explanation to a broader orientation, also including exploration – where researchers anticipate and respond to developments affecting OM practice. Holmström and Romme (2012) propose that this reorientation can be done by adding 'design' to the research cycle of practice and science (Holmström and Romme, 2012). This may help in achieving good OM research; strong relevance for practice, significant contribution to knowledge, and trustworthiness achieved through research which is well conducted methodologically – providing a good fit between problem, method and contribution (Karlsson, 2009). This design science paradigm is further described in the next sub-section.

2.1.2 Design science

In response to some of the criticisms against OM research described above, the design science paradigm has been receiving increasing interest as an alternative research approach. The approach has its roots in Herbert Simon's seminal book 'The sciences of the artificial' (Simon, 1996), where he contrasted the natural sciences, which aim to analyse and explain the behaviour of natural systems, with research aiming to design artefacts, e.g. engineering and medicine. Whereas research in the natural sciences is description-driven, design science is prescription-driven. Design science is interested in systems that do not yet exist or in the improvement of a given system – with a mission of developing knowledge to solve problematic situations in reality in a quest for improving the human condition (Denyer et al., 2008, van Aken and Romme, 2009). A main outcome of a design science study is therefore a new or improved design. Design can here be understood as devising the artificial, in other words courses of action aimed at changing existing situations into preferred ones (Simon, 1996), much in the same manner that a medical doctor prescribes remedies for a sick patient.

Table 2-1 outlines the main differences between the explanatory sciences' description-driven research and design science's prescription-driven research.

Table 2-1: Differences between description and prescription-driven research (based on van Aken, 2004)

Characteristic	*Descriptive-driven research programmes*	*Prescription-driven research programmes*
Dominant paradigm	Explanatory sciences	Design sciences
Focus	Problem focused	Solution focused
Perspective	Observer	Player
Logic	Hindsight	Intervention-outcome
Typical research question	Explanation	Alternative solutions for a class of problems
Typical research product	Causal model; quantitative law	Tested and grounded design propositions
Nature of research product	Algorithm	Heuristic
Justification	Proof	Saturated evidence
Type of resulting theory	Organisation theory	Management theory

Design science research has been defined as research that develops valid general knowledge to solve field problems based on the approach of the design sciences (van Aken and Romme, 2009). As such, the design science paradigm is characterised by (Denyer et al., 2008);

- Research questions driven by an interest in field problems
- Research methodologies emphasising production of prescriptive knowledge, linking it to interventions and systems to provide outcomes, providing the key to solving field problems
- Research products justified largely based on pragmatic validity, i.e. the ability of the knowledge-based actions to produce the intended outcomes

Typically, a design science research study consists of one or more cycles of research moving between exploration and explanation, often using a multiple-case study approach to generate several reflective cycles. Inspired by a research framework from the information systems field where design science has been practised for decades, Figure 2-1 illustrates how three types of research cycles connect the design science research with the environment and the knowledge base (see Hevner, 2007, Hevner et al., 2004). The aim is to integrate the highly different but complementary modes of developing knowledge and expertise; science, design and practice (Holmström and Romme, 2012).
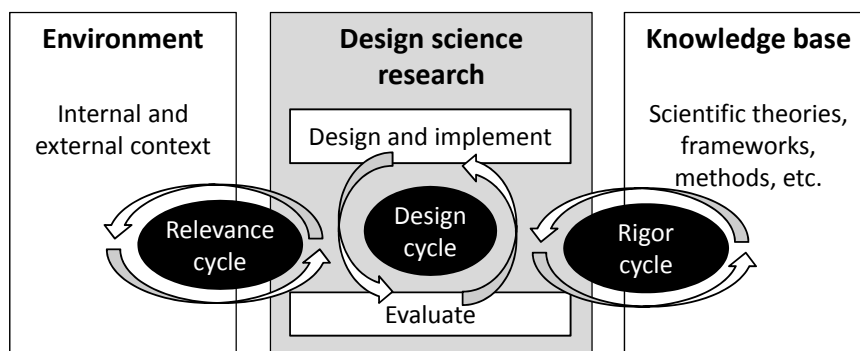
Figure 2-1: Design science research cycles (adapted from Hevner, 2007, Hevner et al., 2004)

The relevance cycle initiates the research by providing the requirements for the research, i.e. the field problem, while the output from the design science research is returned to the envi-

ronment for study and evaluation in the real-life context. The results of the field testing determine whether additional iterations of the relevance cycle are needed.

The rigor cycle provides past knowledge to the study to ensure its innovation and is predicated on the researcher's skilled selection and application of the appropriate theories, frameworks and methods for constructing and evaluating the solution design. Outputs from the design science research will generate additions to the knowledge base, including any extensions to the original theories and methods, the designed artefacts (solutions, products, processes, etc.) and all experiences gained from the research and field testing in the environment.

The design cycle is the core of any design science study and consists of generating design alternatives and evaluating the alternatives against requirements until a satisfactory design is achieved.

While a study's research strategy or approach describes the scientific reasoning and argument building, a study's research process is the summary of the sequential steps necessary for following the path of a specific research approach (Kovács and Spens, 2005). Table 2-2 outlines the typical stages of a design science research cycle.

Table 2-2: Design science stages (based on van Aken and Romme, 2009, Holmström et al., 2009)

Stage	Objective	Research phase	Description
1	Framing of field problem	Exploration phase 0	Choice of field problem to be addressed, including identifying, understanding and framing the problem.
2	Development of initial solution design	Exploration phase 1	Initial solution design based on systematic review of literature, abductive reasoning and research synthesis based on empirical findings and theoretical insights. Outcomes include design propositions and design exemplars.
3	Solution refinement through field testing	Exploration phase 2	Initial solution is tested and refined through iterations between solution design, implementation and evaluation.
4	Development of substantive theory	Explanation phase 1	Establishment of theoretical relevance through theoretical reflection on refined solution design, linking it to the theoretical discourse and refining original design propositions. Theoretical justification beyond the single context and demonstration of theoretical utility is sought.
5	Development of formal theory	Explanation phase 2	Theoretical and empirical examination of relevant contingencies in order to generalise knowledge to contexts beyond the empirical context under study. Beta-testing of design propositions by others to eliminate bias and optimise its ease of use.

In stages 1-4, design propositions are developed (see sub-section 2.2.2) and their ability to solve the problem is tested through one or more case studies carried out in close collaboration with the people in the field. Following a reflective cycle after each case study, the researcher

develops knowledge that can be transferred to similar contexts on the basis of reflection and, in the case of multiple-case studies, through cross-case analyses (van Aken, 2004).

Formal theories such as those resulting from stage 5 often develop from substantive theories as time progresses, aiming at broader generalisability in terms of both theoretical abstraction and statistical generalisability (Holmström et al., 2009). Once propositions have become formal theory they do not require an empirical context and their meaning is rather embedded in the logic of the theory itself. The development of such formal theory requires cumulating research by adding cases until theoretical saturation is reached – in other words to the point at which incremental learning is minimal because the researchers are observing phenomena seen before (Eisenhardt, 1989). Such replication studies also avoid researchers' biases in how observations are gathered and interpreted.

In practice, theoretical saturation must often be combined with pragmatic considerations such as time and money in the determination of when to end case collection (Eisenhardt, 1989). Thus, for a PhD study such as this one, reaching stage 5 is rather unlikely due to such practical constraints. Instead, this study focused on steps 1-4, conducting an in-depth case study which is described in detail – thereby providing a basis for other researchers to conduct additional testing in other cases and contexts until theoretical saturation has been reached.

2.1.3 Abductive reasoning

A particularly important aspect in the reporting on any research is how the arguments are built (Karlsson, 2009). The two most common sets of logic are deduction and induction. Deductive approaches are concerned with developing propositions from current theory and making them testable in the real world, while inductive approaches rely on 'grounded theory' where theory is systematically generated from data (Dubois and Gadde, 2002). In addition, there is a third logic – abductive reasoning, also referred to as systematic combining. Abduction relies more on refining existing theories than on inventing new ones – where research studies successively modify original frameworks based on unanticipated empirical findings and theoretical insights gained during the process (Dubois and Gadde, 2002). Thus, abductive research starts with a real-life phenomenon and observation, where the researcher initiates a creative iterative process of systematic combining or 'theory matching' in an attempt to find a possible matching framework or to extend theory (Spens and Kovács, 2006).

A key characteristic of the abductive approach is its movement back and forth between the empirical world and the model world. This process of systematically combining theoretical frameworks, empirical fieldwork and case analysis is illustrated in Figure 2-2.
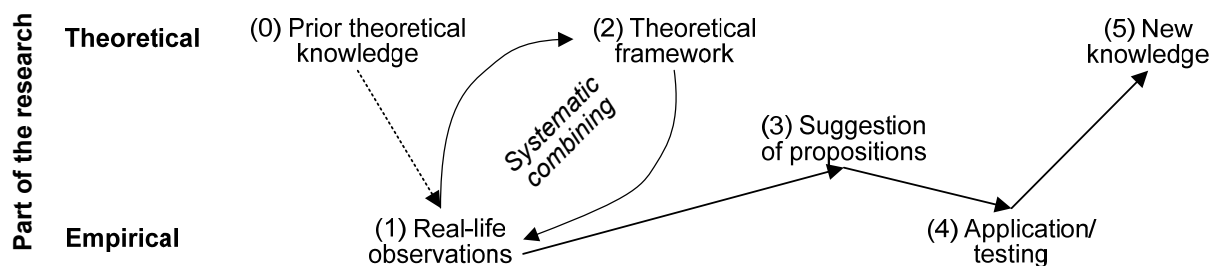
Figure 2-2: Abductive research process (adapted from Kovács and Spens, 2005, Spens and Kovács, 2006)

Abduction is a useful tool in a design science study, particularly in the development of the initial solution design (stage 2 in Table 2-2) (Holmström et al., 2009, Järvinen, 2007), but also in the other stages as it assists in linking the study with the environment and the knowledge base.

2.2 Research design

In empirical research, research design is the logical sequence that connects the empirical data to the study's initial research questions and its conclusions (Yin, 2009). The design guides the process of collecting, analysing and interpreting data. As Karlsson (2009) noted, not all research questions can be answered by all research methods – and similarly, one particular method cannot answer all types of research questions. The design of a research study should therefore ensure a good fit between the research questions asked, the methods applied and the intended contributions of the study.

It has been suggested that the research products of a design science study can be justified on pragmatic validity, i.e. the ability of the knowledge-based actions to produce the intended outcomes (Denyer et al., 2008, van Aken and Romme, 2009). On the other hand, some criteria for judging the quality of empirical research can still be helpful in ensuring rigor in the design of a design science research study. Since this type of studies is generally based on a combination of qualitative and quantitative methods, the quality of the research cannot be judged on the traditional quantitative criteria of validity, reliability and objectivity. Rather, it has been suggested that qualitative inquiries should be evaluated on the combined qualities of trustworthiness, expressed as credibility, transferability, dependability and confirmability (Halldorsson and Aastrup, 2003), see Table 2-3.

Table 2-3: Criteria for trustworthiness of qualitative research (based on Halldorsson and Aastrup, 2003)

Criteria	*Description*
Credibility	Degree of 'match' between respondents' constructions and researchers' representation of these, where respondents play a central role in falsifying/correcting the picture of reality drawn by the researcher.
Transferability	Extent to which the study is able to make general claims about the world, depending on the similarities between contexts over time and space.
Dependability	Concerns stability of data over time and is achieved when the replication of the same or similar instruments of the same phenomenon results in a similar measurement.
Confirmability	Extent to which the findings can be confirmed through the data and conclusions, interpretations and recommendations can be traced back to their sources such that an external actor can assert the results of the study.

The criteria in Table 2-3 were used in the design of the research in order to increase trustworthiness, and they are later in sub-section 7.6.1 to assess the quality of the study's findings and conclusions.

As mentioned, a study's research design should ensure a good fit between research questions, methods applied and intended contributions. Given that this study's research questions were driven by an interest in solving a practical problem faced by food producers and that the study aimed to contribute both to knowledge creation and solving an identified problem in the real

world, conducting the research under the design science paradigm was appropriate. Design science therefore guided the way the study was structured, planned and carried out.

The design science approach does not determine the actual methods used to perform the research. Although design science can, in principle, use all known methods for data collection and analysis, in practice the strategies tend to be case-based, collaborative and interventionist (van Aken and Romme, 2009). In the following sub-sections, the central aspects of the study's design are elaborated in terms of:

- Research stages
- Design proposition
- Unit of analysis
- Case selection
- Data collection
- Data analysis

2.2.1 Research stages

Inspired by Table 2-2, the different stages of the study are described below. Although the stages are described as a step-by-step process, there was overlap and iteration between the stages – reflecting the abductive approach.

Stage 1 – Framing of field problem
The process of identifying and framing the problem started in 2009 as part of the Smart flow of goods project (see 0). Although that study had a main focus on the use of radio frequency identification (RFID) technology in food supply chains, there was also an activity investigating how demand and other types of information could be shared and utilised in the planning and control of production and logistics processes. The findings of the study indicated that although the producers wished they had access to up-to-date demand information from downstream actors, they did not have a clear idea of how this information could be used in PPC to increase responsiveness or efficiency.

Based on the findings from the Smart flow of goods project, a literature study into the characteristics of food supply chains was initiated as part of the PhD study. This confirmed that the challenges related to the responsiveness - efficiency trade-off for food producers had been reported in previous studies. The literature study provided an understanding of the trade-off and identified a lack of strategic fit between external requirements stemming from product and market characteristics and the capabilities of the production system as a potential problem. The field problem was consequently framed as a lack of responsiveness in food production, and the study was focused on investigating how the PPC perspective could contribute in increasing responsiveness, without increasing costs or lowering efficiency.

In addition to framing and defining the problem, this stage resulted in the development of a framework for characterisation of supply chains, a structured description of food supply chain characteristics, and a methodology for linking characteristics with supply chain requirements. Stage 1 provided the answers to RQ1.

Stage 2 – Development of initial solution design
The literature study in stage 1 identified a number of articles which suggested that differentiating the way products are managed in the supply chain could be a potential solution to the problem. The empirical insights from related research projects (see 0) and the empirical stud-

ies reported in literature were then combined with theoretical insights from literature in an abductive process. Through successive modification of original frameworks a conceptual framework for differentiated PPC in food production was developed as an initial solution to the defined problem. The framework was also discussed with company representatives on several occasions and presented at two international academic conferences (see Romsdal et al., 2012c, Romsdal et al., 2012b, Romsdal et al., 2013) and an international workshop (Romsdal et al., 2012a). The framework represented a design exemplar which could be used as a template for designing solutions to the same class of problems in different contexts. Stage 2 provided input to RQ2.

Stage 3 – Solution refinement through field testing
In this stage, a literature study and a case study were conducted. Based on an analysis of the current PPC performance, a new PPC solution was designed for the case company. The proposed solution was then evaluated on its ability to solve the identified challenges and improve the performance of the PPC system. In addition to developing the case-specific solutions as further input to RQ2, stage 3 provided input to answer RQ3 through the substantiation of potential effects of the differentiation concept and framework, and RQ4 by providing empirical insights on the associated tactical and operational challenges.

Stage 4 – Development of substantive theory
Stages 1-3 provided inputs to stage 4, where the theoretical relevance of the findings from the field testing and the theoretical contributions from the study was discussed. In addition, the initial assumptions from stage 1 and the design proposition from stage 2 were refined into a more detailed proposition and its relevance beyond the context of the case and the food industry discussed.

Stage 5 – Development of formal theory
As mentioned in sub-section 2.1.2, reaching stage 5 in a PhD study is difficult due to practical constraints. Beta-testing by other researchers than the original developers of the proposition is critical to eliminate bias and optimise its ease of use. Therefore, to provide a basis for further testing, detailed descriptions of the case, its internal and external context, as well as the methods used for field testing and analysis, are provided in the thesis. These will also aid practitioners in the evaluation of whether or not the findings apply to their particular situation.

2.2.2 Initial design proposition

In design science, design propositions (also known as technological rules, design principles and design rules) are essential. A design proposition can be defined as a piece of general knowledge which links an intervention or artefact with a desired outcome or performance in a certain field of application (van Aken, 2004, Holmström and Romme, 2012). The proposition was a key outcome of stage 2 of the study and is often accompanied by a design exemplar – a general prescription which must be translated to the problem at hand. These prescriptions are often of a qualitative and heuristic nature, meaning that their effects cannot be proved conclusively but that sufficient evidence can be collected through repeated testing (van Aken, 2004).

The initial design proposition of this PhD study was that:

- If you want to increase the responsiveness of a food producer, differentiate the way production is planned and controlled

Broken down into the 'CIMO-logic' of Pawson and Tilly (1997), the components of the initial proposition are outlined in Table 2-4. Context (C) here refers to the factors of the external and internal environment that influence change, Interventions (I) refer to the interventions managers have at their disposal to initiate and implement change, Mechanisms (M) refer to the mechanisms that in a certain context are triggered by the interventions, and Outcome (O) refers to the results of the intervention.

Table 2-4: Components of the study's initial design proposition

Component	*Description*
Context (C)	The context is industrialised food production, with a main focus on handling demand variability resulting from downstream actors. The institutional setting is a single production facility which produces a given number of product variants on a limited number of production lines.
Intervention (I)	The proposed intervention is a redesign of the PPC system based on a differentiation of the principles used to plan and control production. An operational prerequisite is that the production process can be decoupled.
Mechanism (M)	Differentiated PPC can increase food producers' responsiveness by providing a better strategic fit between external requirements for responsiveness and production system capabilities.
Outcome (O)	The expected outcome of the intervention is higher responsiveness without increasing costs.

2.2.3 Unit of analysis

The unit of analysis sets the scope of the research and hence defines the boundary for data collection and analysis (Yin, 2009). In this study, the research questions were addressed by taking the perspective of a production facility producing a number of products with a defined set of production resources. Thus, the unit of analysis was the production facility.

The dependent variables were the performance characteristics of the case in terms of the efficiency of the PPC system, while the independent variables were the characteristics that might affect that performance. The independent variables included:

- External environment in terms of the kind of business environment within which the food producer operates (suppliers, customers, competitors, products, demand, etc.)
- Internal environment in terms of the resources, policies and procedures the company has designed to operate and serve its customers (production equipment, technology and processes, PPC system, CODP, inventory policies, etc.)

2.2.4 Case selection

Case studies rely on analytical as opposed to statistical inference. This means that the case sampling should be concerned with arriving at an appropriate matching between reality and theoretical constructs (Dubois and Gadde, 2002). In a multiple-case study, each case must be carefully selected so that it either (a) predicts similar results (literal replication) or (b) predicts contrasting results but for anticipatable reasons (theoretical replication). As mentioned, development for formal theory in design science rests on adding cases until theoretical saturation is reached. However, for practical reasons, the number of cases which can be carried out in a single research project is limited since there is a trade-off between the number of cases per-

formed and the depth it is possible to achieve within each case with the resources available (Dubois and Gadde, 2002).

The starting point for the case selection was an opportunity to collaborate with the TINE Group. The director of TINE Supply Chain Manager Egil Sørset found the topic highly interesting and relevant for TINE and subsequently granted access to facilities, informants and data required to carry out the research. A contract regulated the details of the use and publication of company data and information. In addition, there was a good opportunity to link the research to the master student and TINE employee Terje Bye who was following a continued education master program at NTNU. He therefore became the main contact person in TINE and the key informant for the study.

Initially, three facilities were selected for the study to enable literal replication. The cases represented the three types of production facilities in TINE's production network;

- Case 1: a packing facility cutting and packing cheese into finished products
- Case 2: a dairy processing and bottling consumer milk, juice and other liquid products
- Case 3: a cheese factory producing cheese and butter

The three cases were selected to enable cross-case analysis, observing differences in the case data and looking for patterns across cases (Eisenhardt, 1989). However, during the data collection and analysis of the packing facility (the first case in the study), discussions with TINE informants revealed that the PPC of dairies and cheese factories is driven more by a need to handle supply uncertainty rather than the demand uncertainty which is the scope of the study. For instance can each facility not influence the amount of incoming milk due to TINE's role as market regulator, and thus all milk collected from farms has to be received by a cheese making plant or a dairy. Further, TINE's dairies only make products with high perishability and short customer order lead times, which means that the potential for exploiting long lead times and low perishability to increase the flexibility of the production system is limited. For dairies, the biggest PPC challenge is related to sequencing on the production lines and converting the raw milk into processed products within 36 hours of arrival at the facility. An additional factor is that the latter two facility types have limited opportunities to decouple production processes, and thus the potential for an MTO approach is more limited (for more on the differentiation between facilities, see sub-section 6.2.2).

For these reasons, the dairy and cheese factory cases were dropped from the study and the study was redesigned as a single case study focusing on TINE Heimdal; one of three cheese packing facilities in TINE.

2.2.5 Data collection

Case study evidence may come from a range of different sources and by employing different data collection procedures. Regardless of the types of sources and data collection procedures, Yin proposes following three principles for dealing with the problems of strengthening construct validity and reliability (Yin, 2009):

1. Use multiple sources
2. Create a case study database
3. Maintain a chain of evidence

The three principles guided the design of the study's data collection and a number of different methods were used for data collection.

A particular feature of this study is the PhD candidate's close relationship with the company since 2006 (for an overview of related research projects, see 0). This enabled the researcher to gain in-depth knowledge of the company and its operations, as well as establish personal relationships with employees and in particular the key informant. The extensive involvement strengthened the researcher's credibility with informants, and provided ample opportunities to discuss challenges, and generate and test ideas on a continuous basis. It also enabled the use of multiple data sources, thus increasing the data richness. To illustrate, the interaction with the company and its employees included:

- Countless formal and informal meetings, conversations and workshops as part of the PhD and other research projects, including access to large amounts of quantitative data, project notes and reports.
- Supervision of four TINE employees writing semester papers as part of continued education courses at NTNU, involving physical meetings, telephone conversations, email communication, and reading of numerous drafts and final reports over a period of two years.
- Supervision of the key informant Terje Bye's master project over a period of 1,5 years, including countless formal and informal meetings and conversations, email communication, and reading of numerous drafts, notes and case data.
- Numerous facility tours as part of meetings and workshops in other projects.
- Use of TINE as a case in NTNU master courses, including a guest lecture by the key informant, two facility tours, case descriptions, and other company documentation.
- Organisation of a seminar on Lean for all employees in TINE's replenishment department.
- Acting as a liaison with TINE for numerous NTNU students using TINE as a part of their project and master theses.

The multiple data sources did however complicate the use of a case study database for documenting every piece and type of data obtained over the years. During stage 3 of the study, a case study database was however established in order to document and compile formal interviews, sound recordings of interviews, and the researcher's case study notes. In addition, the case study report, as well as all formal documents received from the company, both confidential and non-confidential, were stored in the database.

In order to take into account principle 3 of maintaining a chain of evidence, the analyses in stage 3 were as far as possible based on data documented in the case database and the logic of how conclusions were arrived at were articulated in the case study report and this thesis.

Different ways of collecting data were utilised to overcome the weaknesses of one method with the strength of another. Below, each type of evidence source used in the study is described in more detail.

Interviews[3]
Interviews were used for as a data collection method during stage 3 of the study. A number of formal semi-structured interviews were conducted as part of the case study to get insight into

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[3] For a list of formal interviews, see Appendix 1.

the more general planning and control processes of the company on a network and facility level. This information was compiled over a long period of time and the purpose of the formal interviews was to corroborate impressions, facts and data previously collected. The semi-structured interviews were conducted in collaboration with the key informant and the questions were derived from the case study protocol. In addition, the respondents were to some extent asked about their opinions about the current situation. Some of the interviews were recorded with the consent of the respondents in order to facilitate the documentation and allow the researcher to focus fully on what the interviewees were saying instead of on taking notes.

Documents
Documents were a rich source of evidence in the case study during stage 1-3. Documents included annual reports, company presentations, presentations from workshops and meetings, case reports from other research projects, minutes of meetings, layout drawings, facility maps, reports from company-internal projects, TINE-students' semester papers, newspaper and magazine clippings, case study descriptions from NTNU courses, and information system user documentation.

Informal discussions
Informal discussions with company representatives, and in particular the key informant, were one of the richest sources of data in all stages of the study – both before, during and after the case study was carried out. Through informal discussions problems were formulated, ideas generated, tested and rejected, solutions refined, and clues for further investigation continuously developed.

Observations
Observations mostly took place during stage 1 and 2 of the study in the form of casual data collection activities during site visits related both to the PhD project, other research projects and an NTNU master course. The purpose was to become familiar with the facilities, production processes, layout, operator tasks, etc. Observations were accompanied by photographs of production processes and equipment where appropriate.

Participant-observation
Participant-observation was a cornerstone in stage 1-3 since solutions were developed and refined in collaboration with company employees, in particular with the key informant. On some occasions, the researcher was invited to give presentations on various topics relevant for the study, both for employees of the company and its customers. Through participation in other research projects, the researcher also had a role in defining research topics and scoping projects in collaboration with the company – both during the proposal and project phases. This extensive access enabled the researcher to study the company more from the 'inside' rather than being an external observer. A tactic to overcome the danger of potential bias was to triangulate information from meetings where the researcher had participated with information from interviews and documents, as well as having the key informant and other participants review minutes and meeting notes. During the study, a number of formal meetings, interviews and workshops were conducted with employees at operative, tactical and strategic levels, involving resources both at the central and local level (for more details, see Appendix 1).

Extracts from company information systems
During stage 2 and 3 of the study, quantitative data from the company's information systems was used to map and analyse the product, market and production system characteristics of the

company and the case facility. In addition, quantitative data was needed to analyse the performance of the PPC system and develop new solutions. Examples of quantitative data include number of products, forecast accuracy, service levels, inventory levels, waste levels, capacity utilisation, and response times.

2.2.6 Data analysis

Data analysis consists of examining, categorising, tabulating, testing or otherwise recombining evidence in order to draw conclusions from empirical data (Yin, 2009). Thus, the process of data analysis involves making sense out of all the data collected (Creswell, 2003). Below, the study's strategies for data analysis are outlined, as well as the different techniques employed during data analysis.

2.2.6.1 Strategies for data analysis

Determining the analytic strategy for linking data and conclusions is not an easy task, particularly for case study evidence because the techniques are still not well defined. Since there are no formulas for the transformation of data into findings, the use of guidelines can be helpful (Patton, 2002). Yin (2009) suggests different strategies which can be used for analysis, in any combination, and below is a description of how three of these were implemented in the study.

Strategy 1 – relying on theoretical propositions
As mentioned, a key feature and strength of a design science research study is its grounding on theoretical propositions. In this study, some preliminary assumptions evolved through previous research projects and these guided the initiation of the PhD study itself, the definition of objectives and the research design. The assumptions were used to identify and frame the problem in stage 1 of the study, and in stage 2 these were refined into an initial design proposition for the study. Although the formulation of the proposition was an iterative process, it was used to guide the literature study in stage 1, the abductive process of developing the initial solution design in stage 2, and the orientation of the empirical study carried out in stage 2 and 3.

Strategy 2 – using both qualitative and quantitative data
The study was designed to use both types of data in different stages and for different purposes. In stage 1, qualitative empirical data about markets, products and production systems was collected from literature and used to generate a description of food supply chain characteristics. In stage 2, qualitative data in the form of empirical insights from previous studies and literature, as well as theoretical insights from literature, were used as inputs to the abductively developed initial solution design. In the case study in stage 2 and 3, qualitative and quantitative data was collected on products, markets and production systems, planning and control processes, company principles and policies, current strategic, tactical and operational challenges, etc. The case analysis also required collection of quantitative data from company information systems in order to analyse the performance of the PPC system and to operationalise the concept into new solutions.

Strategy 3 – examining rival explanations
As described above, theoretical assumptions and proposition guided the design of both the theoretical and empirical parts of the study. Thus, there is a risk that some bias was introduced into the research design. In order to alleviate this risk, some potential rival explanations for the findings from the case study were collaboratively discussed in stage 3 and 4 of the study (see chapter 7).

2.2.6.2 Techniques for data analysis

Analytic techniques are used to deal with the problems of ensuring internal and external validity of a study's results. Below, the analytical techniques and procedures used to address each of the four research questions are described.

RQ1: literature study

The first research question focused on food supply chain characteristics. In stage 1, a literature study was used to develop a theoretical framework for characterising supply chains. Relevant academic articles dealing with supply chain configuration, classification and characterisation were identified through keyword and backward literature searches[4], focusing on highly cited and renowned articles. The collected articles were read and their categories and subcategories coded and categorised to form the characterisation framework. The framework was then populated with empirical data from literature, resulting in a structured description of food supply chain characteristics. The impact of the characteristics on food producers were then logically derived by linking characteristics and supply chain requirements, where the impact of each individual characteristic was identified, as well as the overall impact of each category of characteristics.

RQ2; literature study and case study

In stage 2, a concept, a framework and an initial design proposition for how PPC can be differentiated were developed. These were developed through abduction, where original frameworks for configuration, differentiation, segmentation and PPC were successively modified based on empirical insights from previous research projects and literature, as well as theoretical insights from literature. The solutions served as design exemplars for the case study.

For the purposes of the detailed analysis and development of new solutions in the case study, a sample of 15 products were strategically selected, ensuring that the products captured the most important characteristics of the facility's products in terms of product, market and production system characteristics.

The case study consisted of the following analyses:

1. Supply chain characteristics; in order to confirm the representativeness of the case, characteristics were mapped using the characteristics framework developed in stage 1. The findings were subsequently qualitatively compared to the findings from the analysis of general food supply chain characteristics from stage 1.
2. Planning and control – consisting of;
   o PPC performance; qualitative and quantitative analyses in order to both confirm the presence and provide increased understanding of the field problem identified in stage 1. Analyses were based on the key performance indicators identified in section 3.3.
   o Differentiation; the current degree of differentiation in the way production is planned and controlled in the case company was identified and qualitatively evaluated, and weaknesses and improvement opportunities identified.

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[4] Backward literature search involves searching the literature discussions of other papers and articles to find references to other relevant studies

Further, the concept, framework and design proposition were tested thought the design of new solutions for the case company. This also required some quantitative and qualitative analyses in order to populate the conceptual framework.

RQ3; literature study and case study
The potential benefits of differentiated PPC were investigated as part of the case study in stage 3. Based on the analyses and testing of the concept and framework in stage 2, the potential benefits of the new solution were substantiated through a combination of logic reasoning 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.

RQ4; literature study and case study
In the second part of stage 3, the tactical and operational challenges of differentiated PPC were investigated. The challenges were derived from a combination of a literature study and insights from the case study. Academic literature on food production, frameworks for PPC, and differentiated and hybrid planning and control was collected, coded and categorised. The challenges were structured and discussed through a synthesis of literature, case findings, logical reasoning, and reflections with company representative.

2.3 Summary; linking research questions and methods

Table 2-5 summarises the key aspects of the study's research design by showing the link between research questions, stages in the study, methods used, types of data collected and data analysis techniques.

Table 2-5: Summary of research design

Research question	Stage and purpose	Method	Data types	Analysis
RQ1: Supply chain characteristics	Stage 1; identification, framing and definition of problem	Literature study	Theoretical frameworks collected from literature. Empirical data collected from literature.	Framework for categorisation: categories and subcategories from theoretical frameworks coded and categorised. Characteristics: framework populated with empirical data. Impact on PPC; logically derived through linking of characteristics and requirements.
RQ2: Differentiation of PPC	Stage 2; design of initial solution	Literature study	Empirical insights from previous studies, literature and case study. Theoretical insights from literature.	Concept framework and design proposition abductively developed through successive modification of original frameworks.
		Case study	Qualitative and quantitative case data.	Qualitative and quantitative analyses of characteristics and planning and control. Development of new solutions based on qualitative and quantitative analyses to populate conceptual framework.
RQ3: Potential benefits of differentiated PPC	Stage 3; solution refinement through field testing	Literature study, case study	Theoretical insights from literature. Empirical insights from case study.	Substantiation of potential benefits through logic reasoning and discussions and reflections with case representatives.
RQ4: Tactical and operational challenges of differentiated PPC	Stage 3; solution refinement through field testing	Theoretical discussion	Theoretical insights from literature. Empirical insights from case analysis	Challenges derived and structured through synthesis of literature and case findings, logic reasoning, and discussions and reflections with company representatives.

3 THEORETICAL BACKGROUND

The aim of this chapter is to provide an overview of the study's theoretical foundation. The chapter identifies research gaps and opportunities, demonstrates the theoretical relevance of the study and presents previous research to which the study aims to contribute.

Figure 3-1 shows the structure of the chapter.

| Operations management and strategy | PPC | Evaluating PPC performance | PPC design |

- *Definitions*
- *From operations to supply chains*
- *Supply chain characterstics*
- *Supply chain requirements*

- *Definition*
- *Key terms and concepts*
- *Challenges*

- *Performance objectives*

- *Strategic fit*
- *Key concepts*
- *Design options*
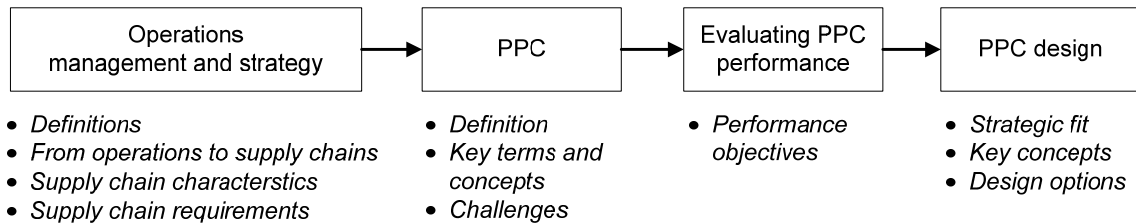
Figure 3-1: Structure of chapter 3

Section 3.1 introduces and defines OM, operations strategy and the supply chain paradigm. The section also includes the development of a framework for characterisation of supply chain which is later used to structure and analyse empirical data in chapters 4 and 6.

Section 3.2 defines PPC and key terms, frameworks and methods on which the study is based, and outlines some key challenges of traditional planning and control.

Section 3.3 presents some common objectives and measures for evaluating PPC performance. These are later used to analyse the empirical data in sub-section 6.2.1.

Section 3.4 focuses on design of PPC, presenting key concepts and design options for differentiated planning and control. These provide inspiration and input for the conceptual framework which is later developed in chapter 5.

Finally, section 3.5 summarises the chapter with regards to the identified research gaps and potential solutions.

3.1 Operations management (OM) and strategy

The topics of the study described in this thesis fall within the OM domain. As the term suggests, OM deals with the management of operations – and the way an organisation transforms resources by converting inputs into outputs (Slack et al., 2007). There is a plethora of definitions of OM but in brief it can be understood as the activity of managing the resources involved in the conversion and delivery of an organisation's goods and services through the creation, design and coordination of business operations (Slack et al., 2007, Holmström and Romme, 2012).

The exact nature of an organisation's OM function depends on the way the organisation has chosen to define the boundaries of the function, but in general there are some classes of activities that apply to all types of organisations (based on Slack et al., 2007, Karlsson, 2009):

- Understanding and developing operations' strategic objectives in order for operations to support the organisation's long-term goals. A set of general principles to guide decision making constitutes the operations strategy.
- Design involves organising the organisation's resources in a way that will give the production system desired characteristics through its processes, products and services, supply network, layout and flow, process technology, and job and work organisation.
- Planning and controlling operations by deciding what the operational resources should be doing and then ensuring that they are really doing it. Relevant areas to plan and control include capacity, materials, inventory, transformation processes, projects and quality.
- Improving the performance of operations is a continuing responsibility of all operations managers.

The key activities of OM are summarised in Figure 3-2 where we see how the OM function consists of strategy development, design, planning and control, and improvement – which again provides input to strategy development.

Figure 3-2: Operations management (Slack et al., 2007, p. 25)

As mentioned, the operations strategy defines the objectives for the OM function and sets the general principles which should guide decision making – thus forming the starting point for design, planning and control, and improvement of operations; see Figure 3-3.

Figure 3-3: The role of operations strategy in OM (adapted from Slack et al., 2007, p. 25)

In the following sub-sections, the link between OM and strategy is further explored, as well as the transition from a mainly internal OM focus to the supply chain paradigm. The resulting needs to understand both the characteristics of the supply chain environment within which operations are executed and the requirements exerted upon the OM function are outlined.

3.1.1 Linking OM and strategy

Strategy is defined at multiple levels in an organisation; corporate, business and functional (see Figure 3-4). At the corporate level, long-term strategic decisions are made about the scope of the company and the industries and markets in which it will participate. At the business level, the specific market segments are determined, as well as how the company will position itself within these and obtain competitive advantage. At the functional level, activities to support or create competitive advantage are structured so that they offer the resources, capabilities and competencies from which competitive advantage may be derived and on which the business strategies may be developed.
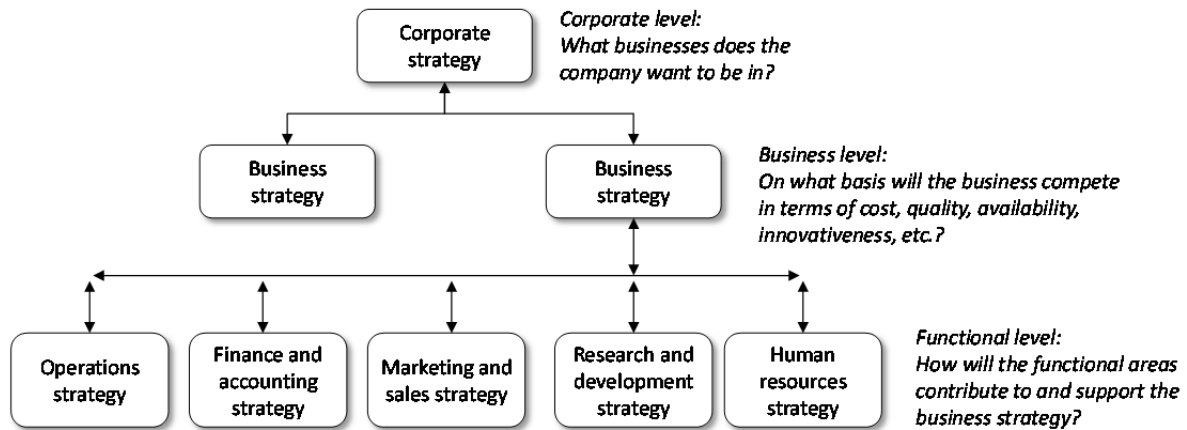
Figure 3-4: Levels of strategic planning (Beckman and Rosenfield, 2008, p. 16)

The operations function is key in the achievement of a company's strategic objectives and has three roles within the organisation (Slack et al., 2007):

- Implementer of the organisation's strategies
- Supporter of the organisation's overall strategy
- Driver of strategy

Hill (2000) describes the difference between OM and operations strategy in terms of efficiency and effectiveness, where production executives traditionally have been pressured to manage reactively and to focus on operational efficiency, i.e. doing things right, whereas the strategic role of operations in terms of doing the right thing (effectiveness) has largely been ignored. The importance of such a bottom-up approach is reflected in the four perspectives on operations strategy of Slack et al. (2007) (see Figure 3-5) where the experience from day-to-day operations is used as input to the strategy process. In addition, there must be a top-down translation of higher-level strategies into the functional strategy. The operations strategy should translate market requirements into operations decisions, while also exploiting the capabilities of operations resources in the chosen markets.

Figure 3-5: Four perspectives on operations strategy (based on Slack et al., 2007, p. 64)

Another way of viewing OM in a strategic perspective is in terms of the three levels of management. In Figure 3-4, the top level of operations strategy is where the overall strategy of the OM function is determined, whereas design and improvement activities represent the tactical level; and finally the planning and control activities are concerned with achieving efficiency at the operational level.

Building on Skinner's seminal 1969 article on the link (or rather missing link) between production and corporate strategy, many authors have developed comprehensive lists of strategic decisions for the operations function (see Alfnes, 2005 for some examples). Figure 3-6 shows a framework for linking the corporate and business strategies with the functional operations strategy. The gap between columns 2 and 3 illustrate that the corporate and marketing strategy processes are typically performed separately from the process of determining how the operations strategy will support the products in the marketplace as well as fulfil its strategic role in the company.

Corporate objectives	Marketing strategy	Market winners and qualifiers	Operations strategy	
			Structural choices	Infrastructural choices
• Growth • Survival • Profit • Return on investment • Other financial measures	• Product and market segments • Range • Mix • Volumes • Standardisation vs. customisation • Level of innovation • Leader vs. follower alternatives	• Price • Quality conformance • Delivery; speed, reliability • Demand increases • Colour range • Product range • Design • Brand image • Technical support • After-sales support	• Choice of alternative processes • Trade-offs in process choice • Role of inventory • Make or buy • Capacity; size, timing, location	• Function support • Production planning and control • Quality assurance and control • Production systems engineering • Clerical procedures • Compensation agreements • Work structuring • Organisational structure

Figure 3-6: Operations strategy issues in corporate decisions (adapted from Hill, 2000, p. 32)

A commonality between the frameworks for operations strategy issues is the separation of structural and infrastructural decision as suggested by Hayes and Wheelwright (1984). Structural decisions are primarily concerned with design activities related to long term commitments and heavy investments, while infrastructural decisions are more related to how the or-

ganisation is operated and organised in terms of work force, PPC, and improvements in a shorter time perspective (Alfnes, 2005).

A key infrastructural decision area is the company's system for the planning and control of operations - and this should be closely connected to the on-going needs of the market and the production processes (Berry and Hill, 1992). This is particularly important because of the inter-dependencies that exist between different strategy levels and functional areas. In Figure 3-6, we see how the corporate strategy sets performance expectations, typically related to objectives such as growth, profit, return on investment and other financial measures.

3.1.2 From operations to supply chains

Towards the end of the 1990s, the focus of operations strategy and management was extended to a supply chain view, replacing the strategic issue of matching products with internal processes with the issue of matching products with the broader supply chain (see e.g. Fisher, 1997, Christopher, 1998, Naylor et al., 1999). The supply chain thus became an integral part of business strategy and the means by which customer demand is fulfilled (Chopra and Meindl, 2010).

A supply chain can be understood as a linkage of operations between organisations that provide goods and services to end customers. A dominating paradigm of modern business management is the notion that competition no longer takes place between individual companies but rather between entire supply chains (Lambert et al., 1998, Kaplinsky, 2000). Such supply chains consist of several organisations acting together, with each organisation dependent on the performance of the others in the chain. Recognising that each node in a supply chain cannot be managed in isolation supply chain management (SCM) grew as a discipline, referring to the management of the multiple relationships and dependencies across the chain. The Supply-chain Council (2008) defines supply chains and SCM in the following way:

> *'The supply-chain… encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer. Supply-chain management includes managing supply and demand, sourcing raw materials and parts, production and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer. Due to its wide scope, supply-chain management must address complex interdependencies; in effect creating an 'extended enterprise' that reaches far beyond the factory door'.*

An essential objective of SCM is to meet the requirements of end customers by supplying appropriate products and services when they are needed, at a competitive cost. A number of methods or models for matching supply with demand exist, and in a supply chain perspective an essential challenge is to ensure a good fit between the requirements stemming from the company's external environment and the capabilities of the company's operations. The first step in achieving this fit is to understand the characteristics of the supply chain to which the organisation belongs – and this is further explored in the next sub-section.

3.1.3 Supply chain characteristics

A supply chain can be described and understood in terms of its configuration - i.e. the arrangements of parts of elements in a particular form, figure, or combination[5]. The configurational approach to SCM aims to characterise a specific configuration as a set of variables or commonly occurring clusters of attributes in harmony (Neher, 2005) – where each configuration is dominated by a 'theme' expressing the characteristics of the configuration (Miller, 1986). Configurations can in this way provide an understanding of organisations or supply chains in terms of spans of control, types of decentralisation, planning systems, and organisation structure (Miller, 1986). As such, configurations are generic types or archetypes composed of variables or attributes that provide a fit between mutually supportive elements like context, strategic orientation and effectiveness (Miller, 1986, Neher, 2005).

A starting point for the configurational approach to SCM is that supply chains are described and analysed in terms of their characteristics. A number of supply chain configuration frameworks have been developed focusing on describing product and market characteristics, e.g. Fisher (1997) in his framework for matching supply chains with products, the work of Mason-Jones et al. (2000) and Bruce and Daly (2004) on the differentiation between lean and agile supply chains, Naylor et al. (1999) on the leagile concept, and Aitken et al. (2005) on order winning and order qualifying criteria (for more on these frameworks, see sub-section 3.4.3). In the food sector, however, certain aspects of the production system's processes, infrastructure, and related logistics processes have been found to have important implications for supply chain design (van Donk, 2000, van Wezel et al., 2006, van Donk et al., 2008, Verdouw and Wolfert, 2010). Also other more generics studies have emphasise the importance of taking the production system and its characteristics into consideration, e.g. Jonsson and Mattsson (2003) on selection of MPC methods, Pagh and Cooper (1998) when looking at supply chain decision determinants, Olhager (2003) on positioning of the order penetration point (OPP), and Sharda and Akiya (2011) on selecting inventory management policies. Thus, a more comprehensive framework for characterisation of food supply chains should describe key aspects related to:

1. Product characteristics
2. Market characteristics
3. Production system characteristics

Based on a review of key references from previous research on configuration, classification and characterisation of supply chains and supply networks, Table 3-1 defines the key aspects which are thought to have an impact on OM and operations strategy in a supply chain setting.

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[5] http://oxforddictionaries.com/definition/english/configuration

Table 3-1: Framework for characterisation of supply chains

Aspect	*Description*	*Authors dealing with aspect*
Product characteristics		
Product perishability and shelf life	Refers to products with a finite or fixed lifetime (Ferguson and Ketzenberg, 2006), where the item has a short shelf life and deteriorates in value and/or quality over time (van Donselaar et al., 2006, Karaesmen et al., 2011).	Ferguson and Ketzenberg (2006), van Donselaar et al. (2006), van Donk et al. (2008)
Product complexity	Number and interrelatedness of product components (Lamming et al., 2000)	Lamming et al. (2000), Olhager (2003), Srai and Gregory (2008)
Product variety	Level of variety demanded by the market place (Aitken et al., 2005), ranging from 10-20 up to millions of variants per category (Fisher, 1997)	Fisher (1997), Pagh and Cooper (1998), Mason-Jones et al. (2000), Christopher and Towill (2002), Olhager (2003), Ferguson and Ketzenberg (2006), Christopher et al. (2009), Verdouw et al. (2010)
Product life cycle (PLC), innovation and new product development	Length of a product's life cycle from launch to termination (Aitken et al., 2005), frequency with which new products are introduced in the market.	Fisher (1997), Pagh and Cooper (1998), Lamming et al. (2000), Mason-Jones et al. (2000), Christopher and Towill (2002), Walters (2008), Christopher et al. (2009), Kittipanya-ngam (2010)
Product volume and volume variability	Volume related to level of demand in market (Aitken et al., 2005). Variability related to unpredictability of volume (Aitken et al., 2005)	Fisher (1997), Olhager (2003), Aitken et al. (2005), van Donselaar et al. (2006), Christopher et al. (2009)
Market characteristics		
Delivery lead time and lead time variability	Time window between customer order and delivery to customer (Aitken et al., 2005). Variability related to unpredictability of lead time (Aitken et al., 2005).	van Donk (2000), van der Vorst et al. (2001), Olhager (2003), Cecere et al. (2004), Holweg et al. (2005), Alfnes et al. (2006), Christopher et al. (2006), Strandhagen et al. (2006), van Donselaar et al. (2006), Christopher et al. (2009), Kittipanya-ngam (2010), Verdouw et al. (2010)
Demand uncertainty	Predictability and stability of demand (Lee, 2002)	Fisher (1997), Pagh and Cooper (1998), van Donk (2000), Lee (2002), Olhager (2003), Cecere et al. (2004), Taylor and Fearne (2006), van Donselaar et al. (2006), Christopher et al. (2009)
Inventory management and stock-	The management of raw materials, work in progress, and finished goods within the supply chain (Chopra and	Fisher (1997), Mason-Jones et al. (2000), Christopher and Towill (2002), Slack et al. (2007)

out rates in retail stores	Meindl, 2010). Stock-out rates refer to the frequency of which a given item is unavailable and customer demand cannot be met from available inventory (Chopra and Meindl, 2010).	
Production system characteristics		
Production or make-to-order lead time	Lead time required for MTO products (Fisher, 1997), also referred to as replenishment lead time (Christopher et al., 2006).	Fisher (1997), Olhager (2003), Christopher et al. (2009)
Plant, processes and technology	The machines, equipment, devices and physical processes involved in manufacturing good (Slack et al., 2007), as well as the plant within which the product is produced.	van der Vorst et al. (2001), Jonsson and Mattsson (2003), Vollmann et al. (2005), Alfnes et al. (2006), Strandhagen et al. (2006), van Donk et al. (2008), Soman et al. (2004)
Supply uncertainty	Predictability and stability of supply (Lee, 2002).	Lee (2002), Cecere et al. (2004), van Donk et al. (2008), Christopher et al. (2009)

This framework can be used for describing supply chains in order to provide a better understanding of the environment within which operations are conducted. It will therefore be used as a tool for structuring and analysing empirical data in section 4.2 and sub-section 6.1.1. Although the framework has been developed with the aim of describing the characteristics of food supply chains, it may also be applicable to other sectors.

3.1.4 Supply chain requirements; responsiveness and efficiency

A number of frameworks exist for helping companies understand product characteristics and customer requirements and link these with market interaction strategies (sub-section 3.4.3). However, before the appropriate strategies can be determined, companies need to understand the strategic response required from the supply chain to meet the requirements (Godsell et al., 2011). Key constructs in this respect are responsiveness and efficiency – and this sub-section provides an overview of these concepts and defines how the terms are used in this thesis.

It has been claimed that responsiveness may be one of the most important capabilities needed for organisations to achieve competitive advantage (Matson and McFarlane, 1999, Holweg, 2005, Storey et al., 2005, Reichhart and Holweg, 2007, Bernardes and Hanna, 2009). Despite this, there is inconsistency and ambiguity regarding the use of the responsiveness construct in literature, and a discussion and definition of the phenomenon is therefore appropriate.

Reichhart and Holweg (2007) propose that responsiveness be understood as the speed with which a supply chain can adjust its outputs to an external stimulus like a customer order. The speed can be related both to replenishment and the total time it takes for a product to go through a pipeline; labelled replenishment speed and supply chain speed respectively (Kittipanya-ngam et al., 2010). Such a responsiveness strategy is often found in markets where lead time or product availability are the order winning criteria (Christopher and Towill, 2002, Aitken et al., 2005).

Given that companies are rarely completely vertically integrated, it is important to recognise that the supply chain strategy not only defines what processes the company should do well

within the firm, but also what role each company plays in the supply chain (Chopra and Meindl, 2010). Chopra and Meindl (2010) therefore define supply chain responsiveness as a company's and a supply chain's ability to:

- Respond to wide ranges of quantities demanded
- Meet short lead times
- Handle a large variety of products
- Build highly innovative products
- Meet a high service level
- Handle supply uncertainty

The responsiveness term is often used interchangeably with agility and flexibility in OM literature. In an attempt to provide a clear definition of responsiveness, Bernardes and Hanna (2009) performed a literature review and content analysis, and proposed a conceptualisation of the three terms. Responsiveness was defined as the business level performance capability to quickly respond to external stimuli – where a key aspect is timely behaviour change in the presence of external stimuli like signals from customers or the market.

Further, flexibility was defined as the operating characteristic which enables the organisation to respond to these changes within the existing parameters of the production system – i.e. an operating characteristic and system property. Agility was defined as the ability to rapidly reconfigure the business with a new set of parameters and is therefore outside the scope of the thesis since the focus is on enabling the production system to meet external requirements within the existing system. The conceptualisation of the three terms is summarised in Table 3-2.

Table 3-2: Conceptualisation of flexibility, agility and responsiveness (Bernardes and Hanna, 2009)

Organisational perspective	*Flexibility*	*Agility*	*Responsiveness*
Scope	Operating characteristic Inherent system property	Business level organising paradigm Approach to organising the system	Business level performance capability System behaviour or outcome
Definition	Ability of a system to change status within an existing configuration (of pre-established parameters)	Ability of the system to rapidly reconfigure (with a new parameter set)	Propensity for purposeful and timely behaviour change in the presence of modulating stimuli

The most obvious reason for developing flexibility is to enable an organisation to respond to variations in demand for its products and services (Beckman and Rosenfield, 2008), thus absorbing disturbances and variability stemming from both the internal and external environment. This does however not imply reacting immediately to every signal from the customer but rather using knowledge about the market to design service offerings that meet customers' requirements. Flexibility can therefore be seen as an ability that does not directly provide superior value to customers, but rather as an enabler to providing this value – in other words as a means rather than an end in itself (Bernardes and Hanna, 2009).

In addition to the definitions above, Bernardes and Hanna (2009) propose a conceptual definition of customer responsiveness which links responsiveness and flexibility. While responsiveness is about reacting to any modulating stimuli, customer responsiveness describes the propensity to react on market knowledge to rapidly address modifications in customers' expectations. This is in line with Reichhart and Holweg (2007) who maintain that responsiveness is a concept that is solely customer focused. Thus, flexibility can be said to express the production system's ability to reduce variability, while responsiveness expresses how well the system performs with regards to reacting to changes in the market place. Flexibility thus provides stability to the production process and reduces the impact of external variability.

Figure 3-7 summarises the definitions of the responsiveness concept used in this study.

Concept	Definition	Scope
Responsiveness	*A propensity for purposeful and timely behaviour change in the presence of modulating stimuli*	Performance capability and system behaviour or outcome
Customer responsiveness	*A propensity to react on market knowledge to rapidly address modifications in customers' expectations*	
Flexibility	*Enabling ability to change status within existing configuration (of pre-established parameters)*	Operating characteristic and system property

Figure 3-7: Definition of key concepts used in the study (based on Bernardes and Hanna, 2009, p. 46)

Reichhart and Holweg (2007) pointed out that a shortcoming of the majority of existing frameworks for responsiveness is that they do not enable companies to match their operations and supply chains to their environments. In their article, they reconciled concepts from the responsiveness literature in a conceptual framework for supply chain responsiveness, separating internal factors which determine responsiveness from the external factors which require responsiveness. In their framework, flexibility was divided into internal and external flexibility. The proposed external flexibility be understood as the flexibility the customer is interested in and which is linked to achieving competitive advantage, see Table 3-3.

Table 3-3: External requirements for responsiveness (based on a literature synthesis by Reichhart and Holweg, 2007)

Factor	Impact
Demand uncertainty	Identified in literature as the main reason for being responsive and the most severe type of uncertainty. Related to volume and mix changes.
Demand variability	Linked to uncertainty but conceptually different since reliable demand with large swings still require responsiveness.
Product variety	Amplifies demand uncertainty as the same aggregated demand is split over more SKUs, leading to an increase in the aggregated errors associated with each forecast. Increases the cost of using finished goods inventories to fill orders.
Lead time compression	Directly increases need for responsiveness as less time is available to respond to customer orders.

Further, internal flexibility refers to the internal means by which external flexibility can be achieved – and these can be divided into operational factors and factors related to supply chain integration. The supply chain factors include information integration, coordination and resource sharing, and organisational integration – and since these are more related to organisational issues and not to the planning and control of production, they are outside the scope of this thesis. The operational factors are however highly relevant for PPC and their link to responsiveness are outlined in Table 3-4.

Table 3-4: Internal determinants of responsiveness (based on a literature synthesis by Reichhart and Holweg, 2007)

Factor	Impact
Demand anticipation	The most important enabler of responsiveness. Particularly advantageous to identify the hard-to-forecast products.
Production flexibility	Traditional focus in literature. Can directly reduce production lead times and changeover times.
Inventory	Buffer stock often used against uncertainty. Linked to CODP.
Product architecture/postponement	Determines to a large extent where CODP can be placed and thus how responsiveness can be achieved.

Reichhart and Holweg (2007) further differentiate between demonstrated and potential responsiveness, where demonstrated responsiveness expresses what the company does and how it balances actual performance with required performance, while potential responsiveness refers to what the company could do in terms of adjusting and re-configuring its supply chain to deliver the required level of responsiveness cost-efficiently.

The resulting conceptual framework of Reichhart and Holweg (2007) is illustrated in Figure 3-8.
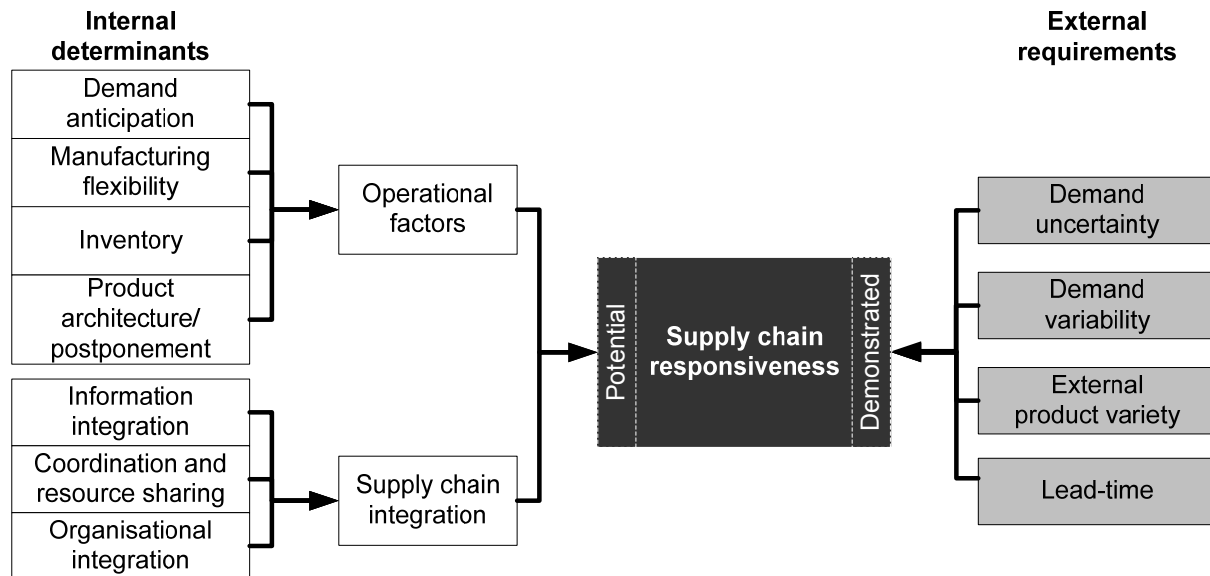
Figure 3-8: Conceptual framework for supply chain responsiveness (adapted from Reichhart and Holweg, 2007, p. 1161)

For the purposes of this thesis, the framework provides an illustration of how responsiveness is affected both by the external requirements exerted on operations and by the internal determinants related to the operational factors of the organisation.

Slack (2005) provides another perspective for understanding flexibility in terms of different types of external flexibility:

- Product flexibility; referring to the company's ability to introduce new or modify existing products
- Mix flexibility; referring to the company's ability to change the range of products made within a given time period
- Volume flexibility; referring to the company's ability to change the level of aggregated output
- Delivery flexibility; referring to the company's ability to change planned or assumed delivery dates

Beckman and Rosenfield (2008) further link the need for flexibility in operations to different variability types;

1. Demand variability
2. Supply variability
3. Product or service variability
4. Process variability
5. Workforce and equipment variability

Much of this variability originates outside the firm and the particular mix of variability experienced varies with industries and competitive environments (Beckman and Rosenfield, 2008) thus falling into what Reichhart and Holweg (2007) labelled external requirements. Since the focus of this thesis is on customer responsiveness, the type of variability addressed is demand variability and the how an organisation's PPC system can be designed to provide the flexibility required to meet the need for volume flexibility.

Beckman and Rosenfield (2008) suggest three methods for responding to variability (Figure 3-9):

1. Reducing variability itself
2. Buffering
3. Developing flexible operations

Reducing variability requires involvement of all functions in the organisation to work with suppliers and customers to reduce variability in both supply and demand, similar to the supply chain integration factors in Figure 3-8. Buffering against variability involves carrying inventory – where raw materials inventory protects operations against variability in supply, work-in-process inventory buffers against variability in workforce and equipment, and finished goods inventory buffers from variability in demand. The third method is to develop flexible operations. Again, this requires participation across the organisation and even across the supply chain. Within the operations function itself, a number of methods for increasing flexibility exist, including developing flexible process types and technology, shortening setup and cycle times, postponement, maintaining excess capacity, cross-training the workforce, and having a flat organisational structure.
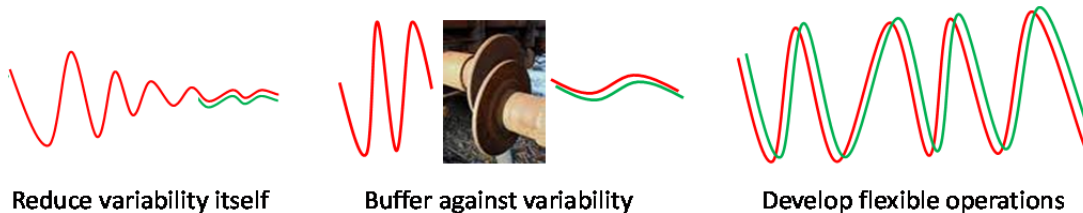
Figure 3-9: Three methods of responding to variability (based on Beckman and Rosenfield, 2008, Semini, 2012)

The option of reducing variability is outside the scope of this thesis since the focus is on investigating how PPC can enable the flexibility the operations function requires to deal with the variability stemming from the market[6]. Thus, the two main strategies considered in this study are buffering, e.g. strategically locating inventories in the material flow to buffer against demand variability, and developing flexible operations through postponement, i.e. differentiation of the principles used to plan and control production operations.

Responsiveness comes at a cost – related to supply chain efficiency. Efficiency in this context can be understood as the inverse of the cost of making and delivering a product to the customer. Increases in cost lower efficiency, which means that for every strategic choice to increase responsiveness, there are additional costs that lower efficiency (Chopra and Meindl, 2010). Efficiency is further often associated with the ability to produce and deliver products in a cost-effective manner utilising economies of scale to reduce cost per unit (Slack et al., 2007). Efficiency strategies are common in markets where price is the order winning criteria (Aitken et al., 2005, Christopher and Towill, 2002).

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[6] Two large contributors to demand variability and the bullwhip effect in food supply chains include market activities and limited sharing of demand information which reduce the flexibility and efficiency of the production operations function. Eliminating or reducing the effect of these for the sake of operations does not appear to be a realistic option within the current competitive environment between suppliers and wholesalers/retailers and the power of the marketing function.

Cost-efficiency has, together with greater speed, been hailed as the holy grail of SCM over the past decades. However, as Lee (2004) pointed out, high-speed, low-cost supply chains tend to lack the ability to respond to unexpected changes in demand or supply – and studies have shown that being efficient and cost-effective is not necessarily enough to maintain competitive advantage. In fact, studies found that the performance of such firms often deteriorated, product availability fell, and stock outs and mark-downs increased (Lee, 2004). Thus, the production system as a whole should not only focus on costs and efficiency but also aim for responsiveness in reacting to changing market conditions, fluctuating demand forecasts and actual demand (Bertrand et al., 1990).

3.2 Production planning and control (PPC)

In sub-section 3.1.1, it was seen that a key infrastructural decision area in operations strategy is PPC – through which the flow of information and materials for production is coordinated. In the OM perspective, the planning and controlling of operations provides feedback on performance which should be used in improvement processes (see Figure 3-10). This section defines PPC and outlines some of the key issues, approaches, methods and challenges related to PPC in different production environments.
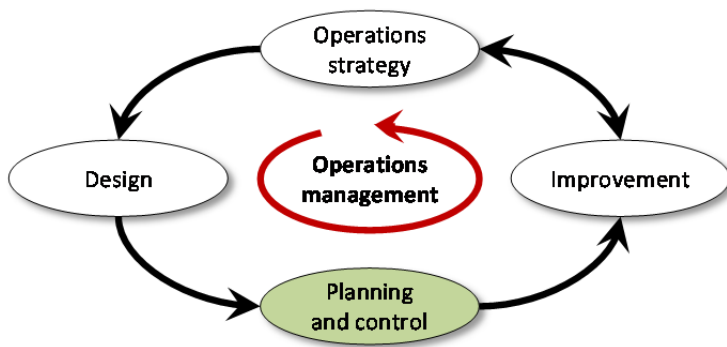
Figure 3-10: The role of planning and control in OM (adapted from Slack et al., 2007, p. 25)

3.2.1 Definition

All operations require both plans and control. Planning is a formalisation of what is intended to happen in the future, while control is the monitoring of operations activities and coping with any deviations from the plan for instance through re-planning (Slack et al., 2007).

PPC can be defined as the tasks required to:

> *'... manage efficiently the flow of material, the utilization of people and equipment, and to respond to customer requirements by utilizing the capacity of our suppliers, that of our internal facilities, and (in some cases) that of our customers to meet customer demand.' (Vollmann et al., 2005, p. 4)*

Planning and control is thus concerned with operating and coordinating the company's resources on a day-to-day basis. The purpose is to ensure availability of the 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 planning and control task ensures that company operations are run effectively and efficiently, and provides the systems, procedures and decisions which are required to bring together the different aspects of supply and demand in terms

of time, quantity and quality (Slack et al., 2007). The typical functions of a PPC system include (Stevenson et al., 2005):

- Material requirements planning
- Demand management
- Capacity planning
- Scheduling and sequencing of jobs

In sum, the PPC system should provide an overview of the key planning and control activities and decisions within a production system and thus define the structures and information upon which managers make effective decisions.

Planning and control involves making decisions regarding future activities and events, and decision situations differ both in their time perspective and the level of precision and detail required for the information on which decisions are based (Jonsson, 2008). Another way of looking at planning is as preparation for decision-making, where the planning phase identifies alternatives of future activities and selects among these (Fleischmann et al., 2008). In this perspective, Fleischmann et al. (2008) subdivide planning into a number of phases or activities:

1. Recognition and analysis of a decision problem
2. Definition of objectives
3. Forecasting of future developments
4. Identification and evaluation of feasible activities or solutions
5. Selection of good solutions

There is no clear distinction between planning and control. In general, planning can be seen as a formalisation of what is expected to happen in the future (Slack et al., 2007). Thus, a plan is built on a number of assumptions which may be subject to changes during the implementation of the plan, while control is concerned with dealing with the consequences of these changes. In this way, the control task executes the adjustments required to achieve the objectives of the plan, despite the changes in original assumptions (Slack et al., 2007). This means that the significance of planning and control changes with the time horizon; see Figure 3-11.
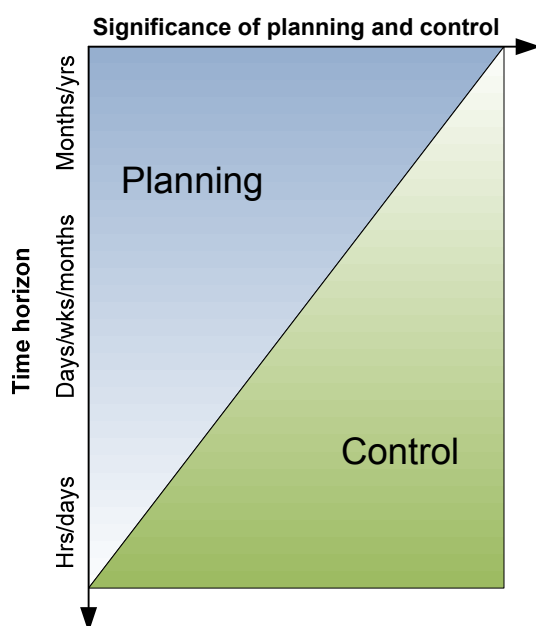
Figure 3-11: Significance of planning and control over different time horizons (Slack et al., 2007, p. 291)

Longer term PPC tasks are more focused on the planned activities, the resources needed to execute the plan and the objectives to be achieved. On the medium horizon, the relationship between planning and control is more balanced, where activities are focused on the more detailed planning. In the shortest term, resources are already planned for and changes are harder to make, thus PPC activities are more focused on controlling activities on the operational level.

Planning and control tasks can also be structured according to planning functions at different levels of the planning hierarchy – each with their own planning objects, horizons, period lengths and frequency of re-planning, see Table 3-5.

Table 3-5: Planning functions in a production company (adapted from Jonsson, 2008)

Planning level	*Planning object*	*Horizon*	*Period length*	*Content*
Strategic network planning	Supply chain links and nodes	Several years	Quarter/ year	• What to make where • Product flow • Facility capacities
Sales and operations planning	Product group	1-2 years	Quarter/ month	• Overall plans for sales, supply and production • Generates overall production requirements based on forecasted demand
Master production scheduling (MPS)	Product within product group	6-12 months	Month/ week	• Generates sales and production plans based on orders and/or forecasts and stock on hand • Specifies quantities per product group
Order planning	Item in product	1-6 months	Week/ day	• Material plans specifying planned production orders and purchasing orders, broken down into items in products
Production activity control	Operation for order on item	1-4 weeks	Day/ hour	• Based on materials planning methods to generate orders • Planning of operations between planned start date and order delivery date • Planning release of new production orders and sequence of orders and operations

3.2.2 Historical development of PPC

Modern production enterprises reconcile the supply of resources with demand and customer orders using computer-based PPC systems (Koh and Saad, 2003). The development of such systems started back in the 1970s when there was a major push from informal production planning methods to computer-based systems (Vollmann et al., 2005). The planning problems were structured, knowledge was made explicit, and informal paper-based systems were replaced with explicit computer-based systems. A major enabler of this development was the bill of materials (BOM) which permitted material requirements planning (MRP) with calculation of net requirements and a new structure for scheduling work.

The next major development in the PPC field was the development of ICT systems to support operating processes. During the 1980s, solutions were developed which helped companies implement MRP systems, develop new processes/practices and match systems to operations. MRP was further developed into the more advanced Manufacturing Resource Planning (MRPII), which focused on integrating the various PPC activities (for more on MRP and MRPII, see sub-section 3.2.4).

The third important historical PPC development came in the 1990s, when operating processes were developed to support standardised systems (Vollmann et al., 2005). Standard Enterprise Resource Planning (ERP) systems were developed to integrate all significant resource planning systems in an organisation. In an operations context the ERP system thus integrates planning and control with the other business functions (Slack et al., 2007).

Since the 1990s, the approach to PPC has shifted from a primary focus on integration of internal operations to a focus on integration of operations and the flow of materials and information across business units and companies in the supply chain (Vollmann et al., 2005).

Figure 3-12 summarises the historical development of PPC from the 1970s to the 1990s.

1970s From chaos to order	1980s Systems to support operating processes	1990s Operating processes to support systems
• Implement formal systems • From paper to computer • Problem structuring • Execution accuracy • Bill of materials processing	• Tailored solutions • Integrated operations • New processes/practices • Match systems to operations • MRP/MRPII	• Standard solutions • Company integration • Implement packages • Match operations to systems • ERP

Figure 3-12: Historical view of computer-based PPC systems (Vollmann et al., 2005, p. 556)

The shift towards more of a supply chain focus is also reflected in the frameworks for PPC. Supply chain planning and control originates from the PPC tradition, which originally focused on the production and operations activities within a single company. Again, the planning and control task can be divided according to the planning horizon but now also incorporating the main supply chain processes of procurement, production, distribution and sales, resulting in a planning matrix depicted in Figure 3-13.
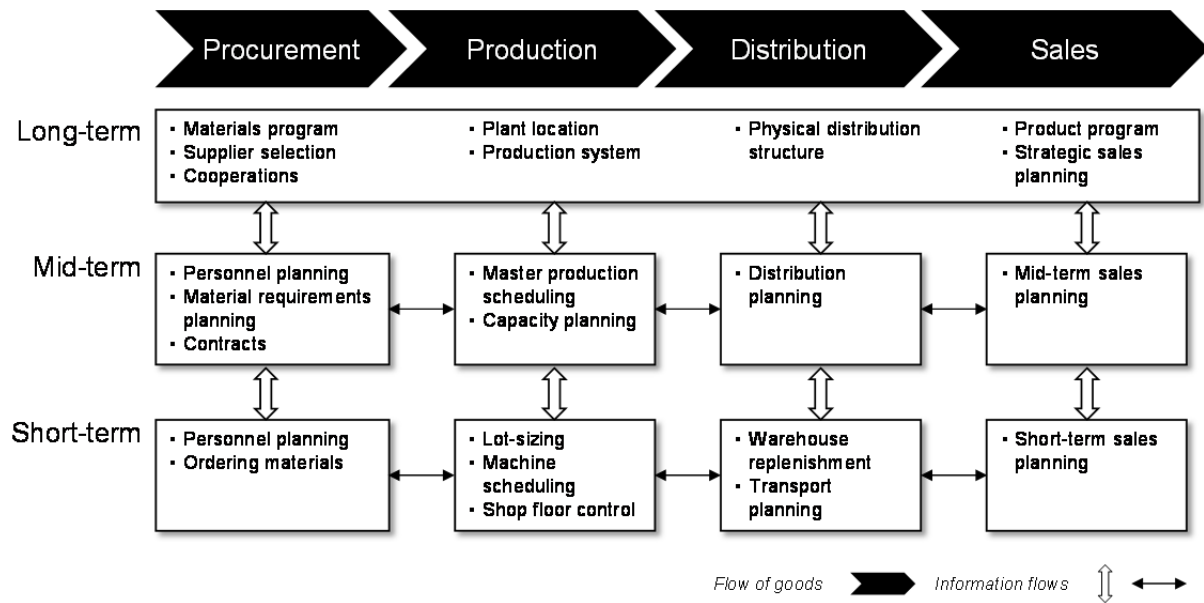
Figure 3-13: The supply chain planning matrix (Fleischmann et al., 2008, p. 87)

From Figure 3-13, it can be seen that long term planning decisions include design of production systems, determination of product programs and strategic sales planning. This planning level includes localisation of the CODP, in other words determination of production approaches like MTS and MTO.

In the medium-term, mid-term sales planning is performed, where sales are forecasted for instance for specific regions, with products grouped according to production characteristics (e.g. preferred resources and changeover times). This level also includes consideration of effects of mid-term marketing events and promotions, and determination of safety stocks based on forecasting quality. At this level, MPS and capacity planning is also performed to show how the available production capacity of one or more facilities will be used in a cost-efficient manner taking seasonal demand fluctuations and necessary amounts of overtime on a product group level into consideration. Further, material requirements are planned, production and order quantities determined and frames set for order quantities and safety stock levels which ensure the desired production service level.

Before principles and methods for mid- and short-term planning and control of production are explored further, the strategic determination of PPC approaches use to guide operations is described in the next sub-section.

3.2.3 PPC approaches; make to stock (MTS) and make to order (MTO)

Commonly, production systems in high volume industries like the food sector are classified as either MTS or MTO (Soman et al., 2004). In this sub-section, the two PPC approaches are therefore introduced and contrasted.

Firms that serve their customers from finished goods inventory are known as MTS firms (Vollmann et al., 2005). An essential issue in an MTS environment is handling the trade-off between the cost of inventory and the level of service to the customer (Vollmann et al., 2005). High levels of inventory may for instance be desired by the sales and marketing function in

order to ensure high customer service levels – but simultaneously this increases holding costs and may have negative impacts on product quality and the risk of obsolescence.

The MTS approach to PPC supports products of standard design produced in high unit volumes in narrow product variety for which short customer delivery lead times are critical. Finished goods inventory is used to provide short, reliable lead delivery lead times to customers, and can allow buffering against demand variations and enable stabilisation of production levels, thereby enabling higher cost efficiency in production (Vollmann et al., 2005).

The main focus in an MTS environment is on anticipating demand (forecasting) and planning to meet this demand (Soman, 2005). Since orders are filled from inventory, the competitive priority is higher fill rates and the main operations issues are inventory planning, lot size determination and demand forecasting.

MTO products can be understood as products for which no inventory is held in stock (Soman et al., 2004). MTO thus represent a postponement strategy which allows production schedules to be based on actual orders, thus reducing the distortion caused by multiple layers of forecasting, or 'double guessing', and providing a degree of demand visibility which is otherwise hard to achieve (Holweg, 2005). Although the MTO approach is often associated with products that are custom-built to individual customer specifications (Vollmann et al., 2005), the term is also used to describe a production environment where production activities are not initiated until a customer order is received. A typical feature is that MTO companies generally carry no finished goods inventory (Vollmann et al., 2005).

The MTO approach to PPC typically supports products of a wide variety and custom design, often produced in low unit volumes. Typical candidates for an MTO approach are products with highly irregular demand, client-specific products, tendered products, trial products, or products with very short shelf life (Soman et al., 2004).

The planning focus in an MTO environment is on order execution and the competitive priority is shorter delivery lead time. The main operations issues are capacity planning, order acceptance/rejection, and attaining high due date adherence (Soman, 2005).

Assemble-to-order (ATO) is another PPC approach which is used when the variety and cost of end products prevent investment in finished goods inventory and production lead time exceeds that desired by customers (Vollmann et al., 2005). The main difference from the MTO environment is that components or intermediate products are held in inventory and that the final assembly of these are initiated once a customer order is received.

The key characteristics of the MTS and MTO approaches are contrasted in Table 3-6 and further explored in sub-section 3.4.2.

Table 3-6: Differences between MTS and MTO (based on Soman et al., 2004)

Characteristic	*MTS*	*MTO*
Products	Low variety, producer specified, less expensive products	High variety, customer specific, more expensive products
Planning focus	Forecasting and planning to meet demand	Order execution
Performance measures	Product focussed (line item fill rate, inventory levels)	Order focussed (response time, order delay)
Competitive priority	Higher fill rates	Shorter delivery lead time
Operations issues	Inventory planning, lot size determination, demand forecasting	Capacity planning, order acceptance/rejection, due adherence

3.2.4 Control principles for PPC

A key task of PPC is to manage the flow of materials from suppliers into the company, flow within the company related to production processes, and flow of finished products from the company to its customers (Jonsson, 2008). These flows are initiated by various types of orders specifying materials needs in terms of items, quantities and timing. The purpose of material planning is to ensure that materials are available for production and that products are available for delivery to customers, while maintaining the lowest possible material and product levels in inventory. Material planning is thus the starting point for planning production activities, delivery schedules and purchasing activities.

A number of different planning principles and methods exist for determining material needs and balancing supplies with demand. Broadly, material planning methods are characterised as either pull or push based, where production orders in pull-based methods are consumption-initiated, while orders in push-based methods are requirement-initiated.

Consumption-initiated planning methods include the re-order point and run-out time planning methods. In the re-order point method, an order is initiated when stocks fall below a predetermined re-order point – where the quantity corresponds to the expected or forecasted demand during the lead time for replenishment plus a safety stock quantity to protect against unpredictable demand variations.

The run-out or cover-time planning method is similar to the re-order point method but expresses requirements as time instead of quantities, i.e. how long present stock is expected to last (Jonsson, 2008). For both methods, replenishment is either based on continuous review, where fixed order sizes are placed whenever inventory reaches a defined level, or on periodic review, where varying order sizes are placed at fixed time intervals. Both methods are fairly easy to use and do not require computerised software. However, both require even demand and are not very suitable for products with complicated BOMs.

The most common requirement-initiated planning method is MRP. Instead of basing production on consumption that has taken place, MRP is based on the points in time when net requirements arise, i.e. when future calculated stock availability becomes negative (Jonsson, 2008). MRP is thus based on backward scheduling, which means that jobs are started as late as possible (Slack et al., 2007). The method is more suitable than the consumption-initiated

methods for planning of products with complex product structures, dependent demand, long lead times and erratic demand (Jonsson, 2008).

A central element in MRP is the BOM. The BOM is a list of component parts required to make the complete product, including information regarding their level in the product or component structure and the quantities required of each component (Slack et al., 2007). MRP further requires a computerised system and assumes the production of standard products with well-known BOMs and product routings, and possibility to forecast the future demand as a basis for the MPS (Stevenson et al., 2005).

One of the most commonly used frameworks for structuring the PPC task in an MRP production environment is Vollmann et al.'s (2005) MPC framework. This generic framework is built on the MRP/MRPII logic and consists of what has been called 'front end', 'engine' and 'back end'; see Figure 3-14.

Activities in the front end set the overall direction for the company's PPC, including long-term decisions regarding capacity for meeting future market demands and acquiring the resources required to meet demand, resulting in the MPS. In the engine, the detailed material and capacity planning is performed. This involves matching supply and demand in the intermediate term in terms of volume and product mix, and specifying the exact material and production capacity needed to meet customer needs. Finally, the back end is the execution system where the detailed scheduling and monitoring of resources is performed with regards to time, people, material, equipment and material. This level also provides support for re-planning and problem solving.
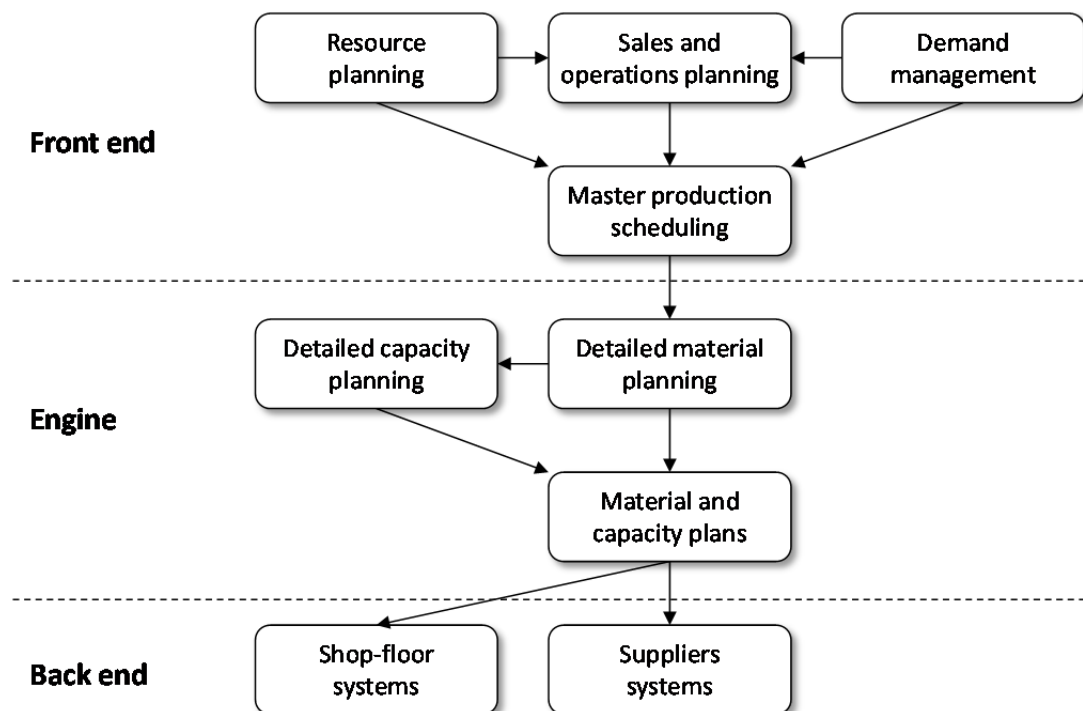
Figure 3-14: The traditional MPC framework (Vollmann et al., 2005, p. 8)

The MPS is MRP's most important planning and control input. The MPS summarises the volume and timing of the end products based on a summary of known and forecasted demand,

the BOM and inventory records (Slack et al., 2007). The key inputs to the MPS are illustrated in Figure 3-15.
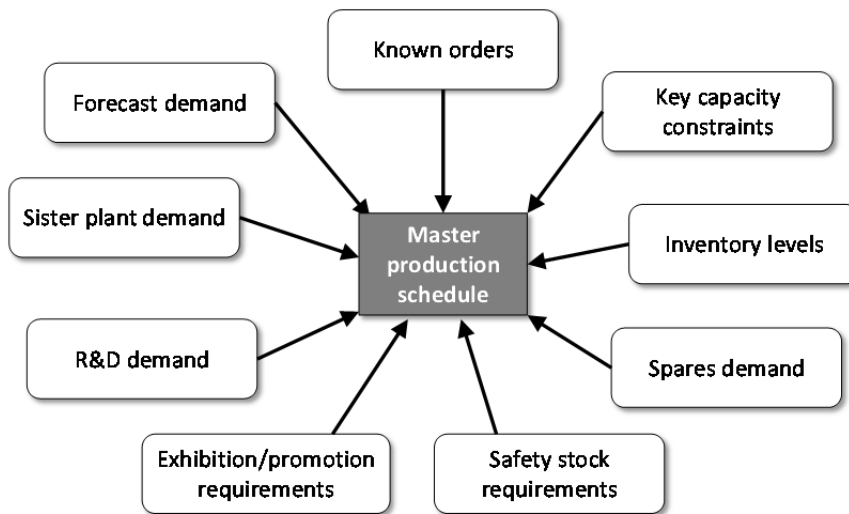
Figure 3-15: Inputs to master production schedule (Slack et al., 2007, p. 441)

Based on an MRP netting process, the MPS is 'exploded' to determine how many sub-assemblies and parts are required and when they are required. The key outputs are purchase orders, material plans and work orders, see Figure 3-16.
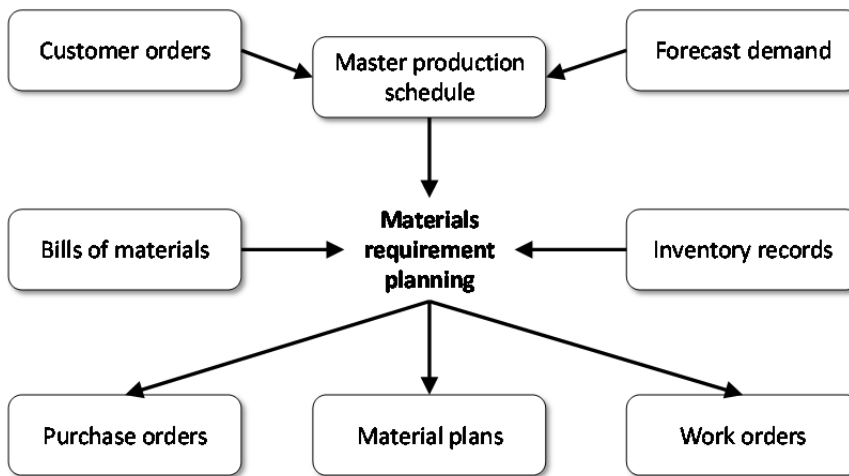
Figure 3-16: Materials requirement planning (MRP) schematic (Slack et al., 2007, p. 439)

As mentioned, MRP is closely linked to the MRPII concept which is an integrated system containing a database which is accessed and used by the whole company according to individual functional requirements (Slack et al., 2007). A key functionality of MRPII is the closed-loop MRP, which checks that material plans (production plan, master production plan and materials plan) are feasible when compared to capacity plans (resource requirements plan, rough-cut capacity plan, and capacity requirements plan) (Slack et al., 2007).

MRP is highly suitable for an MTS approach to PPC. However, the PPC requirements in a MTO environment differ from the MTS environment, which means that the 'one size fits all' PPC tools from the MRP tradition are less applicable (Stevenson et al., 2005). In many cases, several of the underlying assumptions of MRP are not fulfilled in a MTO environment, for

instance the existence of standard products with well-known BOM and product routings, and the possibility to forecast future demand as a basis for the MPS. In addition, MRP does not specifically address the customer enquiry stage, nor adequately consider capacity decisions at the point of job entry and job release (Stevenson et al., 2005) – issues which are critical in an MTO environment (Soman et al., 2004).

Over the past decades, the increased demand for specialised products and increasing product proliferation has led to a large increase in the application of MTO approaches (Stevenson et al., 2005) – and with it the need to find PPC methodologies which are suitable for the MTO environment. Stevenson et al. (2005) suggest that a PPC methodology for MTO must meet the following criteria:

1. Inclusion of the customer enquiry stage for delivery date determination and capacity planning
2. Inclusion of the job entry and job release stages, focusing on due date adherence
3. Ability to cope with non-repeat production, i.e. highly customised products
4. Ability to provide planning and control when shop floor routings are variable, i.e. general flow and job shops
5. Applicability to small and medium sized enterprises

Based on these criteria, Stevenson et al. conducted an assessment of the most common 'classic' and 'new breed' methods in the MTO context: Theory of Constraints (TOC), Workload Control (WLC), Kanban, Constant Work-In-Process (CONWIP), and Paired cell overlapping loops of cards with authorisation (POLCA). The applicability of the methods was investigated for different shop configurations (general flow shop and general job shop) and levels of customisation (medium volume and medium variety vs. low volume and high variety). Although the authors note that all the approaches could be effective under the right shop conditions, they conclude that WLC is the most appropriate approach for the MTO environment.

WLC is a PPC method that was specifically designed for the MTO industry. WLC uses a pre-shop pool of orders to reduce shop floor congestion and consists of a series of short queues which stabilises the performance of the shop floor and allows it to work independent of variations in the incoming order streams. Although there is no generic WLC concept, most solutions only release jobs onto the shop floor if released workload levels will not exceed pre-set maximum limits. Simultaneously, WLC ensures jobs do not stay in the pool too long, thereby reducing work in progress (WIP) and lead times (Stevenson et al., 2005). Thus, WLC ensures high due date adherence and considers capacity simultaneously.

Stevenson et al. further note that although they concluded the WLC approach is the best approach for MTO, in reality an organisation often needs a combination of methods in order to take advantage of the strengths of each. Although much literature may present PPC approaches as mutually exclusive, in practice most system consist of both push and pull elements and many of the emerging approaches are hybrid methods based on established concepts. Thus, if a system does not cover all of the required PPC levels, it can rely on the simultaneous adoption of complementary approaches for effective use in an MTO environment.

3.2.5 Challenges of traditional planning and control[7]

Planning and control, both internally in a company as well as in a supply chain setting, involves a number of particularly challenging aspects. Most of the planning and control systems are based on traditions of MTS and MRP/MRP II, where forecasts and expectations of future demand are the main inputs (Zijm, 2000). Economy of scale arguments are frequently used when dimensioning and controlling processes like production, warehousing, distribution and transport. The main planning and control logic of ERP systems is also based on aggregation, optimal batch sizes, order quantities, transport frequencies, and sequencing, etc. (Alfnes and Strandhagen, 2000). As a consequence of these traditions major elements of uncertainty are introduced into the plans and a number of operations are decoupled from actual end customer demand, reducing supply chain actors' ability to effectively balance supply and demand.

For supply chains involving perishable products such as food items, the limited shelf life and rapid deterioration of product quality has a huge impact on the need for speed in both processing and distribution in order to maximise remaining shelf life. The perishability aspect adds to the complexity of food supply chains because managers must design a supply chain that enables the companies, through their planning and control systems, to operationally meet the requirements for both cost efficiency and market responsiveness. Although these trade-offs are well known for many practitioners, the operational implications stemming from the particular supply chain requirements in the food sector have not been dealt with sufficiently in research (van Donk et al., 2008). Thus, there is still a need to identify both the particular constraints which influence the design and efficient operations of planning and control in food supply chains, and to assess the efficiency and effectiveness of current planning and control systems in balancing supply and demand.

Planning and control processes must support cross-company processes, as well as the coherence between internal decision levels and functions (Berry et al., 1995, Dreyer et al., 2010). Additionally, planning and control systems include a set of design elements that governs the execution of operational activities within the constraints set by the chain configuration and strategic objectives (van der Vorst and Beulens, 2002). Thus, designing supply chain operations and the associated planning and control system to fit with the higher-level strategies and other external and internal constraints is a complex task. A lack of alignment between this design and the characteristics of a specific supply chain environment can result in ineffective balancing of supply and demand, with considerable amplification of demand signals backwards in the chain (the bullwhip effect), high stock levels, inefficient capacity utilisation, and long lead and response times (Dreyer et al., 2009).

The existing frameworks for planning and control emphasise the importance of ensuring coherence among functions on different system levels (Berry et al., 1995), as well as across supply chain functions and planning intervals (Meyr et al., 2008). As a consequence, such frameworks tend to be fairly comprehensive and complex, making it difficult for companies to both generate an illustrative and easy-to-understand picture of their planning and control system, and to ensure alignment and consistency across planning levels and supply chain stages.

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[7] Parts of this sub-section is based on STRANDHAGEN, J. O., DREYER, H. C. & ROMSDAL, A. 2011. Control model for intelligent and demand-driven supply chains. *In:* FLYNN, B. B., MORITA, M. & MACHUCA, J. (eds.) *Managing Global Supply Chain Relationships: Operations, Strategies and Practices.* IGI Global.

From the above, we see that designing appropriate PPC systems is a challenging task, particularly when there is high demand uncertainty and operations are decoupled from end-customer demand. In addition, the need for speed related to the perishability aspect of food products complicates this design task even further. Thus, ensuring alignment between decision levels and functions in a holistic perspective is critical. However, before we look at how PPC systems can be designed, evaluating the performance of the existing PPC system is helpful to identify improvement potentials and this is explored in the next section.

3.3 Evaluating PPC system performance

As mentioned, improving the performance of operations is a continuing responsibility of all operations managers. In order to identify improvement needs or opportunities that require adjustment of the strategy, continuous monitoring of performance is required as input to the improvement process; see Figure 3-17.
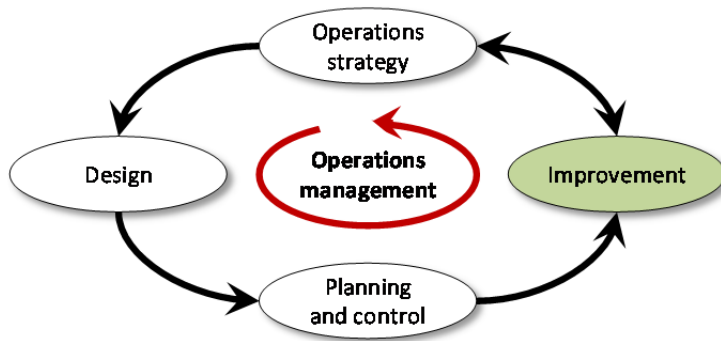
Figure 3-17: The role of improvement in OM (adapted from Slack et al., 2007, p. 25)

A key objective in PPC system design is to ensure that there is a good match between the design of the PPC system, the production processes and the performance objectives (Berry and Hill, 1992). The PPC system design defines how the elements of the system support the company's strategic objectives and the objectives set for the operations function. In order to track the effectiveness and efficiency of a PPC system and identify improvement needs or potentials, a company should therefore continuously evaluate its performance on these aspects.

Skinner (1969) argued that a company cannot perform well on every performance measure and that managers must prioritise and make trade-offs in the design and the operation of the production system. Although there has been some debate on the existence of trade-offs since Skinner's article, aligning operations with market requirements inevitably involves making some compromises between competitive objectives. Although such trade-offs cannot be eliminated, there is a clear requirement for operations managers to understand the performance of their operations – which will again drive the cycle of strategy, design, planning and control, and improvement.

Typical performance objectives for the operations function include (Slack et al., 2007):

1. Quality; doing things right
2. Speed; doing things fast
3. Dependability; doing things on time
4. Flexibility; changing what you do

5. Cost; doing things cheaply

Each of these objectives impacts on customers' satisfaction with the company's products and services and therefore reflects the degree to which the capabilities of the operations and the production system are effective in meeting market requirements. In addition, the objectives impact on the efficiency of operations. There are also interdependencies between the objectives – where good performance on one aspect can have been achieved at the expense of performance in others. Thus, in order to evaluate how well a company's PPC system is performing and whether or not there is a need to change the strategy or redesign the system, it is essential to take a holistic perspective looking at a range of aspects. These should both reflect the performance within the parameters of the current PPC system design and describe relevant characteristics of the system and the environment within which operations are performed.

Below, each of the six performance objectives is described in more detail based on Slack et al. (2007) and linked to relevant indicators which can be used to describe the effectiveness and efficiency of a company's operations in a production and inventory perspective within the scope of this thesis. In addition, some qualitative aspects and characteristics which impact on PPC system performance are outlined.

Quality
Quality is about doing things right and can be understood as consistent performance to customers' expectations. Quality can reduce costs and increase dependability – thus providing both an external impact which influences customer satisfaction and an internal impact leading to stable and efficient processes.

A relevant aspect to consider in terms of the quality of a company's PPC system is service level which expresses the company's delivery performance to customers and shows the degree to which current operations enable the company to satisfy demand.

Speed
Speed is about doing things fast and is related to the time it takes from a customer places an order till he or she receives the product or service. The importance of speed depends on customer requirements and for some customers, speed increases value and thus enhances operations' offering to the customer. From an internal perspective, speedy decision making and speedy movement of materials and information can reduce inventories and reduce risks.

A number of PPC characteristics which are the result of how a PPC system is designed will have an impact on the speed aspect. Such characteristics include:

- Frequency of delivery; how often orders are delivered to customers and thus the time that elapses between deliveries.
- Delivery response time; the time it takes from a customer places an order until he or she received a complete delivery from the supplier. This characteristic is also related to the frequency of delivery and expresses who quickly the producer can respond to demand signals from finished goods inventory.
- Production response time; how often each product/SKU is produced. This characteristic expresses how quickly the production system can respond to demand signals based on how often products are produced.
- Physical throughput time; the time from raw materials are withdrawn from inventory until the product has been produced and is available for delivery to the customer. This

characteristic expresses the responsiveness of the production system based on how long it physically takes to produce each product.

Another relevant performance measure related to speed is inventory turnover rate, which expresses the number of times inventory is turned over in a period and thus the speed with which inventory is moved through the warehouse. What is defined as high and low turnover rates vary between industries, but in general very low rates can indicate overstocking and obsolescence, while very high rates may indicate inadequate inventory levels.

Dependability
Dependability is about doing things on time like delivering a customer's order when it is needed or promised. Dependability over time is a value for which customers may be willing to pay a premium. Internal dependability in the delivery of materials and information can save time, reduce costs and provide stability.

Dependability can be expressed as delivery reliability in terms of the frequency of late or imperfect deliveries from the producer. Another measure is the variation in service levels, where large variations indicate that customers cannot rely on always receiving their orders in full and on time.

In terms of internal dependability, re-planning frequency shows how stable plans are. Frequent re-planning consumes PPC resources and reduces the stability of the production system. Re-planning can be a result of both PPC system design, where re-planning can be planned as part of the process, or as a result of changes in demand or supply of production inputs.

Flexibility[8]
Flexibility is about the ability to change an operation in some way, e.g. what, how and when. Flexibility enables the organisation to better customise its offering to customers and respond to different types of variability. Internal flexibility speeds up response, saves time and maintains dependability.

A key characteristic which impacts on the need for flexibility is demand variability or uncertainty. Commonly used measures of demand uncertainty include forecast accuracy and the coefficient of variation (COV), in addition to more qualitative factors which may impact on demand uncertainty.

Buffering is a relevant characteristic describing how inventories are used to provide flexibility and protect operations against demand variability – expressed through the CODP. Further, the level of safety stock used to mitigate the risk of stock-outs can give an indication of the uncertainties in supply and demand. The number of days in inventory expresses how long goods stay in inventory before they are sold.

In terms of how flexible operations are, capacity utilisation expresses the degree to which there is excess capacity in the system to provide volume and delivery flexibility. Low levels of capacity utilisation indicate that there is some flexibility in the system, while high levels limit this flexibility.

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[8] For more on flexibility and variability, see sub-section 3.1.4.

Another alternative for providing additional capacity is use of overtime. Extensive use of overtime can indicate high flexibility in the workforce but simultaneously that the system may not be designed with sufficient capacity.

Cost

Cost is about doing things cheaply and is a universally attractive objective which influences the cost of the company's products and services. This allows the company to increase profitability on existing volume levels or reduce their prices to customers in order to gain higher volumes. The interdependencies between performance objectives also mean that a good way to improve cost performance can be to improve performance on the other objectives.

When evaluating the costs related to the PPC task, the number of full-time equivalent resources dedicated to PPC gives an indication of how much PPC is costing the company and how efficient the PPC process is.

Other relevant aspects

In addition to the more quantifiable indicators described above, there are a number of qualitative aspects that should be considered when evaluating the performance of a PPC system. These should aim to uncover weaknesses in how the PPC system is designed. In some situations, these aspects can be the result of decisions make in a dedicated design process, while others are the result of company traditions and developments that have happened over time. Relevant aspects to consider include how integrated information flows are in the company, how the PPC process is organised in terms of centralised and local decision making, how PPC performance is tracked and monitored, the type and quality of decision support tools available, and how different company functions are involved and collaborate in the PPC process.

3.4 PPC system design

As mentioned, the strategic part of OM puts operations in the context of business and develops the strategy for operations. Based on this, financial, physical and human resources are organised, and the design phase thus involves organising these resources in ways which will give the production system the desired characteristics (Karlsson, 2009).

The previous sections presented concepts and tools which can be used to understand a company's supply chain characteristics and the requirements these impose on operations, and to assess the need for improvement which feeds into the strategy formulation process. Once this has been done, the structural and infrastructural elements of operations can be redesigned in order to provide the production system with the capabilities required to both implement and support the organisation's overall strategy.

While the physical design of the company's operations provides the fixed resources required to satisfy customers' demand, PPC is concerned with operating those resources. This means that the PPC system should be designed in a way that ensures consistency between the different levels of PPC. PPC system design is thus a crucial strategic decision which involves determining how the elements of the system will support the company's strategic objectives (Stevenson et al., 2005), achieve the desired performance (Berry and Hill, 1992), and ensure consistency between the different levels in the planning hierarchy. The role of the design phase in OM is illustrated in Figure 3-18
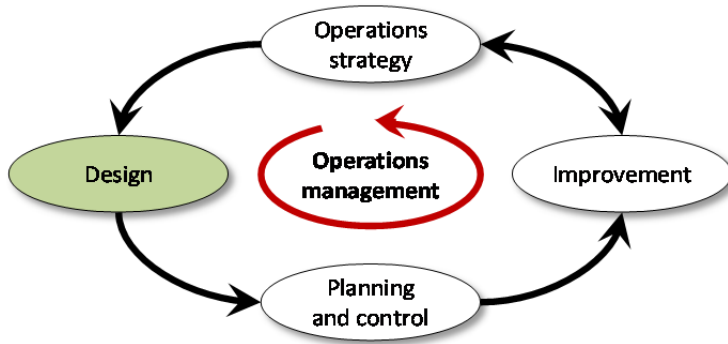
Figure 3-18: The role of design in OM (adapted from Slack et al., 2007, p. 25)

In the following sub-sections, a number of issues and alternatives relevant in the design of PPC are presented. Firstly, the concept of strategic fit is outlined. Then, the CODP concept is introduced, before a number of studies into differentiation strategies to achieve strategic fit are presented.

3.4.1 Strategic fit

Until the early 1980s, production, particularly in the US, was dominated by a paradigm whose roots went back well over a hundred years. The assembly line technique made famous by Henry Ford and Taylor's principles of 'Scientific Management' (Taylor, 1911, 2006) made mass production possible. For decades, production emphasised on mass markets, standard designs, and mass production using interchangeable parts, processes based on long runs, equipment specialised for each stage of the production process, and inventories to buffer between stages. Underlying this paradigm and managers improvement efforts was the assumption that there was a 'one best way' to manage production. Eventually this notion was disputed, most effectively by Skinner (1969) who argued that:

- Different companies have different strengths and weaknesses and can choose to compete in different ways
- Different production systems have different operating characteristics
- The task for a company's production function is to construct a production system that, through a series of interrelated and internally consistent choices, reflects the priorities and trade-offs implicit in its specific competitive situation and strategy

In the 1970s, the idea of the focused factory emerged, suggesting that a factory could be broken into separate 'focused' facilities which were each focused on accomplishing the particular production task demanded by a specific strategy (Skinner, 1974). Building on this, Hayes and Wheelwright (1984) showed how a 'product-process matrix' could be used to help a company adjust its strategy and production system to reflect the changes in its competitive environment. The matrix focuses on the relations between product characteristics and technological processes adopted by firms. The product structure dimension varies from customised, tailor-make products produced in small quantities to standard commodities. The process structure dimension refers to the material complexity within the factory, from highly automated continuous flow of homogeneous materials like sugar and oil, to a job shop environment where the material flow differs per product like for airplanes and specialised industrial machinery. The flow-type processes can further be divided in batch and continuous processing, where batch processing can be defined as a production technique in which parts are accumulated and pro-

cessed together in a lot, while continuous flow production refers to lot-less production in which products flow continuously rather than being divided (Slack et al., 2007).

Figure 3-19 illustrates the product-process matrix of Hayes and Wheelwright (1984), with some product examples.

Product structure and life cycle stage
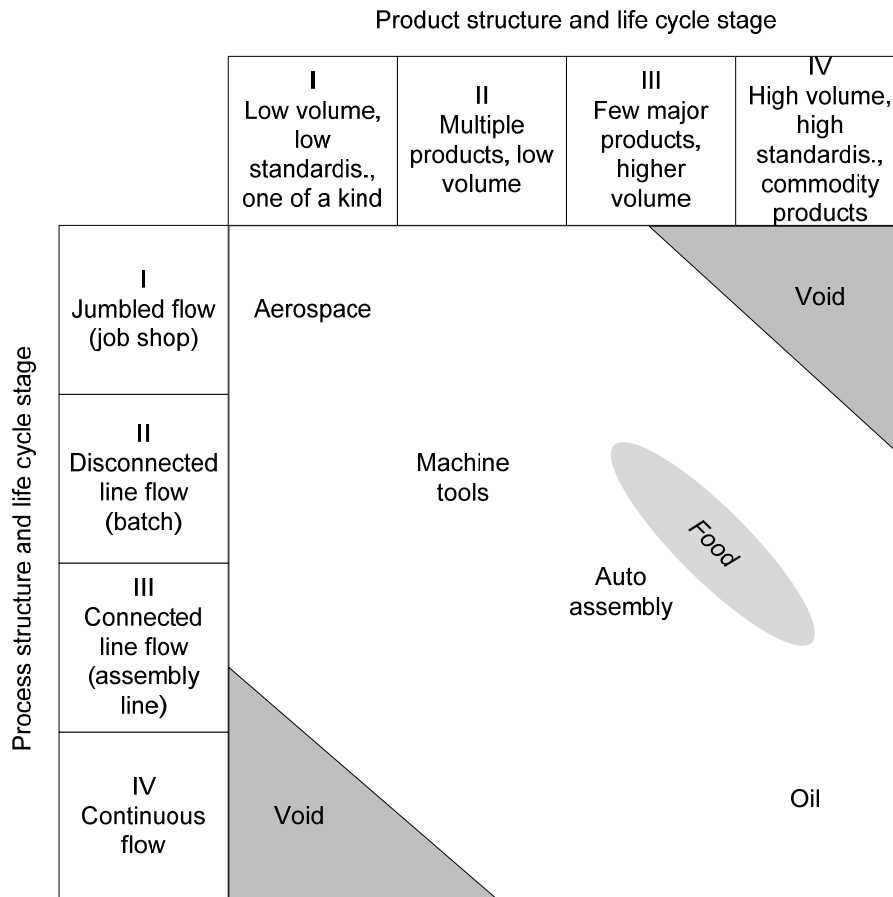
Figure 3-19: Product-process matrix (based on Hayes and Wheelwright, 1984, p. 209)

Traditionally, process industries like food have mostly been concentrated in the lower right part of Figure 3-19, associated with commodity products and continuous flow layout. This positioning has however evolved as process industries have adopted more market-oriented strategies leading to diversified product lines with more customer-specific characteristics and produced using more of an MTO approach to PPC (Crama et al., 2001). Thus, as customer requirements for increasing product variety have led to lower volumes per product, the importance of disconnected line flow with large to mid-size batches has become increasingly important (Berry and Cooper, 1999, Entrup, 2005).

Shifts in the process or product structure increase the importance of ensuring proper alignment between the marketing and production strategies pursued by a company as failure to align these strategies can have serious financial consequences (Berry and Cooper, 1999). Achieving the flexibility required to continuously adapt to the changing environment is however challenging, particularly in a high volume batch-process context like food production (Berry and Cooper, 1999).

A company's performance is affected by the strategic fit between the company's competitive strategy and its supply chain strategy (Chopra and Meindl, 2010, Wagner et al., 2012). The concept of strategic fit was popularised by Fisher's conceptual match/mismatch framework (see sub-section 3.4.3) and refers to the consistency between the customers' priorities and the supply chain's capabilities - reflected in how the supply chain's design, processes and resources provide the capabilities to support the supply chain strategy (Chopra and Meindl, 2010). Several studies have found a positive relationship between supply chain fit and performance (see e.g. Wagner et al., 2012, Selldin and Olhager, 2007).

Once a company has developed a good understanding of its customers' needs, the degree of demand uncertainty in the environment within which it is operating and the limitations imposed by the characteristics of its products, it can determine how to best meet demand through its supply chain capabilities in the form of an appropriate degree of responsiveness, thus ensuring that its strategy is within the zone of strategic fit, see Figure 3-20. Implied uncertainty in this context refers to the demand uncertainty the supply chain imposes on itself through strategic decisions about how to satisfy customer needs (Chopra and Meindl, 2010). If a company for instance decides to decrease lead time, implied uncertainty increases because there is less time to react to orders, or if a company increases the variety of products offered to customers, the implied demand uncertainty increases because the demand per product becomes more disaggregate.
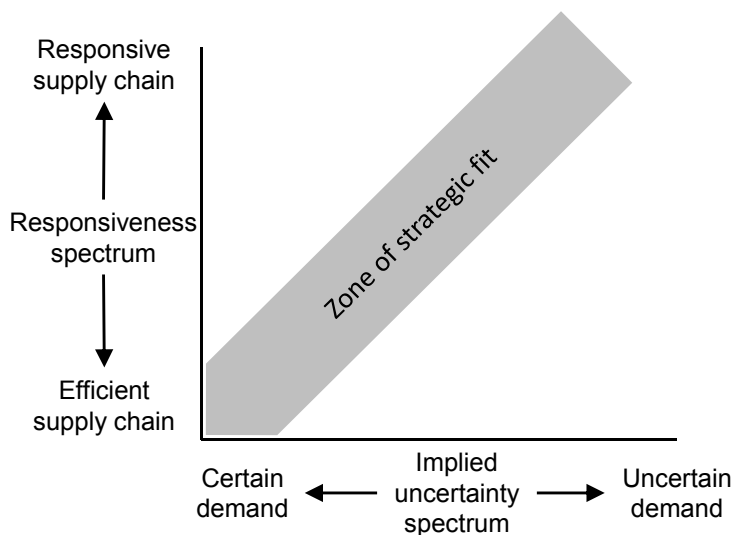
Figure 3-20: Finding the zone of strategic fit (Chopra and Meindl, 2010, p. 51)

While markets are dynamic and can change quickly and are outside of a company's direct control, investments in production plants, equipment and infrastructure are strategic decisions which are the results of conscious efforts by company managers. Thus, over time the essential link between markets and production may drift out of alignment (Hill et al., 1998). Before companies can seek ways to realign markets, products and production, it is essential that they identify the elements of misalignment and understand their origin. The realignment can then take on several forms and involve trade-offs between the different elements. In some instances the companies may even decide not to make changes and live with the mismatch, recognising the consequences to expect in the short and long term (Hill et al., 1998).

The essence of the developments described above is that there is no 'one best way' when it comes to the way production is organised and managed, and that different situations require

different solutions. Since the 1980s, authors have also been challenging the notions of static trade-offs between for instance cost and flexibility, realising that instead of focusing primarily on static trade-offs, companies could achieve improvements in both cost and flexibility performance by focusing on dynamic trade-offs through the selection, development and exploitation of superior capabilities (Hayes and Pisano, 1996). Also, it became clear that in terms of the planning and control of production and inventory, the principles of the MRP based 'push' system and the more 'pull'-based systems like Kanban or just-in-time (JIT) were not as incompatible as first thought and that they could in fact also complement each other (Hayes and Pisano, 1996), for instance through a combination of MTS and MTO in the same company, and the combination of lean and agile in the 'leagile' concept where lean and agile approaches are combined (Mason-Jones et al., 2000).

3.4.2 Customer order decoupling point (CODP)

A central issue in operations strategy and the design of a company's PPC system is determining the degree of form, temporal and spatial postponement of production and distribution activities (Payne and Peters, 2004). In any operating system, there are dependencies and fluctuations that disrupt the flow and affect processes down the line of dependency (Stratton and Warburton, 2003). A traditional means of overcoming the effects of such fluctuations is to place stock between processes to decouple the impact of the fluctuations.

The localisation of this decoupling point has been studied for several decades under a range of different labels, e.g. logistics configurations (Sharman, 1984), decoupling stock point (Bertrand et al., 1990), CODP (Giesberts and van der Tang, 1992, Hoekstra and Romme, 1992), master production planning approaches (Berry and Hill, 1992), speculation, postponement and customer order point (Pagh and Cooper, 1998), material decoupling point (Mason-Jones and Towill, 1999), production strategy and CODP (Hvolby et al., 2001), product delivery strategy and OPP (Olhager, 2003), MPS approach (Vollmann et al., 2005), and simply 'different types of planning and control' (Slack et al., 2007).

This thesis uses the CODP term to describe the point in the process flow where products are linked to a specific customer order; see Figure 3-21. The CODP 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). The stock points decouple successive stages of the production process, thereby allowing stock to create greater flexibility in the upstream production processes (van Dam et al., 1993).

A control principle determines the signals on which activities in a PPC system are initiated, e.g. forecasts, inventory levels and customer orders. As a general rule, activities upstream of the CODP should be controlled using forecasts, while downstream operations are initiated on actual demand or customer orders. The five most common CODPs a company can choose from are (based on Hoekstra and Romme, 1992, Pagh and Cooper, 1998):

1. Engineer to order (ETO): full postponement where no stocks are kept at all and design, purchasing of raw materials and other input factors, production, assembly and distribution are done on customer orders.
2. Make to order (MTO): full postponement where purchasing is done on forecasts, and processing, assembly and distribution on customer orders.

3. Assemble to order (ATO): production postponement where purchasing and production is done on forecasts, and assembly and distribution on customer orders.
4. Make to stock (MTS): logistics postponement where products are produced and assembled based on forecasts, and finished goods are distributed from inventory based on customer orders.
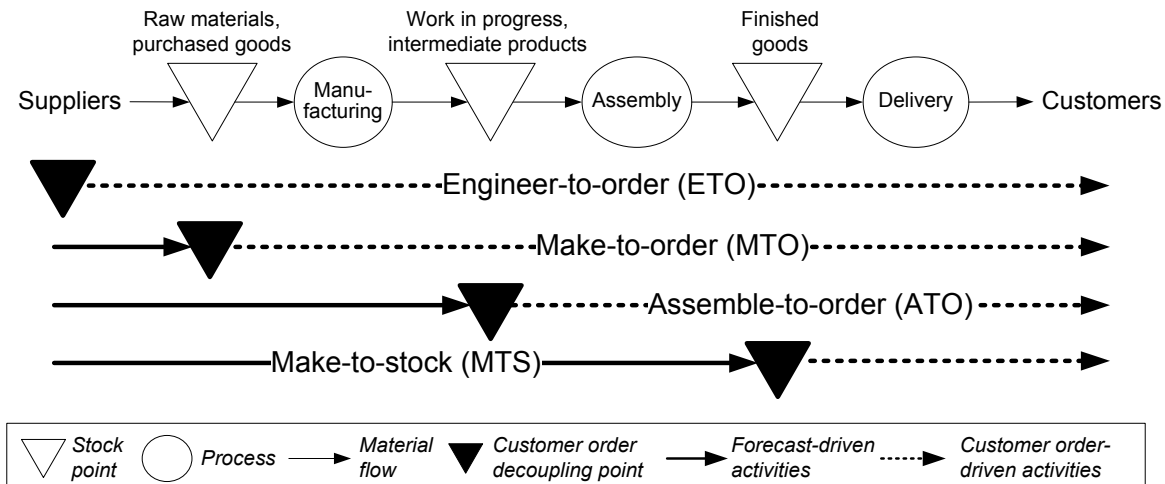
Figure 3-21: Common CODPs (based on Olhager, 2003, Hoekstra and Romme, 1992)

The positioning of the CODP is a strategic and complicated issue since the company must handle the trade-off between market requirements and lead times in production and distribution processes – which again affect costs, customer service levels and investments in stocks and the production process (Hoekstra and Romme, 1992, Olhager, 2003). Several authors have studied the variables affecting the generic MTS vs. MTO decision. Olhager (2003) shows conceptually how the positioning of the CODP is mainly affected by a product's demand volatility and the ratio between production and delivery lead time; see Figure 3-22. Fisher (1997) bases his conceptual model on one single criterion; the predictability of the product's demand. In an empirical study, Wanke and Zinn (2004) found that the MTS vs. MTO decision was mainly dependent on delivery time and the coefficient of variation of sales related to the risk of product obsolescence.
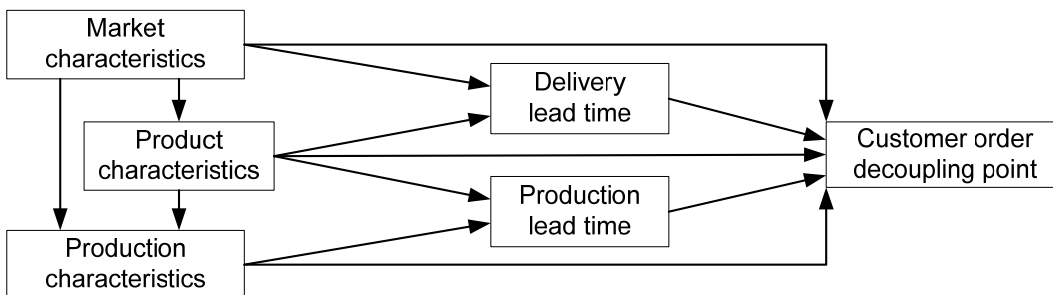
Figure 3-22: Conceptual model for factors affecting CODP positioning (Olhager, 2003, p. 323)

For particular industries other aspects also affect this decision. Empirical studies by van Donk (2001), Soman et al. (2004) and van Kampen and van Donk (2011) show that in the food industry a number of sector-specific characteristics influence the CODP placement. Therefore, the design of a company's PPC system should always be based on the needs and characteristics of the company and its specific environment (Stevenson et al., 2005).

MTO and MTS have traditionally been viewed as entirely distinct and incompatible with each other. Simultaneously, in some industrial sectors like food processing, a pure MTO approach is not viable because of the large number of set-ups this would require. On the other hand, a pure MTS approach is also not practical due to the unpredictability of demand and the perishability of the products (Soman et al., 2004). Over the past couple of decades, the food sector has attempted to respond to the changes in consumer and market demands through increased application of MTO and hybrid strategies where MTO and MTS are employed in combination within the same production system (Crama et al., 2001, Soman et al., 2004).

An interesting contribution in this regard comes from Soman (2005) who developed a framework to assist food producers in determining an appropriate mix of MTO and MTS. The framework consists of a four step sequential process;

1. Service considerations in terms of the ratio between production and customer delivery lead time (P/D). In this stage the desired maximum customer delivery lead time (D) is compared to production lead time (P). In cases where a product's P/D > 1, the product has to be delivered from finished goods inventory using an MTS approach.
2. Demand analysis in terms of volume and variance, where low volume, high variance products are classified as MTO.
3. Cost analysis where the cost of making a product to stock is compared to making it to order, taking the costs of inventory, setup and safety stock into consideration.
4. Capacity considerations to ensure that the initial MTO-MTS division from the previous steps is feasible within the available capacity.

The architecture of the MTO-MTS decision aid is illustrated in Figure 3-23 (for a discussion of the model and its limitations, see sub-section 7.2.2.2).
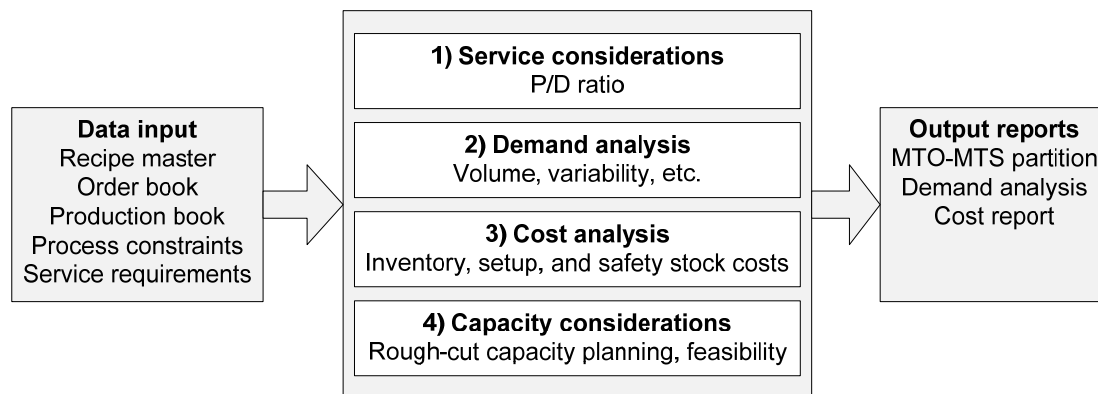
Figure 3-23: Outline of Soman's MTO-MTS decision aid (adapted from Soman, 2005, p. 32)

The topic of hybrid and differentiation strategies combining MTO and MTS within the same production system is further explored in the next sub-section.

3.4.3 Differentiation

As mentioned, building on the realisation that there is no 'one best way' to organising and managing operations, a number of concepts and frameworks have been developed for matching situations with different characteristics with appropriate solutions. The idea of such differentiation is to identify the characteristics of a particular context, determine the most appropriate organisational response or strategy, and then group for instance products with similar characteristics so that these can be managed together. Below, a number of differentiation ex-

amples that are relevant for and have inspired this study are outlined and discussed – starting with generic frameworks and then looking at differentiation examples from the food supply chain context.

In sub-section 3.1.3, we saw how several studies have used a configurational approach to matching product demand characteristics with the 'right' supply chain strategy or design. As mentioned, one of the first and most influential configuration frameworks is Fisher's taxonomy for choosing between a market responsive and physically efficient supply chain strategy (Fisher, 1997). Fisher maintained that a supply chain's competitive priorities should depend on the nature of the product. Supply chains for innovative products with unpredictable demand should balance supply and demand through market responsiveness by focusing on speed, flexibility, and positioning of inventory and production capacity. For supply chains of functional products with predictable demand, Fisher argued that the main focus should be on minimising physical costs and inventory, and maximising production efficiency through economies of scale. The resulting matching of products and supply chains is illustrated in Figure 3-24.

	Functional products	Innovative products
Efficient supply chain	Match	Mismatch
Responsive supply chain	Mismatch	Match

Figure 3-24: Fisher's framework for matching supply chains with products (Fisher, 1997, p. 109)

Examples of similar configuration concepts include the differentiation between lean and agile supply chains based on product and market characteristics. Lean here refers to forecast-driven supply chains where the focus is on developing a value stream to eliminate all waste, including time, and ensuring a level schedule, while agile refers to demand-driven supply chains using market knowledge and virtual corporation to exploit opportunities in a volatile marketplace (Mason-Jones et al., 2000, Bruce and Daly, 2004).

Expanding on the concept of lean and agile enterprises authors like Naylor et al. (1999) and Bruce and Daly (2004) suggested combining lean with agile as an alternative supply chain strategy. This concept of leagile involves a switch between lean or efficient approaches during the upstream processes of the chain and more agile or market responsive approaches during the downstream processes – i.e. before and after the CODP. The main idea is that this will enable a supply chain to be both efficient in eliminating waste (lean) and better able to achieve rapid and appropriate responses to fluctuating consumer demand (agile).

Another example of differentiation in a supply chain setting comes from Kaipia who developed an information sharing and execution flexibility framework as a basis for selecting between different supply chain planning approaches ranging from order-based to forecast-focused (Kaipia, 2009, Kaipia, 2007); see Figure 3-25. The framework differentiates among three basic sources of flexibility; delivery time, inventory and production. Order-based or 'reactive planning' is here argued to be the appropriate coordination mechanism when the customer accepts a long delivery time. On the other hand, forecast-focused planning, also called 'proactive planning', is found appropriate when the allowance for delivery time is short or production is the main source of flexibility. A prerequisite for such proactive planning is the use of multiple sources and types of information from supply chain partners.
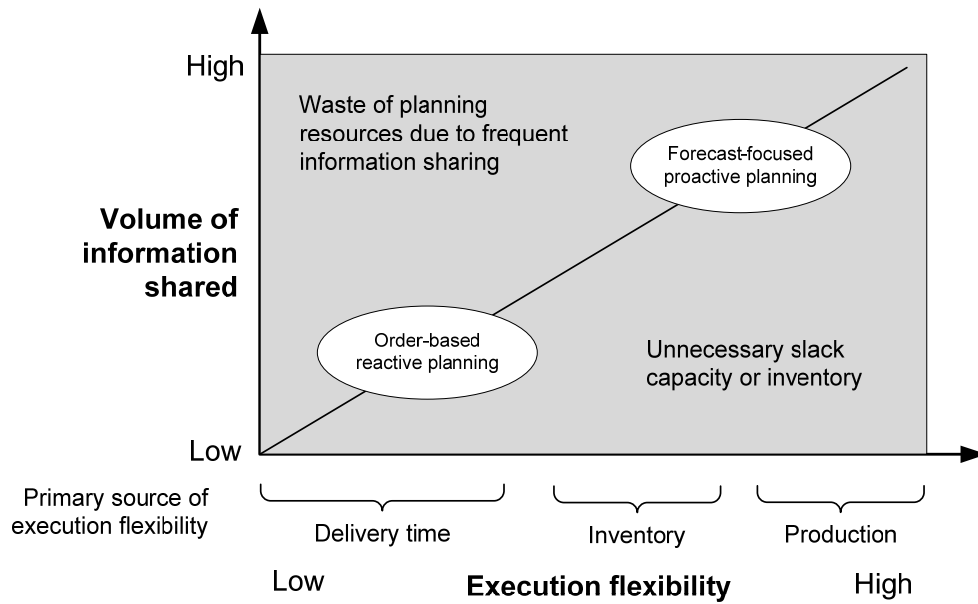
Figure 3-25: Framework for selecting between order and forecast-focused planning (Kaipia, 2007, p. 62)

From Figure 3-25, it can be seen that order-based and forecast-focused planning approaches require different levels of information sharing and levels of integration with supply chain partners. Thus, different types of planning are needed for different products. However, for some products, planning can combine order-based and forecast-focused approach, for instance in the case of campaigns or product introductions where early sales data can be used in combination with historical data.

The concept of differentiated planning has also been applied to products with different demand features and life-cycle phases. Kaipia and Holmström (2007) developed a framework for differentiated planning for innovative products, where different planning approaches were positioned according to the availability of planning resources and information needed, and the possibility to automate the planning task through rules and procedures. This resulted in the framework shown in Figure 3-26.
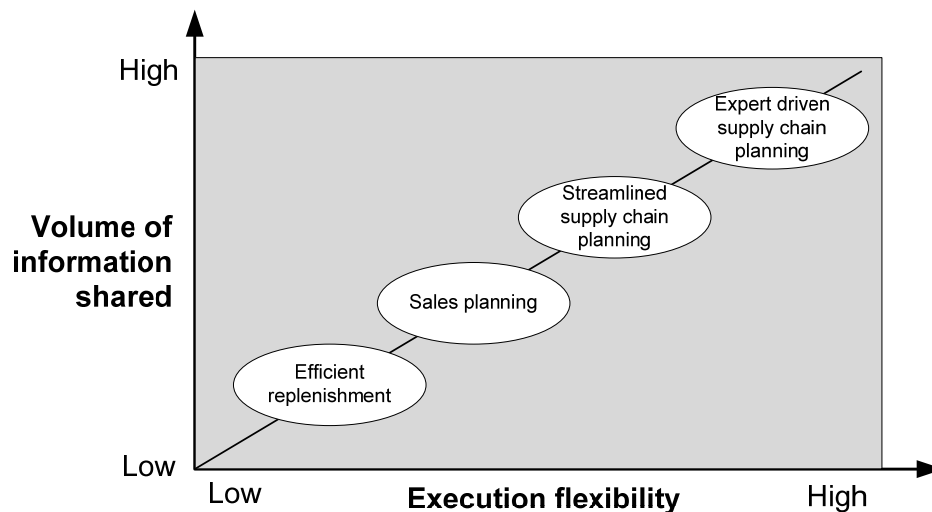
Figure 3-26: Differentiated supply chain planning for innovative products (Kaipia, 2007, p. 64)

A common feature of the above configuration frameworks is that they focus on determining the one best strategy or approach for a whole company or facility. Thus, they do not consider differences between the products or product groups made in the same facility and how this may trigger a need to differentiate within the same production system. There are however examples of studies that have investigated linking different products with different strategies within the same company.

Aitken et al. (2005) looked at how organisations in the 21st century can respond to the need for developing capabilities to achieve higher levels of responsiveness to the different needs of different customers. The authors suggested adding order winning and order qualifying criteria to Fisher's product-driven approach, where market characteristics were expressed through DWV^3 (D = duration of life cycle, W = time window for delivery, V^3 = volume, variety and variability). The DWV^3 could be used to develop context-specific differentiated pipelines, specifying the operational mechanisms and procedures to be employed to service specific product/market contexts, which meant that a supply chain could consist of a number of unique pipelines. The design of each pipeline should be based on in-depth analysis of products, production processes, and market opportunities, accompanied by a clear understanding of the competitive pre-requisites (market qualifiers) and critical differentiators (order winners) in each product/market context. Further, the authors suggested that the design of the pipelines should take the phase of the product life cycle (PLC) into consideration, where different pipeline strategies are suitable for different PLCs depending on the need for agility, leanness and combination strategies like leagile.

An example where different delivery pipeline strategies are applied in different PLC stages is illustrated in Figure 3-27. The example is based on the case of a manufacturer of lighting products for diverse markets (Aitken et al., 2005). Here, a design-and-build strategy was applied in the introduction phase in order to foster design capabilities. In the growth and decline phases, a push-based MRP strategy was used to maintain high service levels to meet unpredictable demand. In the maturity and saturation phases cost was considered the order winner, and in this case a Kanban strategy was appropriate in the maturity stage, while an assemble-to-order strategy in the packing centre was found to meet the needs for low-cost production and more product variants in the saturation phase.
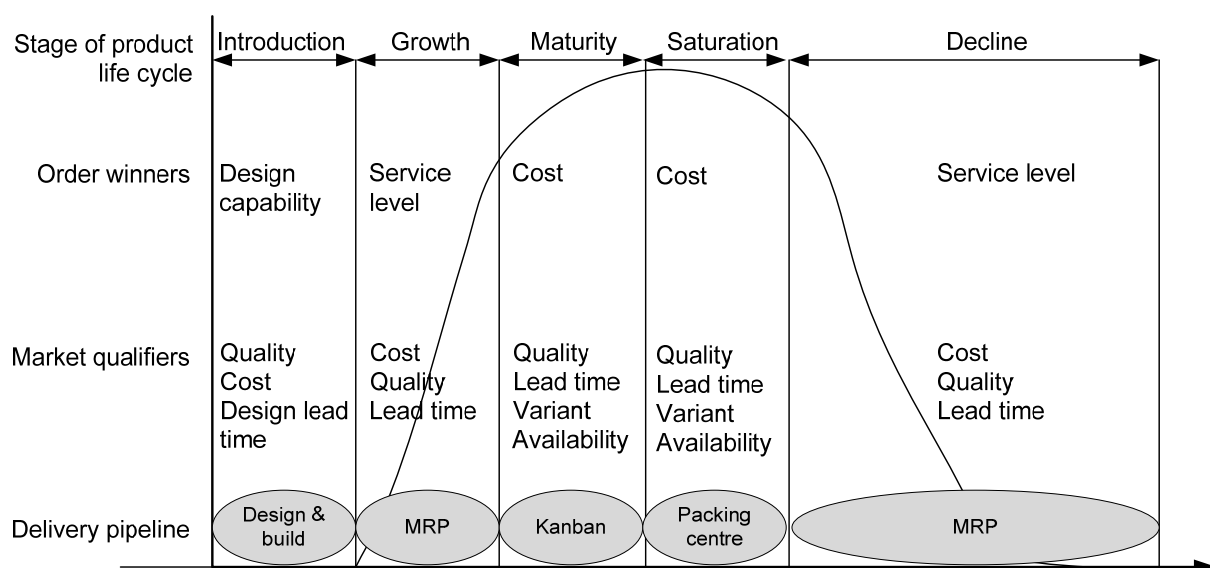
Figure 3-27: Linking delivery pipeline strategies and product life cycle (adapted from Aitken et al., 2005, p. 87)

Similar to Aitken et al. (2005), Wong et al. (2006) raised the question of whether all volatile and seasonal products can be classified as 'innovative' according to Fisher's framework and whether they effectively can be supplied by a market responsive supply chain strategy or whether other strategies may be more appropriate. In a case study of a producer of toys with volatile and seasonal demand, a framework for assessment of responsiveness was developed based on Li and O'Brien (2001) and an extension of Fisher's model. The framework suggested three clusters of strategic and operational levels in terms of responsiveness vs. efficiency and associated PPC approaches:

1. Functional products should be matched with a physically efficient supply chain with an MTO or MTS approach
2. Intermediate products should be matched with a physically responsive supply chain with an MTS approach
3. Innovative products should be matched with a market responsive supply chain with an MTS or ATO approach, which requires capacity and inventory buffers in addition to investments to reduce lead times

The resulting strategy differentiation model is illustrated in Figure 3-28. Although the model was developed using a narrower set of strategy determinants than those considered important in literature, the case illustrates that there may be a need for a more differentiated and nuanced view of Fisher's conceptual framework in order for it to be of practical value.
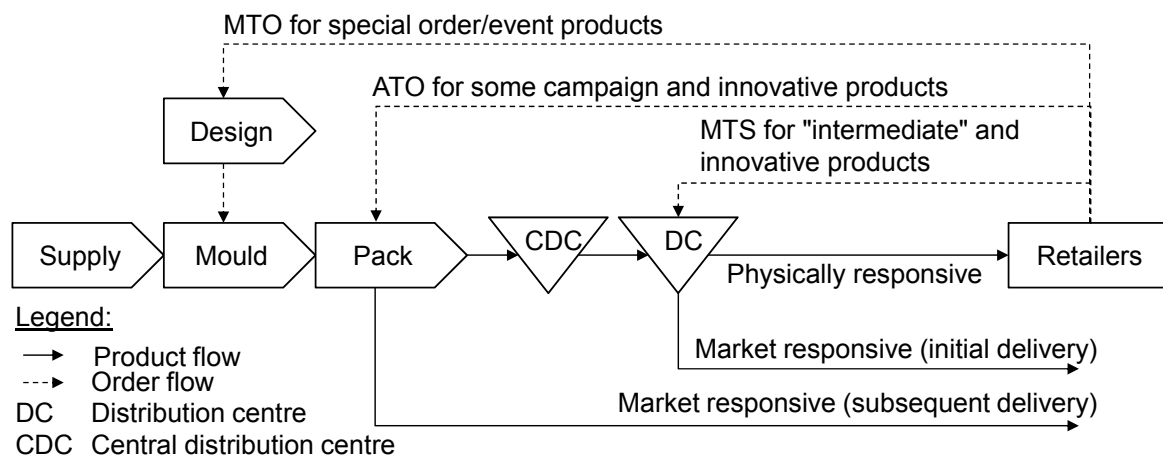
Figure 3-28: Toy manufacturer's strategy differentiation model (adapted from Wong et al., 2006, p. 717)

As previously mentioned, in food processing neither a pure MTO approach nor a pure MTO approach is practical and this has led to increased application of hybrid MTS-MTO approaches (Crama et al., 2001, Soman et al., 2004). Often, a company will place its main CODP at the point in the production process where the largest variant explosion happens to allow exploitation of scale benefits in the upstream operations and focus on market responsiveness in the downstream operations. Other ways of combining MTO and MTS is to use MTS for the majority of products, while MTO is used for products contributing little or irregular work load to the production system (e.g. export orders and tenders), items with low set-up times, items with high holding cost, customised products and highly perishable products (Soman et al., 2004).

Other differentiation approaches have also been seen in the food sector. For instance do some companies use MTS for products sold to local/national customers (where short delivery time

requirements demand supply from stock), and MTO for items with customer-specific packaging since such customers often allow for longer delivery times (van Dam et al., 1993). Treeck and Seishoff (2003) recommend that planning of promotions be completely separated from the planning of standard items since they differ in demand uncertainty and the availability of historical sales data in forecasting. This also shows that there may be a need to use different planning principles for the same SKU since there are important differences between normal or promotional sales. Further, although postponement has been scarce in the food industry compared to other sectors due to the sector's specific operational characteristics, the possibility of splitting the production process in processing and packing allows for some form postponement (van Hoek, 1999).

What the above examples of differentiation demonstrate is that the prevailing 'one size fits all' approach to PPC may not be the best strategy and that there is a trend towards differentiating PPC approaches. However, the variables used to differentiate vary between studies and there is no clear answer to the question of which variables should be used in different contexts. Thus, the logic or rule-base to guide the choice of PPC approaches should be adapted to the specific supply chain characteristics and configurations. For the food sector, this logic is further explored in chapter 5.

3.5 Summary; research gaps and opportunities

Chapter 3 has described the theoretical background for the study. Below, the chapter is summarised with regards to some of the findings and how literature and key concepts relate to the PhD study.

Existing literature emphasises the importance of linking OM with operations strategy and ensuring a good fit between the strategy and the design of the PPC system. With the widening of OM to also encompass supply chain perspectives comes the importance of designing PPC in a way that enables operations to develop the capabilities needed to meet external requirements. A framework for characterising supply chains was developed for this purpose, providing a tool for understanding how product, market and production system characteristics impact on the requirements exerted upon the operations function. The tool is later used to structure and analyse food supply chain characteristics in sections 4.2 and 4.3.

The chapter further demonstrated how operations strategy is no longer a question of aiming for either efficiency or responsiveness, but rather that companies must find a way to be both at the same time since responsiveness may be one of the most important capabilities needed for organisations to achieve competitive advantage. This provided input to the scoping of the study, based on the insight that companies should no longer focus on identifying the one best way of doing things, but rather that a differentiated approach to PPC system design should be used to enable a good fit between operations and strategic priorities.

Further, it was seen that although PPC has also been widened to take supply chain perspectives into consideration, planning and control is still mainly based on MRP/MRPII logic and MTS, thus decoupling operations from actual demand and reducing actors' ability to effectively balance supply and demand. Increasing use of MTO in combination with MTS was identified as a potential solution. However, there is a need for more research to determine a rule-base for this type of differentiation of PPC approaches and investigation of how this can be operationalised in hybrid production environments.

4 FOOD SUPPLY CHAIN CHARACTERISTICS

In this chapter, the characteristics of food supply chains are outlined in order to provide an understanding of the empirical context of the study, thus forming the main contributions towards RQ1. The structure of the chapter is illustrated in Figure 4-1.
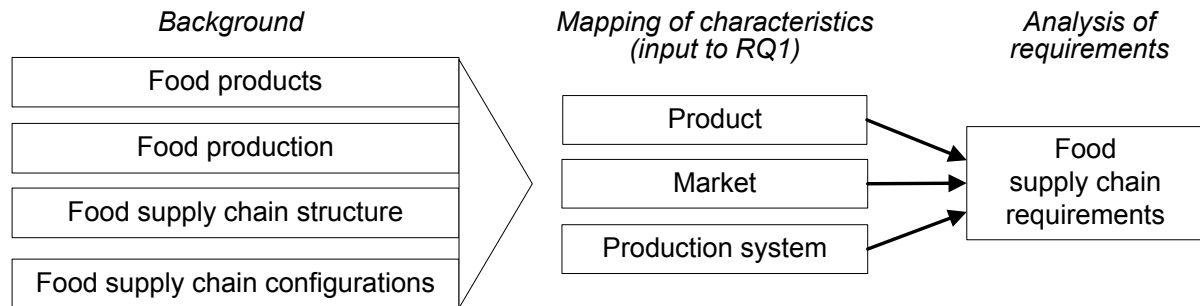
Figure 4-1: Structure of chapter 4

Section 4.1 provides a general introduction to food supply chains in terms of products, production processes, structure and configurations.

Section 4.2 then uses the framework from Table 3-1 to map and structure the key product, market and production system characteristics of food supply chains – thus providing the main input to RQ1.

Section 4.3 analyses each characteristic with regards to the impact it has on the requirements exerted on food producers (the implications of these characteristics and their requirements for PPC are further discussed in section 7.1).

4.1 Background

In this section, a general background to the empirical context of the study is presented. Firstly, food products are defined. Then the food production process is described, before external aspects related to supply chain structure and configurations are presented. Since the case company TINE is located in Norway, some aspects which are particular to Norway are included in the descriptions. However, the majority of the characteristics are likely to be relevant also for food supply chains in other industrialised countries.

4.1.1 Food products

This study focuses on food products, i.e. products which are characterised by a degree of perishability in raw materials, intermediate and finished products. The perishability aspect places some important requirements on supply chain processes particularly in terms of supply chain speed, referring to the time it takes for a product to go through a pipeline – thus capturing procurement lead time, production lead time and distribution lead time.

Although food products with a shelf life of several years can also be considered perishable (e.g. milk processed at ultra-high temperatures (UHT), canned fruits and processed peanuts), this study mainly focuses on products where the perishability has an important impact on supply chain requirements. For this purpose, food products are here defined as products with a

limited shelf life ranging from days up to 12 months, typically including products such as dairy and bakery, fresh and processed meats and fish, and packaged fruit and vegetables.

Further, the focus is on products which require a certain degree of processing since the production of these require a certain maturity and complexity in planning and control, thus fitting with the scope of the study. Products like potatoes, apples and oranges which are distributed and sold in bulk in grocery stores are therefore not considered, although some of the solution elements may be applicable to these as well.

4.1.2 Food production

The typical steps in a food production system are receipt of inputs (raw materials, ingredients, packaging materials, etc.), processing, 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 production processes and stock positions are illustrated in Figure 4-2.
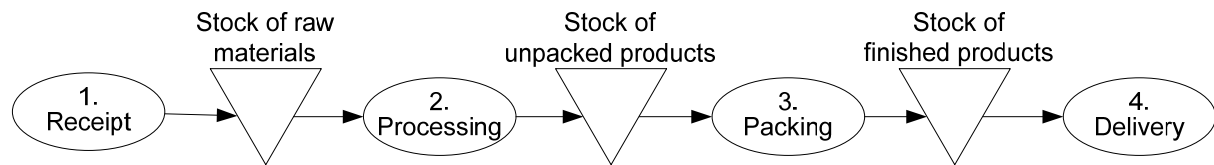
Figure 4-2: Typical processes and stock points in food production (based on Méndez and Cerdá, 2002, van Dam et al., 1993)

Like other homogeneous commodities like chemicals, paint and tobacco, food production can be classified as a process industry where standardised products are produced in large quantities (van Dam et al., 1993). In order to reduce the cost prices per product, there is a tendency towards scaling up production volumes and automating production equipment (van der Vorst et al., 2005, van Donk et al., 2008, Alfnes and Bolseth, 2001).

Typically, food products are produced in batches, where raw materials and intermediates are accumulated and processed together in lots. In many cases, products can only be stored temporarily due to the perishability of raw materials, intermediate products and finished products, and limited storage capacity on the shop floor (van Donk, 2001, van Dam et al., 1993).

The stock of raw materials is often not more than a few days due to the perishability of the biological inputs. 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). This reflects the existence of splitting operations and the generation of co- or by-products as part of the production process (Crama et al., 2001), as well as the different consumer preferences with regards to taste and packaging variants resulting in the funnel-shaped variant explosion of inputs to outputs from step 1 to 3, illustrated in Figure 4-3.

Inputs   Outputs
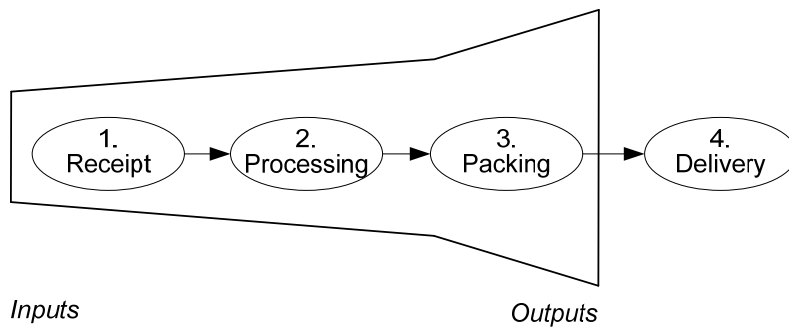
Figure 4-3: Variant explosion in food production

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 a number of different customers or markets before product deterioration becomes an issue.

The differences between the operational characteristics of the packing and processing stages are summarised in Table 4-1.

Table 4-1: Differences between processing and packing stage (based on van Dam et al., 1993)

Characteristic	*Processing stage*	*Packing stage*
Product variety	Low	High
Order sizes	Large	Small
Labour intensity	Low	High

These differences mean that the operational planning and scheduling of the stages should be treated differently (van Dam et al., 1993). However, the packing stage can only be scheduled separately from the process phase when the stock between the phases is large enough (van Dam et al., 1993).

In summary, the fact that food production has traits of both process and discrete production means that the traditional PPC approaches and techniques suited for the two extremes are more difficult to apply in the food production setting. In addition, the trend towards more product variants and the need to produce in smaller batches adds additional complexity to the PPC task of food producers – in addition to the need for speed in all process in order to maximise the remaining shelf life of the perishable products.

4.1.3 Supply chain structure

The largest volumes of food products are produced and distributed through highly industrialised supply chains. These supply chains typically consists of primary production (e.g. meat, fish, vegetables, and grain), suppliers of other production inputs (packaging material, ingredients, etc.), an industrial production or processing unit, a wholesale or distribution unit, and

retailers selling the products to consumers (see Figure 4-4). Transport between the actors is undertaken either by the actors themselves or by independent transport companies.
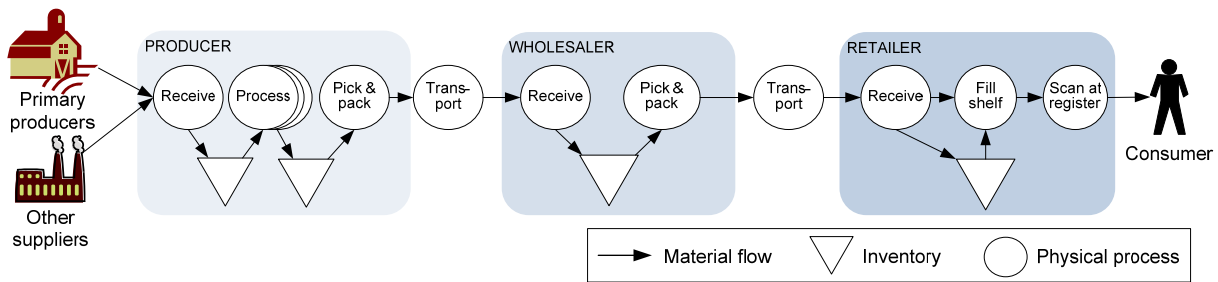
Figure 4-4: A typical industrialised food supply chain

In addition to the retail distribution channel, large volumes of food products are sold to professional customers in the hotel, restaurant and catering (HORECA) and convenience store market, as well as to institutions like hospitals and schools. There is however a trend towards these actors also buying from wholesalers instead of directly from producers.

Like many other industrialised countries, Norway has seen major structural changes in the food supply chain over the past decades, with emergence of large industrial producers and brand owners, consolidation of the wholesale and retail stages, and a general professionalisation of the systems for food production, purchase, distribution and sales. This has resulted in strategies and logistic solutions based on high volumes, high frequencies and consolidation principles in order to achieve economies of scale and high capacity utilisation. This focus on large volumes stems both from food producers wanting to produce in large batches in order to keep production costs per unit down – but also from wholesalers and retailers who prefer to buy in large volumes in order to take advantage of quantity discounts and reduce unit costs in transport and handling. Thus, today's conventional food supply chains are highly efficient, adapted to industrialised production in advanced facilities located in central areas – and with large volumes and exploitation of scale benefits as the main drivers for planning and control of production and distribution.

The Norwegian grocery market consists of close to 4.000 retail stores (NILF, 2013). Although the number of stores is slightly declining, Norway still has one of Europe's highest densities of grocery stores per inhabitant at 464 stores per million inhabitants in 2011 (NOU, 2011). For comparison, the UK had 97 stores per million inhabitants, France 196, Finland 208, the Netherlands 213, Sweden 245 and Denmark 397 (NOU, 2011).

Like in the rest of Europe, there has been a consolidation in the Norwegian food sector, with vertical integration among suppliers, processors, wholesalers and retailers. Presently four umbrella chains (wholesale-retail chain dyads) have an aggregated market share of almost 100 % of ordinary retail distribution in Norway; NorgesGruppen (37,4 %), Coop Norge (23,4 %), REMA1000 (21,3 % + 3,8 %) and ICA Norge (14,1 %) (2011 figures) (NILF, 2013). The strong integration between wholesalers and retail chains has resulted in intensification of competition and a shift of power towards retailers, consistent with developments in other countries (Dobson et al., 2001, van der Vorst et al., 2001, NILF, 2010, Verdouw and Wolfert, 2010, NOU, 2011).

Although there is some direct distribution of certain fresh food products from producers to retailers (e.g. milk, bread and soft drinks), wholesale distribution is increasing (NILF, 2010),

as is the use of cross-docking (Eidhammer and Jean-Hansen, 2008). There is also increasing integration backwards to production with the four umbrella chains wholly or partly controlling and owning processing companies supplying both branded products and private labels to the Norwegian market (NILF, 2010).

Despite the strong integration and consolidation, the Norwegian food supply chain can still be considered fragmented, with many involved actors and limited cooperation, coordination and information sharing. Like the global food sector, the Norwegian supply chain has many stock points, and being a multiple-level supply chain, demand is aggregated between each level. Thus, as one moves up the supply chain, the upstream actors' information about end customer demand is distorted, creating artificial demand variation also known as the bullwhip effect (Lee et al., 1997). The typical effects of the bullwhip effect include large inventories, large amounts of scrapping and waste, and excess capacity both in the production and distribution system (Lee et al., 1997). As a means of overcoming such inefficiencies, large investments in structure and infrastructure have been made over the past couple of decades. Production has been restructured, specialised and centralised, and investments have been made in large-scale production systems. Likewise, distribution channels have been industrialised through highly efficient warehouse and logistics systems focusing on centralisation, high volumes and economies of scale. The grocery retail trade has also had strong focus on increasing productivity and strengthening of the logistics function related to wholesale distribution (NILF, 2013).

In terms of the market qualifying and order winning criteria for grocery stores, the Norwegian market seems to follow general international trends where store localisation, price and product quality are ranked the highest (Axtman, 2006, Romsdal, 2011). Further, the availability of perishables and fresh food products is essential (Axtman, 2006, van der Vorst et al., 2007, Romsdal, 2011), as well as product variety (van der Vorst et al., 2007, Romsdal, 2011) and private labels (van der Vorst et al., 2007, NILF, 2010).

4.1.4 Food supply chain configurations

The food sector deals mainly with what Fisher (1997) classifies as functional products, i.e. products that satisfy basic needs and have long PLCs and low contribution margins (see section 3.4). Thus, using the Fisher framework from Figure 3-24, one would expect most supply chains in the food sector to aim for cost efficiency in their supply chains. However, most producers in the food sector are experiencing multidimensional competition with strong pressures for both cost efficiency and high responsiveness both from consumers and supply chain partners (van Donk et al., 2008, van Hoek, 1999), thus breaking with Fisher's predictions. This observation indicates that Fisher's taxonomy may not sufficiently capture all the most important characteristics of the food sector, and that managers in the sector therefore have difficulties in selecting and executing the 'right' supply chain strategy.

With this in mind, Kittipanya-ngam (2010) makes an interesting extension to existing frameworks based on an empirical study of 21 cases in the Thai food industry. The cases included 10 food product types (perishability ranging from fresh fruit and poultry to canned fruit and soluble coffee), produced by six large food producers, and distributed through local, regional and global market channels. Each case was mapped according to three product and market variables:

1. Customer order lead time
2. Supply chain lead time
3. Demand uncertainty

These three variables are essential in the food supply chain context and define the environment and boundaries within which food producers operate. Customer order lead time was defined as the lead time for replenishment allowed by customers, in other words the time a producer has available before an order must be delivered. Short lead time allowance thus limits the producer's ability to make a product to order, particularly if production lead times are longer than order lead time allowances. On the other hand, long order lead time allowance represents a potential source of flexibility for PPC since the producer can plan production to for instance maximise capacity utilisation.

Supply chain lead time was defined as the lead time allowance determined by the perishability of raw materials, intermediates and finished inputs. Short supply chain lead time (i.e. high perishability) means that the possibility to use inventory to buffer against demand uncertainty is limited. On the other hand, long supply chain lead time (i.e. low product perishability) represents a potential source of flexibility for PPC since raw materials, intermediates and finished products can be kept in inventory for a certain period of time before shelf life limitations dictate that they must be processed, sold or delivered to customers.

As Fisher (1997) argued in his framework, consideration of demand uncertainty is essential in supply chain design and configuration because it determines how the supply chain should be managed. Kittipanya-ngam (2010) defined demand uncertainty as a combination of product variety, frequency and degree of new product development (NPD), and the product's stage in the PLC.

The study concluded that different combinations of product and market characteristics cluster in six food supply chain operating environments, each exerting different primary requirements on food producers in terms of;

- Cost;
    o The fundamental requirement in business competition, where a company utilises economies of scale to reduce cost per unit
- Replenishment speed;
    o The ability to quickly respond to customer orders, i.e. the lead time between when the customers place an order and when they receive it
- Supply chain speed;
    o The ability to quickly respond to customer orders within supply chain lead time allowance, i.e. limitations related to product perishability
- Flexibility;
    o The ability to respond quickly to fluctuations in market requirements (demand volume, product variety and design)

Quality was considered a fundamental requirement in business competition and therefore included in all configurations.

The study found that each of the key characteristics places more importance on one particular requirement compared with the others. In general, it was found that the higher the demand uncertainty, the more flexibility was required of food producers both in volume and variety/design adjustments. When demand was more predictable, economies of scale and cost optimisation came more into focus. Further, the shorter the customer order lead time, the more replenishment speed was required, while the shorter the supply chain lead time allowance, the

more supply chain speed was required. The six operating environments and their primary supply chain (SC) requirements for food producers are illustrated in Figure 4-5.
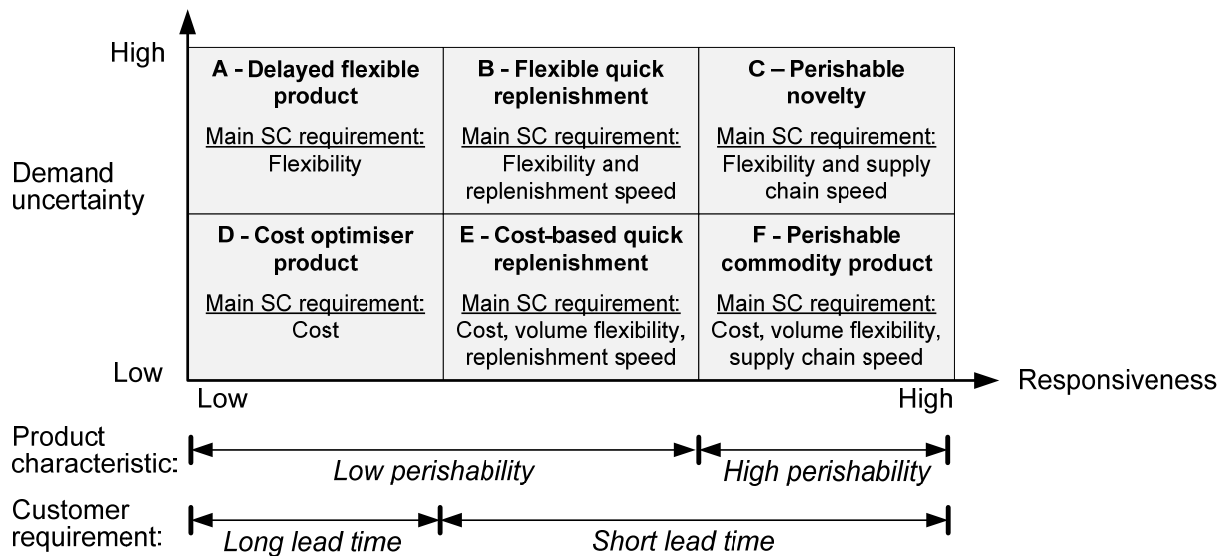
Figure 4-5: Food supply chain (SC) operating environment and SC requirements (based on Kittipanya-ngam, 2010, p. 110)

The Kittipanya-ngam framework emphasises that a food producer's supply chain strategy should ensure a good fit between the product and market characteristics and the capabilities of the production system. The framework further illustrates 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. The six supply chain operating environments provide a more holistic view of food supply chains and the requirements facing food producers than existing generic frameworks. The insights from the framework can therefore be used as a starting point for identifying the appropriate PPC approaches for each configuration – a topic which is further explored in section 5.2.

4.2 Food supply chain characteristics

When designing the PPC system of a food producer, having a good understanding of the characteristics of the context is critical. The framework for supply chain characterisation developed in sub-section 3.1.3 can be used as a tool to structure a description of the most important characteristics of food supply chains. Below, each aspect in the framework is described based on a review of research and literature on food supply chains (see Table 3-1 for the definition of each aspect). The most important product, market and production system characteristics are summarised in Table 4-2.

Product characteristics
In Table 3-1, it was seen that food products can be characterised by their perishability, complexity, variety, PLC and volumes, and each of these aspects is described in more detail below.

A key characteristic of food products is their perishability and limited shelf life which has important implications for the way they are treated throughout the supply chain. Raw materials, intermediates and end products have shelf life constraints (van Donk, 2000, van der Vorst

et al., 2005). The perishability is also related to the need for mark-downs and selling products at reduced margins due to product deterioration (van Donselaar et al., 2006). In Norway, there is an industry standard regulating the distribution of days of shelf life between producer, distributor and retailer/consumer (STAND001, 2006). This means that supply chain actors operate with a 'sell-by-date' in addition to the product expiry date.

With regards to complexity, food products can be considered to have fairly simple and standards BOMs, with complexity ranging from fresh agricultural products where production involves mainly packing and labelling (e.g. apples, bananas, potatoes, and eggs) to processed food products with combination of hundreds of ingredients with many process steps (e.g. processed meats, and ready-made meals) (van der Vorst et al., 2007). Complexity in processing is increasing due to the trends of increasing product varieties (Entrup, 2005), increasing number of packaging sizes, and more frequent product introductions and new product recipes (van der Vorst et al., 2005, van Donk et al., 2008). Food products typically have a divergent product structure, especially in the packing stage (van Donk, 2000), involving transition from bulk to packaged items for less complex products (Axtman, 2006), with mainly a non-modular composition (van Hoek, 1999).

Food as a product category includes both functional, standard, commodity-type products and more innovative, unique and complex products (Axtman, 2006). In general, product variety is high and increasing (van Donk, 2000, Alfnes and Bolseth, 2001, Entrup, 2005, van der Vorst et al., 2005, Ferguson and Ketzenberg, 2006, van Donk et al., 2008, NILF, 2010). In addition to an increase in branded products, there is also an increasing number of private label products with higher margins for wholesalers and retailers (NILF, 2010). There is increasing variety in packaging types and sizes (Axtman, 2006), particularly for promotions, and there is a high percentage of slow moving items (Ketzenberg and Ferguson, 2008), increasing the risk of obsolescence and product expiry.

The high pace of product innovation is resulting in shorter PLC (van der Vorst et al., 2005, Verdouw and Wolfert, 2010) and an increase in the number of new items (van Donk et al., 2008), with failure rates of up to 75 % (Axtman, 2006).

In terms of volume, food products are usually produced and sold in large volumes (van der Vorst et al., 2005). The fairly low product variety in the processing stage means that volumes and batch sizes tend to be larger in the upstream processes (van Dam et al., 1993). In addition, perishable items have been found to have significantly smaller pack sizes than non-perishable items (van Donk, 2000, van Donselaar et al., 2006).

Market characteristics
In Table 3-1, it was seen that the market for food products can be characterised according to delivery lead time, demand uncertainty, and inventory management, and each of these aspects is described in more detail below.

Delivery lead time in food supply chains varies from hours and days to several months, but generally customers like retailers and wholesalers demand and receive short lead times and frequent deliveries (van Donk, 2000, van Donk, 2001, Entrup, 2005, van der Vorst et al., 2005, van der Vorst et al., 2001, Verdouw et al., 2010). It has also been found that perishable items tend to be ordered and delivered more frequently than non-perishable items (van Donselaar et al., 2006).

Food producers mainly meet customer demand from finished goods inventory since production lead times tend to be longer than customers' delivery lead time expectations (van Donk, 2000, Alfnes and Bolseth, 2001). This is a particularly challenging aspect in Norway since the Norwegian geography, scattered population and difficult climatic conditions increase both lead times and lead time variability.

Demand uncertainty varies but is generally high for innovative products and low for functional products (Fisher, 1997). Perishable items have been found to have slightly lower demand uncertainty than non-perishable items (van Donselaar et al., 2006), although consumer demand in general is becoming more unpredictable (van der Vorst et al., 2005, Verdouw and Wolfert, 2010). Much of the variability in consumer demand is caused by high and increasing frequency of promotional activities, particularly since retailers often make last-minute decisions with regards to campaign retail prices (Fairfield, 2003, Entrup, 2005, Taylor and Fearne, 2006, Gedenk et al., 2010, Huchzermeier and Iyer, 2010). The bullwhip effect caused by demand uncertainty is often demonstrated in food supply chains, e.g. in the famous Barilla SpA case (see e.g. Simchi-Levi et al., 2008).

In terms of inventory, ordering is typically periodic (Slack et al., 2007). The perishability aspect limits actors' possibility to keep buffer inventories (van der Vorst et al., 2005, Ahumada and Villalobos, 2009) and means that products require conditioned storage (van der Vorst et al., 2005). In production, there tends to be limited storage space available for unpacked products (van der Vorst et al., 2005), and perishable items have been found to have a significantly lower minimum inventory norm than non-perishable items (van Donselaar et al., 2006).

For most products, inventory carrying costs are low, particularly compared to the cost of lost sales (Ketzenberg and Ferguson, 2008), and low value density make products more sensitive to distribution costs than to inventory costs (van Hoek, 1999). Product availability is crucial both for producers and retailers as customers either cancel purchase or buy substitutes in stock-out situations (Alfnes and Bolseth, 2001, Romsdal, 2011). Despite this, retail stock-out rates for food products have been found to be high and stable at between 5-10 % (Corsten and Gruen, 2003, Verhoef and Sloot, 2010), particularly for promotional, fast selling and new products (Corsten and Gruen, 2003, Treeck and Seishoff, 2003, Entrup, 2005). Stock-outs are often caused by inefficient supply chain practices related to ordering, replenishment and planning (Corsten and Gruen, 2003).

Production system characteristics
In Table 3-1, it was seen that food production systems can be described in terms of production lead time, production processes and technology, and supply uncertainty – and each of these aspects is described in more detail below.

Production or MTO lead times vary, typically being short for less complex products which require simple packing and labelling (e.g. apples distributed in bulk) and longer for products requiring processing and maturation (e.g. cheese matured for 15 months). Generally, production lead and throughput times are long (van der Vorst et al., 2005, Verdouw and Wolfert, 2010). Postponement tends to be applied less frequently in food supply chains than in other sectors (van Hoek, 1999), and the main strategy is to make, pack and label products to stock, with the main variant explosion taking place in the assembly/packing/labelling stage (van Donk, 2000).

Food production is typically highly capital intensive, operating with expensive capacity that have clear similarities with process industries (Crama et al., 2001, Entrup, 2005). Production rates are mainly determined by capacity (van Donk, 2000), with large batch sizes (Ketzenberg and Ferguson, 2008) and mainly integrated and continuous production processes (van Hoek, 1999) and a flow shop oriented design (van Donk, 2001). Production equipment is typically single-purpose, adapted to low product variety (van Donk, 2001, van der Vorst et al., 2005). The processing flexibility tend to be high with regards to product type and low with regards to volume, while packing flexibility is typically low in product type and high in volume (van Donk et al., 2008).

Machinery is typically capital-intensive and specialised, with long setup times and high set-up costs (van Donk, 2000, Alfnes and Bolseth, 2001, van der Vorst et al., 2005, van Donk et al., 2008). Setup times tend to be sequence-dependent (van Donk, 2000, Alfnes and Bolseth, 2001, van der Vorst et al., 2005), with product-dependent cleaning and processing times (van Donk, 2000). Generally, food producers apply a cyclic production policy to reduce the number of changeovers (Soman et al., 2004).

The biological nature of food products and the complexity of the production processes mean that process yield is variable both in quantity and quality (van Donk, 2000, van der Vorst et al., 2005, van Donk et al., 2008).

Food producers typically experience supply uncertainty caused by seasonality (Verdouw and Wolfert, 2010), demand amplification (Taylor and Fearne, 2006), and economy of scale thinking in production and inventory policies (Taylor and Fearne, 2006). The experienced bullwhip effect caused by supply uncertainty is often demonstrated in food supply chains, e.g. in the famous Barilla SpA case (see e.g. Simchi-Levi et al., 2008). The volume, quality and price of the supply of raw materials tends to be variable due to the unstable yield of farmers (van Donk, 2001). Delivery reliability tends to be high in the food processing industry (van Donk, 2000), and in Norway, the agricultural policy determines the amount and timing of incoming raw materials for certain key inputs to food processors (e.g. milk, grain and meat) (NILF, 2010).

Summary of food supply chain characteristics
Based on the descriptions above, Table 4-2 summarises the key characteristics of the products, markets and production systems involved in food supply chains.

Table 4-2: Summary of key food supply chain characteristics

Aspect	*Description*
Product characteristics	
Perishability and shelf life	High perishability, with shelf life constraints for raw materials, intermediates and finished products.
Complexity	Varied, with mainly divergent product structure and increasing variety in products, packaging sizes and recipes
Variety	High and increasing, particularly for promotions. High percentage of slow-moving items.
PLC, innovation and NPD	Decreasing PLC, with high failure rates for new products.
Volume and volume variability	High volume, with higher volume variability in downstream processes.
Market characteristics	
Delivery lead time and lead time variability	Varies by product, but generally retailers 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 and stock-out rates	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 characteristics	
Production or make-to-order lead time	Product dependent, but generally long lead times and low degree of postponement.
Plant, processes and technology	Adapted to low variety and large 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.

4.3 Food supply chain requirements

Table 4-2 summarised the typical key characteristics of food supply chains. A relevant follow-up question is then how these characteristics affect food producers since such insights can be used to identify the potential for improving PPC. In this section, each of the key characteristic is analysed with regards to the requirements it exerts upon food producers. In sum, this will determine the requirements for PPC in terms of how the PPC system should enable the production system to achieve the level or responsiveness required by the external factors. Combining the definitions of responsiveness and efficiency from sub-section 3.1.4 with the findings from the study of Kittipanya-ngam (2010), the requirements for efficiency and responsiveness can be operationalised into the following:

- Responsiveness in terms of customer responsiveness, i.e. a propensity to react on market knowledge to rapidly address modifications in customers' expectations, expressed as:
  - Replenishment speed; the ability to quickly respond to customer orders within the customer order lead time allowance, i.e. the lead time between when customers place an order and when they receive it
  - Supply chain speed; the ability to respond to customer orders within supply chain lead time allowance, i.e. limitations related to product perishability in addition to the replenishment speed required by customers
  - Volume flexibility; the ability to quickly respond to changes in the required level of aggregated output
- Efficiency, expressed as the fundamental requirement in business competition, where a company utilises economies of scale to reduce cost per unit

Below, the impact of the characteristics from section 4.2 on the requirements for responsiveness and efficiency of food producers is discussed.

4.3.1 Product characteristics and requirements

One of the most important characteristics of food supply chains is the perishability and limited shelf life of products, raw materials and intermediates. The perishability reduces lead time allowance and the ability to keep inventories, thus reducing food producer's ability to exploit economies of scale through volume. Simultaneously, the perishability increases the need for replenishment speed since wholesalers and retailers tend to order frequently and expect short replenishment lead times, as well as the need for supply chain speed in order for products to have a maximum of shelf life remaining when reaching the final customer. In a postponement situation, volume flexibility is important to increase product shelf life.

The high and increasing product complexity and variety result in an increasing number of recipes, product and packaging variants, etc. that the production system must be able to deal with efficiently. The increasing variety reduces batch sizes and leads to more frequent changeovers, which again reduces the producers' ability to exploit economies of scale, and increases the need for volume flexibility in order to deliver the required product variants within the required lead time.

The decreasing PLC and high pace of NPD reduces producers' ability to exploit economies of scale since it continuously introduces new products which must be produced, with more disaggregated demand and in smaller volumes per product variant. This also requires replenishment speed to ensure customers receive orders promptly, and supply chain speed to ensure high product quality when the product reaches the consumer. In addition, volume flexibility is important to ensure high product availability, particularly during the introduction and growth phases of the PLC.

In terms of product volume and variability, large batch sizes and low variety in processing allows for some exploitation of economies of scale in this step. However, the smaller batch sizes and higher variety in the packing stage limit this ability. The volume variability requires high volume flexibility in order to deliver the required variants within the lead time.

4.3.2 Market characteristics and requirements

Customer demands for short delivery lead times and frequent deliveries, combined with the limited ability keep inventories, reduce producers' ability to exploit economies of scale since products must be produced in smaller batch sizes. These characteristics simultaneously increase the need for replenishment speed and volume flexibility to fulfil customer requirements within a shorter time window.

The increasing demand uncertainty, particularly related to promotional activities, reduces producers' ability to exploit economies of scale since producing in high volumes increases risk of obsolescence for products in inventory. Thus, there is a great need for replenishment speed to be able to react quickly to changes in demand, accompanied by a need for volume flexibility to meet customer requirements within the available time window.

The perishability aspect limits the possibility to keep inventory, which reduces ability to exploit economies of scale through volume. The increasing product variety can also lead to capacity problems in finished goods storage due to the increasing number of storage locations, again reducing the ability to exploit economies of scale. On the other hand, periodic ordering and the fairly low inventory carrying cost can lead to some scale benefits as customers may order larger quantities to take advantage of volume discounts. The high stock-out rates, combined with demanding customers, lead to a need for replenishment speed and volume flexibility to meet customer requirements in terms of variants and lead time.

4.3.3 Production system characteristic and requirements

The fairly long production lead times and low degree of postponement favour exploitation of economies of scale since products are produced in large volumes, and have negative impacts on replenishment and supply chain speed and volume flexibility.

The current production technology, equipment and processes are designed for high volumes and push the production system towards efficiency and exploitation of scale benefits to increase capacity and resource utilisation. These factors have negative impacts on supply chain and replenishment speed and volume flexibility since they favour production in batch sizes that may exceed customer demand.

Supply uncertainty caused by seasonality and variability in quality and price of raw materials, etc. increases the need for volume flexibility to be able to deal quickly and efficiently with potential shortages. It can further have a negative impact on the ability to exploit economies of scale since the amount of available inputs may not be enough to be able to produce in large batch sizes.

4.3.4 Summary of characteristics and requirements

Table 4-3 summarises the impact the product, market and production system characteristics have on the supply chain requirements facing food producers in terms of efficiency and responsiveness. The directional impact of each characteristic is indicated in columns 2-5. Where a characteristic mainly increases the need for or has a positive impact on the ability to exploit a particular supply chain requirement, this is indicated with a '+'. Where the characteristic mainly reduces the need for or has a negative impact on the ability to exploit a certain supply chain requirement, this is marked by '–'. Where the effect is thought to be neutral, the box is left open.

Table 4-3: Summary of characteristics' impact on supply chain requirements

Characteristic	*Efficiency*	*Responsiveness*		
		Replenishment speed	*Supply chain speed*	*Volume flexibility*
Product characteristics				
Perishability	–	+	+	+
Complexity	–			+
Variety	–			+
Product life cycle (PLC)	–	+	+	+
Volume and volume variability	+/–			+
Market characteristics				
Delivery lead time	–	+		+
Demand uncertainty	–	+		+
Inventory management	–/+	+		+
Production system characteristics				
Production lead time	+	–	–	–
Plant, processes and technology	+	–	–	–
Supply uncertainty	–			+

Table 4-3 shows that each of the characteristics either mainly drives the supply chain towards efficiency or responsiveness. For instance we see that the perishability aspect mostly increases the need for responsiveness and has a negative impact on efficiency, while production lead time increases the ability to exploit economies of scale but has a negative impact on responsiveness.

The table also shows that the individual aspects within each group of characteristics (product, market and production system) tend to exert the same pressures on the supply chain, e.g. all three aspects of market characteristics have a mainly negative impact on efficiency and increase the need for responsiveness.

When looking at each supply chain requirement across the characteristics, it can be seen that in terms of responsiveness, the product and market characteristics in general increase the need for responsiveness, while the production system characteristics tend to reduce supply chain responsiveness. In terms of efficiency, the findings indicate that the product and market characteristics reduce the supply chain's ability to exploit economies of scale in production and distribution, while the production system, through its design for efficiency, favours economies of scale and therefore has limited ability to adapt to changes in the marketplace. Thus, the findings indicate that there is a lack of strategic fit between the requirements exerted by the market characteristics and the ability of the production system to meet these requirements – and that this is further limited by the product characteristics which exert the same requirements as the market characteristics. From this, it is reasonable to conclude that there is a ***lack of strategic fit*** in that the production system is designed for economies of scale (i.e. efficiency) and that this does not match the capabilities required by the product and market characteristics (i.e. responsiveness). This finding represents critical limitations for food producers' PPC system.

4.4 Conclusions on characteristics and requirements

This chapter demonstrated that there are a number of characteristics of food supply chains which impact on the requirements facing food producers and the way they plan and control their production and inventory. A particular challenging aspect is the product perishability which limits producers' ability to keep inventories and simultaneously requires high speed in production and inventory processes. In addition, the high requirements from powerful wholesale and retail customers, combined with producers' wish to provide customers and consumers with more variants of high quality and fresh products with long remaining shelf life, results in great pressure for responsiveness in terms of replenishment and supply chain speed, as well as volume flexibility.

Simultaneously, we see that that the production system's design for efficiency and high volume and low variety production is limiting producer's ability to respond quickly and efficiently to changes in the marketplace. 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. Thus, we can conclude that there is 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.

In addition, most producers are using a limited degree of postponement and MTO to plan and control their products, even though they may be facing a variety of different external requirements. The findings therefore indicate that a differentiation approach to PPC may be appropriate to better meet the complexity in external requirements and enable higher efficiency in internal processes. Thus, in the next chapter, a concept and framework for differentiated PPC in food production is developed.

5 CONCEPT AND FRAMEWORK FOR PPC IN FOOD PRODUCTION

In the theoretical background in chapter 3, it was found that a key decision in operations strategy and the design of a company's PPC system is the determination of the CODP. This point indicates where stocks are held in the production process flow and how processes up and downstream of the point are planned and controlled. Further, it was found that existing supply chain configuration frameworks are not particularly well suited for identifying the appropriate approaches for planning and control of production and inventory in food production. Simultaneously, the trend towards differentiation of market interaction strategies provides an opportunity to develop a differentiation approach to food PPC.

This chapter uses key concepts and developments from the theoretical background to develop a concept and a framework for differentiated PPC particularly suited for the food sector. In section 5.1, the key theoretical elements that form the principles of the concept are outlined. Section 5.2 applies the principles to the six food supply chain configurations identified in subsection 4.1.4 and summarises these in a framework which can be used to determine an appropriate mix of PPC approaches in food production.

5.1 Concept for differentiated PPC

The first inspiration for a differentiation approach to PPC is the six food supply chain configurations identified by Kittipanya-ngam (2010). The configurations provide an understanding of product and market characteristics and the requirements these in turn exert on food producers. These insights can be used to identify the PPC approaches that are suitable in each configuration – thus making it possible to differentiate PPC according to the requirements in each configuration. In addition to identifying the requirements put upon food producers, the Kittipanya-ngam framework can also be used to identify the product and market characteristics which can be exploited to provide flexibility to the production system.

The second inspiration for the concept is the fact that customer demand can be divided into a predictable part and a less predictable part, which means that these two types can be managed differently. This builds on the ideas of separating 'base' from 'surge' demand – where the base level of predictable demand can be planned for, while the demand above the base level, i.e. the surge, is managed through the use of postponement techniques (see e.g. Christopher and Holweg, 2011, Christopher and Towill, 2002, Christopher et al., 2006). These techniques can be related to the CODP concept and the principle of holding input materials as strategic inventory and initiating production activities based on actual customer orders. In a PPC perspective, CODPs here correspond to the approaches used to guide PPC, e.g. MTO and MTS.

The third element of the concept is the use of different techniques for buffering to provide flexibility and protect the production system against demand uncertainty. These slack resources can come in the form of inventory, capacity and time.

In the following sub-sections, each of these topics is further discussed and elaborated in relation to the food context and the scope of the study.

5.1.1 Food supply chain configurations

Given that the configuration framework of Kittipanya-ngam (2010) captures the most important characteristics of food supply chains, the framework can be used as a basis for understanding the challenges and external requirements facing food producers – and subsequently to identify the appropriate PPC approaches for each configuration.

The application of the framework requires determination of the market and product related aspects;

- Degree of product perishability
- Customer order lead time allowance
- Demand uncertainty

Product perishability is easily determined since food products have standard shelf lives. For producers who sell their products to wholesalers, customer order lead time allowances are also fairly easy to determine since these are either fixed or negotiable and thus allowing some flexibility in terms of the determination of delivery dates. However, for the purposes of PPC, the demand uncertainty variable must be operationalised so that it can be quantitatively and/or qualitatively determined.

Kittipanya-ngam (2010) defined demand uncertainty as a combination of product variety, frequency and degree of NPD, and the product's stage in the PLC. As mentioned in sub-section 3.4.2, a key PPC decision is the determination of whether a product should be MTO or MTS. This means that assessment of demand uncertainty should be done on a product level – which means that for the purposes of determining a product's PPC approach, the company's total product variety or the frequency or degree of its NPD is less important. Further, considering a product's stage in the PLC to estimate its demand uncertainty is too general to provide any real benefit to PPC decision making since the time horizon of PPC is much shorter. Instead, the predictability of a product's demand is more relevant since this will have a direct impact on the company's ability to forecast demand and buffer against uncertainty.

Following from the above, for the purposes of this study, the y axis in Kittipanya-ngam's configuration framework is changed to demand predictability with a scale from low to high. Consequently, the configurations with high demand uncertainty in the original framework (A, B and C) are moved to the bottom half of the graph, while the configurations with low demand uncertainty (D, E and F) are moved to the top half, resulting in the adjusted configuration framework illustrated in Figure 5-1.
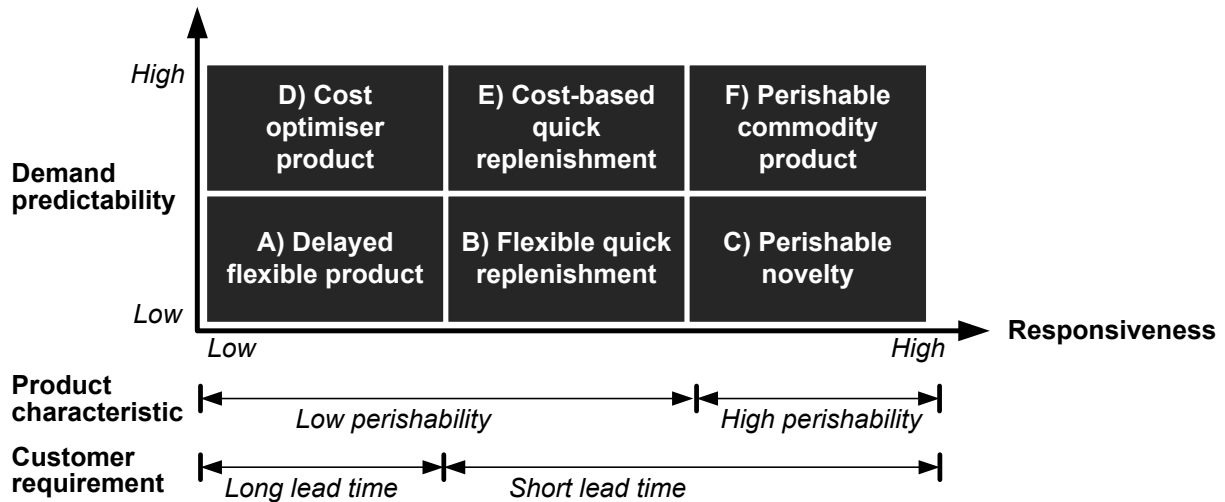
Figure 5-1: Basis for differentiation concept; food supply chain configurations (adapted from Kittipanya-ngam, 2010, p. 110)

As mentioned, the product and market characteristics of each configuration exerts different supply chain requirements upon food producers and these were in sub-section 4.1.4 operationalised as:

- Customer responsiveness – expressed as replenishment speed, supply chain speed and volume flexibility
- Efficiency – expressed as the utilisation of economies of scale to reduce cost per unit

Once the requirements of each configuration are fully understood, the next step for a company is to use these insights to identify the most appropriate PPC approaches for each configuration. The most relevant approaches to consider for this purpose are explored in the next sub-section.

5.1.2 PPC approaches in the food sector

In literature, the determination of PPC approaches, e.g. 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 used for high-volume orders (Soman et al., 2004). Thus, volume may not be the best determinant for PPC approaches, particularly since variability has been found to be less important than forecast accuracy and demand predictability in the MTO vs. MTS decision in food production (van Kampen and van Donk, 2011).

Further, although ABC classification tools are easy to use, the current focus on volume means that only demand characteristics are considered and production and market characteristics like lead times in production and delivery are ignored, as well as product and processing characteristics like perishability, variety, and set-up times. Thus, the existing tools fail to capture several of the configuration dimensions in Figure 5-1. 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 to reduce the dependence on forecasts by basing less of the pro-

duction on speculation and increasing forecast accuracy by aggregating the number of articles that are forecasted in the upstream processes (Slack et al., 2007).

As mentioned, neither a pure MTO nor a pure MTS approach is practical in food processing and a combined MTO-MTS approach is therefore quite common. In addition, an ATO approach in the form of pack-to-order (PTO) can 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 5-2 illustrates the three most relevant PPC approaches in the food sector.
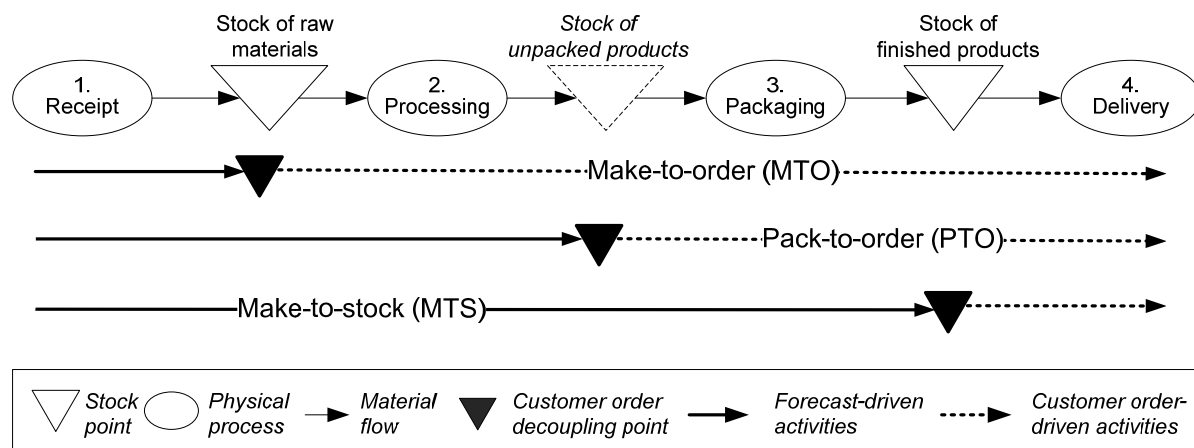
Figure 5-2: Most relevant PPC approaches in food supply chains

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. However, which PPC approach to choose at different levels of the food sector's – sometimes conflicting – characteristics is unclear (van Kampen and van Donk, 2011). Before this is explored further, the next sub-section discusses the buffering techniques currently used in food production.

5.1.3 Buffering against uncertainty in food production

Different techniques exist to address uncertainty in different contexts. In general, supply chains can buffer against uncertainty using inventory, capacity and time. Relating this back to Fisher (1997), he argued that the primary focus for an efficiency strategy should be to aim for scale benefits, high equipment utilisation rates, and a minimum of inventory because the high demand predictability of functional products means that the need to buffer against demand uncertainty is minimal. On the other hand, for innovative products a responsiveness strategy should be used to buffer against unpredictable demand through the deployment of buffer capacity and inventory.

An efficiency strategy in food production seems appropriate when demand predictability is high. An MTS approach to PPC can work well in this environment since forecast accuracy is generally high. MTS environments generally use inventory and capacity as buffers – where

safety stock is used to ensure availability when demand is greater than expected, while safety capacity allows for stock to be duly replenished (Hedenstierna and Ng, 2011). Thus, planners can focus on maximising efficiency through long production runs and a minimum of changeovers which will increase equipment utilisation rates and reduce the cost per unit produced. Since the high demand predictability reduces the need for safety stock, inventory can be kept fairly low. This strategy is however difficult to use for high perishability products since these cannot stay in inventory for very long. This limits the possibility to keep large buffer stocks and increases frequency/reduces batch sizes in production, leading to more frequent changeovers and a higher cost per unit.

Fisher's responsiveness strategy is associated with products with low demand predictability and Fisher recommends buffering against this uncertainty through excess capacity and inventory to enable the company to react quickly to changes in demand. Buffering inventory can work well when perishability is low since products can be kept in inventory for a certain period of time. Also, buffer capacity works well in situations where customers allow lead times that are longer than the production lead time. However, the capacity and inventory buffering strategies are more difficult when perishability and demand uncertainty are high and customer order lead times are short.

What is not considered in Fisher's framework is the concept of buffering time through an MTO approach. In MTO environments, customer orders are not delivered instantly but stored in the order book before they are released as production orders, thus spreading the demand variability out over time (Hedenstierna and Ng, 2011). In this way, production is postponed until demand is certain and thus an MTO approach to PPC appears appropriate for a responsiveness strategy.

The predominant PPC approach in the food sector is as mentioned MTS. This means that a lot of efforts are put into forecasting and inventory management techniques to buffer against demand uncertainty. Different inventory buffering techniques can be relevant. Hedge inventories can for instance be used to protect against speculation from suppliers, anticipatory inventory to protect against seasonal variations, and general buffer inventories to protect against uncertainty in demand. However, there are a number of aspects that reduce the effectiveness and efficiency of inventory management techniques for buffering against demand uncertainty in a food production context.

Firstly, food products tend to have irregular demand characteristics. Demand predictability is influenced by a number of factors, including degree of seasonality and weather dependency, frequency of campaigns and other market activities, a product's stage in the PLC, how 'new' a product is at launch (e.g. extension of existing product line or an innovation), and a product's classification in wholesalers' and retailers' assortment listings (optional or compulsory assortment or no listing at all). The frequent lack of structural demand patterns makes it difficult to use inventory management techniques to identify what type of inventory and what levels to keep in addition to regular inventory.

Secondly, the perishability aspect of food products limits producers' ability to keep inventory. Keeping too high levels of inventory can lead to large amounts of scrapping for expired products and price reductions and buy-back policies for products with short remaining shelf life in cases where demand is lower than forecasted.

The results of food producers' traditional focus on MTS and inventory management includes reduced product quality and high levels of waste for products with lower than forecasted demand (Gustavsson et al., 2011), and problems with service levels and stock-outs for products with higher than forecasted demand (Taylor and Fearne, 2009). In addition, wholesale and retail customers usually demand very high service levels (see sub-section 6.1.1.2) and producers do their utmost to avoid out of stock situations. This leads producers to use overtime and keep extra high levels of inventory, thus reducing PPC efficiency even further.

Yet another planning and control issue is that the traditional focus on inventory management does not allow the production system to exploit favourable product and market characteristics to protect against demand uncertainty and enable flexibility, i.e. orders with long customer order lead time allowances and products with low perishability. Although MTO is on occasion used for such orders, the exploitation of these favourable characteristics is not systematically used in the PPC system. Also, the production of such MTO items is often incorporated into the MTS schedule based on the latest possible start date to meet agreed due dates. In this way, the production system is not able to exploit the potential flexibility of MTO orders to maximise overall capacity and resource utilisation through level production, large batches, and a minimum of changeovers.

The aspects described above illustrate that the food sector's traditional focus on inventory planning and control appears to be inefficient. Although food producers may be effective in meeting customer demand from finished goods inventory, this seems to be achieved at the expense of efficiency in terms of inventory carrying costs, scrapping, re-planning, use of overtime, etc. Thus, there appears to be a need to investigate how different buffering techniques can be used in different food production contexts to meet the external requirements in a more resource-efficient manner.

5.1.4 Concept for differentiated PPC

Based on the discussions in the previous sub-sections, 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 food supply chain configurations
3. Slack resources in the form of inventory, capacity and time should be differentiated to buffer against demand uncertainty

The concept is illustrated in Figure 5-3 and its application to the different food supply chain configurations explored in the next section.
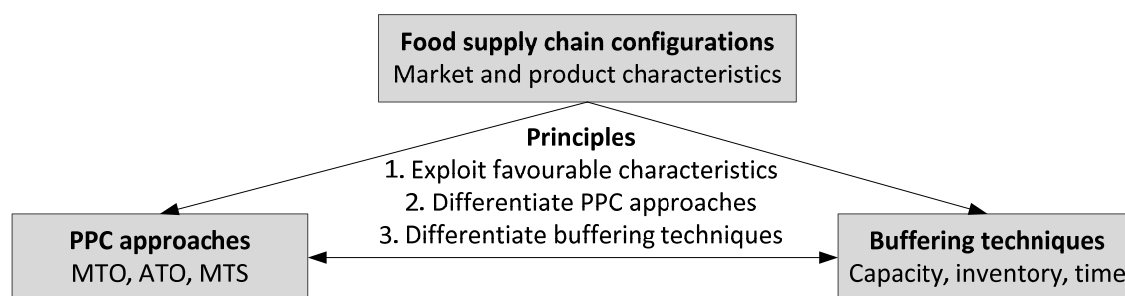
Figure 5-3: Concept for differentiated PPC in food production

5.2 Framework for differentiated PPC

The concept in section 5.1 provides a general frame for how PPC can be differentiated. This section firstly applies the principles, framework, PPC approaches and buffering techniques from the previous sub-sections to each of the food supply chain configurations. These are subsequently joined in sub-section 5.2.2 to form a framework for differentiated PPC.

5.2.1 Planning and control of individual configurations

For each configuration, the key characteristics and associated primary requirements facing food producers are outlined, and the most appropriate PPC approaches and buffering techniques identified.

Configuration A; delayed flexible product supply chain
This configuration is characterised by low product perishability, long customer order lead time allowance, and low demand predictability.

Due to the low demand predictability, the primary requirement in this configuration is volume flexibility to enable production to handle the volumes requested from customers. Here, the low perishability and long customer order lead time allowance can be exploited to provide flexibility and increase responsiveness.

In this configuration, the appropriate PPC approach is MTO since there is high uncertainty related to both the volume and the timing of incoming orders for the product. The postponement of production activities will reduce the risk of obsolescence since it keeps raw materials in a customer-neutral state, allowing them to be used for several customer orders. Simultaneously, the start of the consumption of the finished product's shelf life is postponed. In addition, the MTO approach eliminates the potential waste of other production resources consumed to produce and handle products that are not sold.

In order to protect against the high demand uncertainty, inputs should be buffered so that production does not have to wait for raw materials or other production inputs to be ordered and delivered before the customer order can be put into production. Since the product has low perishability and the customer order lead time allowance is long, the product can be used to level production.

- PPC approach: MTO
- Buffering technique: Production inputs and time

Configuration B; flexible quick replenishment supply chain
This configuration is characterised by low product perishability, short customer order lead time allowance, and low demand predictability.

Again, due to the low demand predictability, the primary requirement is volume flexibility to enable production to handle the volumes requested from customers. In addition, replenishment speed is essential to meet customers' short lead time allowance. The low product perishability can be exploited to provide flexibility and increase responsiveness.

In this configuration, the appropriate PPC approach is again MTO since there is high uncertainty related to both the volume and the timing of incoming orders for the product. The post-

ponement of production activities will reduce the risk of obsolescence since it keeps raw materials in a customer-neutral state, allowing them to be used for several customer orders. MTO will also postpone the start of the consumption of the finished product's shelf life. In addition, the MTO approach eliminates the potential waste of other production resources consumed to produce and handle products for which actual demand turns out to be lower than forecasted.

In this configuration, production lead time is a deciding factor. If the production lead time is shorter than the customer order lead time allowance, an MTO approach is possible. In this case, capacity and production inputs should be buffered so that production can start as soon as the order arrives, and the production processes should focus on reducing changeover times to increase replenishment speed.

- PPC approach: MTO
- Buffering technique: Capacity, production inputs and time

If production lead time is longer than customers' delivery lead time expectations, the product must be MTS and supplied from finished goods inventory. The risk associated with MTS is somewhat mitigated by the low perishability which allows the products to be stored for a certain period of time. In this case, finished goods should be used to buffer against the low demand predictability, and focus should be on levelling production since the product can be kept in inventory for a certain period of time.

Alternatively, a PTO approach may be appropriate if production processes can be decoupled and the packing lead time is shorter than customer order lead time allowance. In this case, capacity and intermediate products should be used to buffer against the low demand predictability, and focus should be on levelling production for the forecast-driven processes.

Configuration C; perishable novelty supply chains
This configuration is characterised by high product perishability, short customer order lead time allowance, and low demand predictability.

This configuration is the most difficult to handle since all characteristics are at their least favourable setting and there are no characteristics that can be exploited to provide responsiveness or efficiency. Thus, the producer is facing requirements for volume flexibility following from the low demand predictability, replenishment speed to meet the short customer order lead time expectations, and supply chain speed to deal with the high product perishability.

Due to the low demand predictability and high product perishability, MTO would be the most appropriate production strategy. The postponement of production activities will reduce the risk of obsolescence since it keeps raw materials in a customer-neutral state, allowing them to be used for several customer orders. MTO will also postpone the start of the consumption of the finished product's shelf life. In addition, an MTO approach will eliminate the potential waste of other production resources consumed to produce and handle products for which actual demand turns out to be lower than forecasted.

Since the customer order lead time allowance is short, the production lead time is again a deciding factor with regards to feasible approaches. If the production lead time is less than the customer order lead time expectation, an MTO approach is possible. In this case, capacity and production inputs should be buffered so that production can start as soon as the order arrives, and the production processes should focus on short changeover times to increase replenish-

ment speed. In addition, it may be advantageous to buffer a certain amount of finished goods to meet the short delivery lead time expectations.

- PPC approach: MTO
- Buffering technique: Capacity, time and production inputs, in addition to a limited amount of finished goods

If production lead time is longer than customers' delivery lead time expectation, the product must be MTS and supplied from finished goods inventory. In an MTS situation, finished goods should be used to buffer against the low demand predictability. This is however a risky strategy due to the high perishability, and efforts should be made to keep inventory levels as low as possible in order to reduce the risk of obsolescence, for instance by investing in advanced forecasting software or investigating opportunities for getting access to real-time POS data from customers to increase demand predictability.

Alternatively, a PTO approach may be appropriate if production processes can be decoupled and the packing lead time is shorter than customer order lead time allowance. In this case, capacity and intermediate products should be used to buffer against the low demand predictability, and focus should be on levelling production for the forecast driven activities.

Configuration D; cost optimiser product supply chain
This configuration is characterised by low product perishability, long customer order lead time allowance, and high demand predictability.

This is one of the easiest configurations to handle since all characteristics are at their most favourable setting. In this situation, all the favourable characteristics can be exploited to provide maximum cost efficiency to the production system and an MTS approach is the most appropriate. There is limited need to buffer against demand uncertainty and the timing of production can be determined based on available capacity and resources.

- PPC approach: MTS
- Buffering technique: Limited buffering necessary

Configuration E; cost-based quick replenishment supply chain
This configuration is characterised by low product perishability, short customer order lead time allowance, and high demand predictability.

The primary requirement in this configuration is replenishment speed due to the short delivery lead time allowance from customers. The producer can exploit the low perishability and high demand predictability to increase cost efficiency and enable volume flexibility.

In this configuration, an MTS approach is the most appropriate as it allows for full focus on economies of scale through maximising capacity and resource utilisation. The short customer order lead time allowance means that finished goods should be buffered in order to maximise replenishment speed.

- PPC approach: MTS
- Buffering technique: Finished goods

Configuration F; perishable commodity product supply chain
This configuration is characterised by high product perishability, short customer order lead time allowance, and high demand predictability.

The primary requirements in this configuration are supply chain speed to deal with the high product perishability and replenishment speed to meet the short customer order lead time expectations. The high demand predictability can be exploited to enable cost efficiency.

Again, the production lead time is an important factor since customer order lead time is short. If production lead time is longer than customer order lead time expectations, products must be delivered from stock using an MTS approach, allowing for full focus on economies of scale through maximising capacity and resource utilisation. However, due to the high product perishability, it is important to ensure effective rolling of inventory for instance through the use of a first-in first-out (FIFO) inventory policy to reduce the risk of product expiry.

- PPC approach: MTS
- Buffering technique: Finished goods, with focus on FIFO

If on the other hand production lead time is shorter than customer order lead time allowance, an MTO or PTO approach might be appropriate to reduce the risk of obsolescence – particularly if the perishability of raw materials or intermediates is lower than for finished products.

5.2.2 Framework for differentiated PPC

In Figure 5-4, the six configurations, their PPC approaches and buffering techniques from the previous sub-section are illustrated.
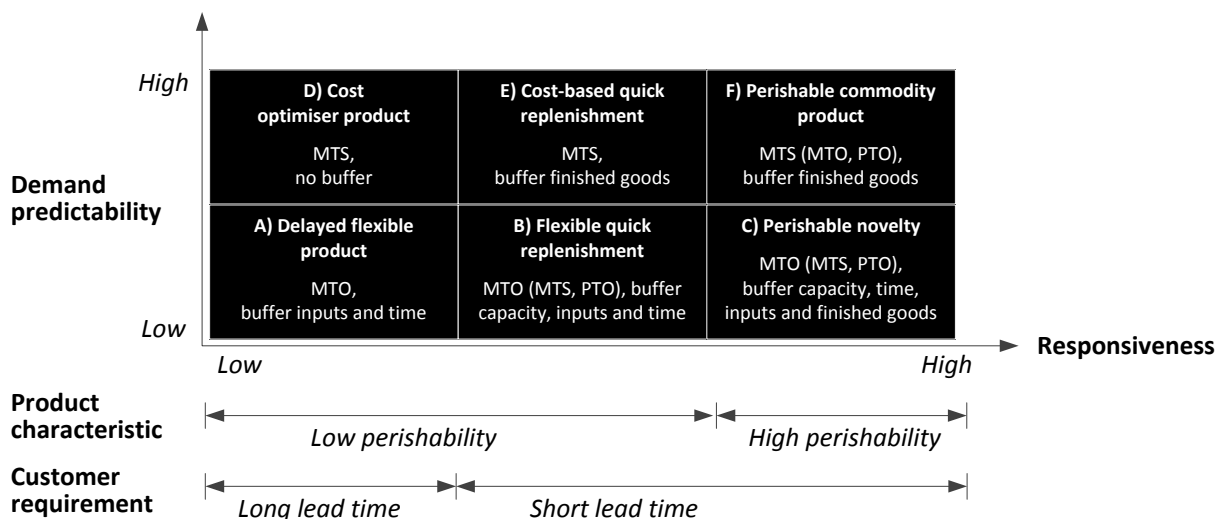
Figure 5-4: Framework for differentiated PPC in food production (based on Kittipanya-ngam, 2010)

In tabular form, the framework is illustrated in Table 5-1, linking each configuration and its supply chain characteristics with the primary supply chain requirements and the most appropriate PPC approaches. COLT here stands for customer order lead time allowance, and '*' indicates the characteristics which determine the most important supply chain requirements in each configuration.

Table 5-1: PPC approaches per configuration

Configuration	Characteristics			Supply chain requirement	PPC approach
	Perish.	*COLT*	*Demand predictability*		
A Delayed flexible product	*Low*	*Long*	*Low**	Volume flexibility	MTO
B Flexible quick replenishment	*Low*	*Short**	*Low**	Volume flexibility, replenishment speed	MTO (MTS, PTO)
C Perishable novelty	*High**	*Short**	*Low**	Volume flexibility, replenishment speed, supply chain speed	MTO (MTS, PTO)
D Cost optimiser product	*Low*	*Long*	*High*	Cost efficiency	MTS
E Cost-based quick replenishment	*Low*	*Short**	*High*	Replenishment speed, cost efficiency, volume flexibility	MTS
F Perishable commodity product	*High**	*Short**	*High*	Supply chain speed, replenishment speed, cost efficiency	MTS (MTO, PTO)

Further, Table 5-2 outlines the buffering techniques which are most appropriate for each configuration.

Table 5-2: Buffering technique per configuration

Configuration	Buffer inputs	Buffer capacity	Buffer finished goods	Buffer time
A Delayed flexible product	X			X
B Flexible quick replenishment	X	X		X
C Perishable novelty	X	X	X	X
D Cost optimiser product				
E Cost-based quick replenishment			X	
F Perishable commodity product			X	

Once the PPC approach for each SKU has been determined, the next step for a company is to systematically classify or group the products with similar properties and plan and control these together.

An implication of the framework is that an individual SKU can be associated with two different PPC approaches under different circumstances. To use the example of TINE Jarlsberg Cheese: in an ordinary situation, this product is sold to wholesalers with an order lead time of one day and fairly predictable demand. In this situation, the product belongs to configuration E and should be MTS. However, sales to another customer where the product is subjected to a campaign or other market activities would lead to low demand predictability, thus placing the product in configuration B, where an MTO approach is more appropriate, see Figure 5-5.
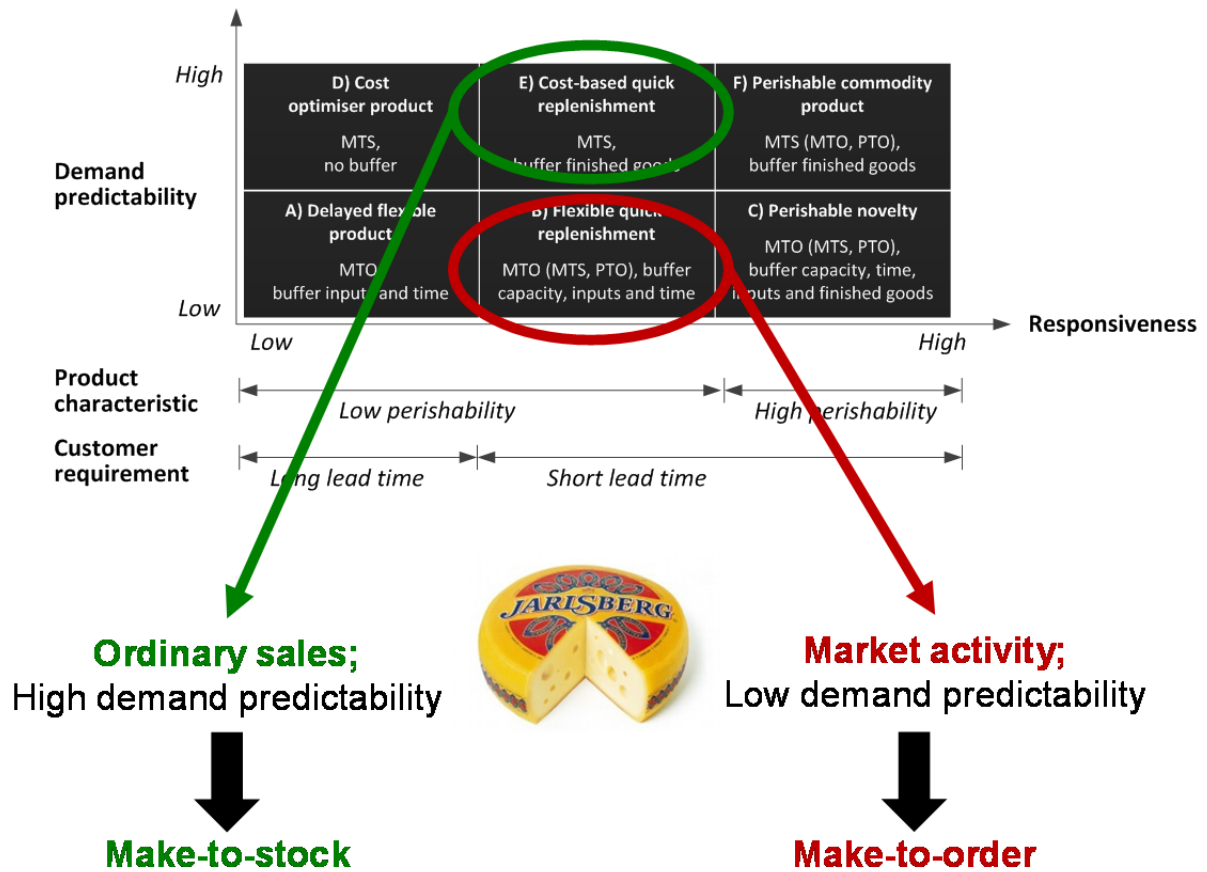
Figure 5-5: One product, two PPC approaches

This example illustrates how the same product, produced in the same facility, on the same production equipment, can have a total demand consisting of a part which is predictable and therefore should be MTS, and another part which is difficult to predict and which should then be MTO. The tactical and operational implications of this type of hybrid situation will be further discussed in section 7.4.

6 EMPIRICAL CASE; TINE SA

The main empirical part of this study is focused on the dairy cooperative TINE[9] SA, Norway's largest producer, distributor and exporter of dairy products. TINE SA is also one of Norway's largest production networks and this network provides the broad frame for the study, while the main focus in on the facility TINE Heimdal. The case study involved both analysing how PPC is performed in the company in order to identify challenges and improvement potentials, and testing the concept and framework from chapter 5 through the design of new solutions for PPC.

Figure 6-1 shows how this chapter is structured.
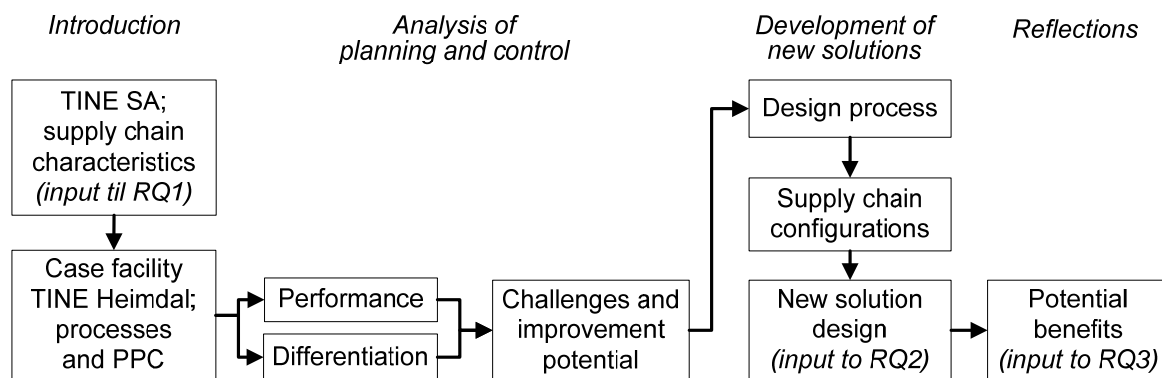
Figure 6-1: Structure of chapter 6

Section 6.1 introduces the TINE SA Group and its supply chain characteristics, providing input to RQ1. In addition, the case facility TINE Heimdal is described in terms of physical processes and how PPC is performed on the local and central level in order to provide a general background to the subsequent analyses and solution development.

In section 6.2, the current PPC at TINE Heimdal is analysed with regards to both the performance of the PPC system and the current degree of differentiation in the TINE production network. The findings are summarised in sub-section 6.2.3 where key challenges and improvement potentials are outlined.

In section 6.3, new solutions for PPC at TINE Heimdal are developed using the concept and framework from chapter 5. The section describes the design process, how supply chain configurations were identified, and the details of the proposed solutions. This section provides input to RQ2 by illustrating how the concept and framework can be operationalised and applied to a real case.

The chapter concludes with sub-section 6.3.3 which reflects on the potential benefits of the proposed solutions, thus providing insights to answer RQ3.

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[9] Pronounced teeneh

6.1 Introduction to TINE

TINE SA is Norway's largest producer, distributor and exporter of dairy products. The TINE Group is organised as a cooperative owned by more than 15.000 Norwegian dairy farmers. Each member is a shareholder in the cooperative to which they deliver cow's and goat's milk which is turned into TINE products.

TINE's strategy is to be a leading supplier of food and beverage brands, with a particular focus on dairy products. In 2011, the TINE Group also consists of several wholly and partially owned subsidiaries, including Diplom-Is (ice cream), Salmon Brands (salmon) and FellesJuice (fruit drinks) in Norway, Wernersson Ost (cheese) in Sweden, Norseland Inc. in the US (cheese), and Norseland Ltd. (cheese) in the UK.

The dairy cooperative is Norway's largest food producer, with a turnover of 19,6 billion Norwegian kroner (NOK) and over 5.500 employees in 2011 (TINE, 2012). Table 6-1 shows the key financial figures for the TINE Group for 2008-2011.

Table 6-1: Key financial figures 2008-2011, TINE Group, in Norwegian kroner (NOK)

TINE GROUP TOTAL		2011	2010	2009	2008
Revenues	NOK million	19 387	18 834	18 712	17 892
Operating profit	NOK million	1 176	1 189	911	619
Net profit margin	Operating income/result	6,1	6,3	4,9	3,5
Profit before tax	NOK million	1 095	1 085	848	513
Net profit for the year	NOK million	937	910	674	375
Assets	NOK million	12 957	11 352	9 999	9 640
Equity	Percentage	41,3	44,6	46,3	45,4
Net interest-bearing debt/ EBITDA	Percentage	1,54	0,92	0,86	1,27
Investments	NOK million	2 365	1 766	1 040	893
Working capital	NOK million	1 627	1 741	1 457	922

The TINE Group was reorganised in August 2012. Previously, the group's facilities were organised in geographical regions but after the reorganisation facilities are grouped according to facility types. Figure 6-2 shows the current organisation chart for the TINE Group, with particular focus on the Operations division and the SCM function which are the most relevant for the case study.
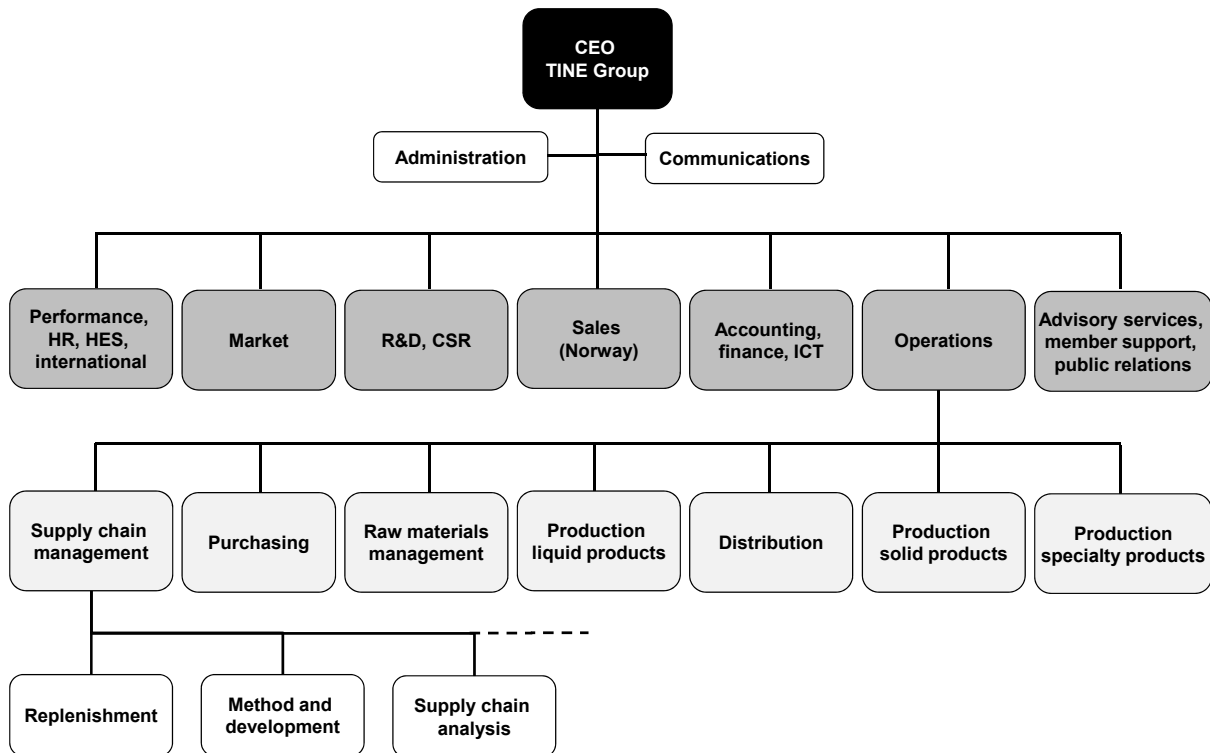
Figure 6-2: Organisation chart, TINE Group, with focus on operations

6.1.1 TINE's supply chain characteristics

This sub-section uses the framework in Table 3-1 to give an overview of the key characteristics of TINE's supply chain with regards to:

- Product characteristics
- Market characteristics
- Production system characteristics

The purpose of the sub-section is to assess the representativeness of TINE in terms of the identified lack of strategic fit between external product and market requirements and production system capabilities previously identified on the food sector level (see section 4.2).

6.1.1.1 Product characteristics

TINE's product portfolio consists of approx. 840 variants and includes milk and milk-based drinks, cheeses, butters, yoghurts, fruit drinks, desserts, and ready-made dough and batters, with a total of 1.300 SKUs. The TINE brand is one of the strongest in Norway, with an 85 % market share on milk and over 60 % on cheese. Some of the brands are illustrated in Figure 6-3.

Figure 6-3: Examples of TINE products

In 2011, 1,2 billion litres of milk were processed into 483 million litres of liquid products, 67.700 tons of cheese and 9.970 tons of butter. The distribution of sales per product category is illustrated in Figure 6-4.

- Liquid dairy products (45,8 %)
- Solid dairy products (38,7 %)
- Ice cream and desserts (6,4 %)
- Juice, fruit drinks and water (5 %)
- Convenience products (3,4 %)
- Other products (0,8 %)
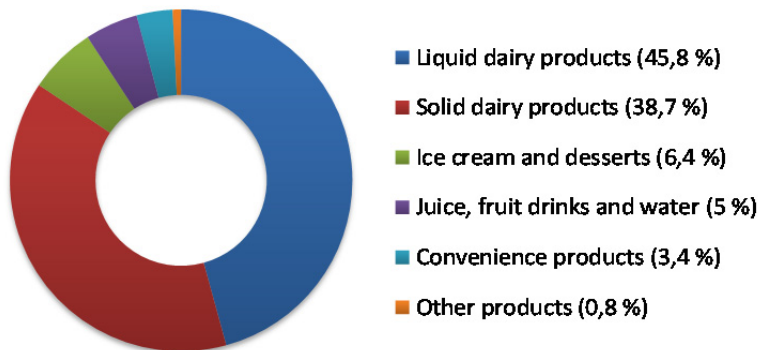
Figure 6-4: Sales per product category, 2011

Similar to the rest of the food sector, TINE is facing a situation with a slow and steady increase in the number of SKUs and a decrease in the duration of PLCs. TINE has a strong focus on product development and 50-80 new SKUs are launched each year. Products are launched during three launch periods agreed among Norwegian food producers, wholesalers and retailers; 1 February, 1 May and 1 September, and TINE defines a product as new during the first three months after launch. The failure rate for new products is high and unsuccessful products are regularly withdrawn from the market. However, the total number of TINE variants in the market has steadily increased over the past 10 years. As an example, the product portfolio of the TINE Heimdal facility increased by an average of 15 products per year in the period 2010-2012, while an average of only four products were terminated per year in the same period; see Figure 6-5.
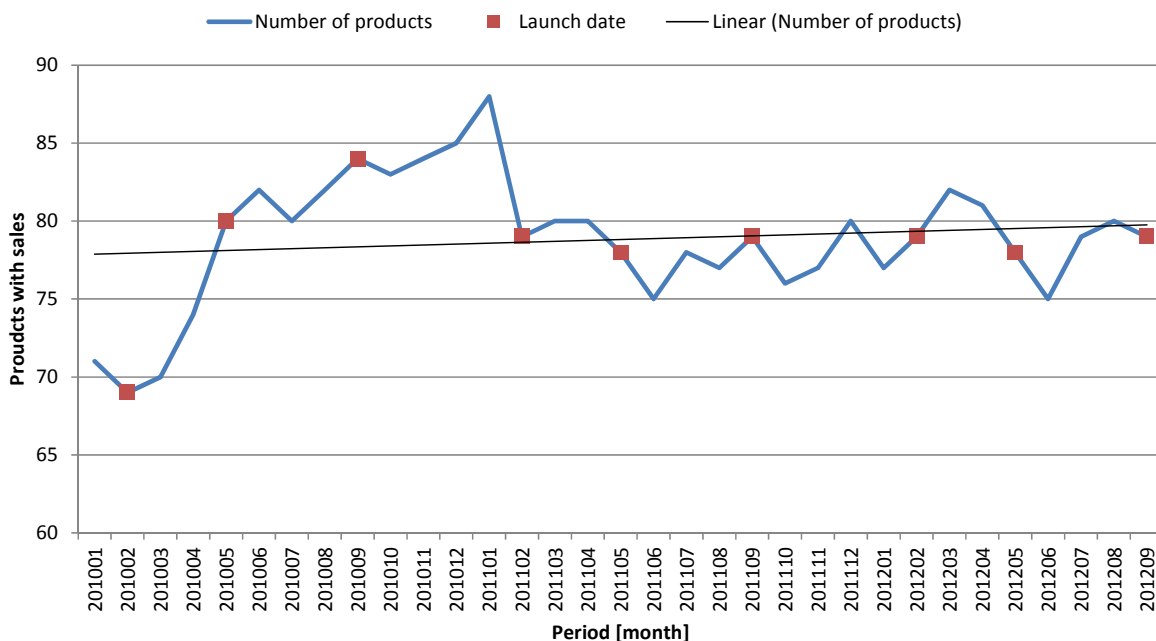
Figure 6-5: Number of product with sales, TINE Heimdal, January 2010 – September 2012

The shelf life for the majority of products ranges from 11 days for consumer milk to 91 days for cheese, but there are also extreme cases of well-matured cheeses that have a shelf life of over 1.000 days. 3 % of TINE's products have a shelf life of less than one week and 16 % less than one month.

Product complexity is characterised by a mixing-process product structure, where 3.800 different input factors are used, of which 1.000 are raw material variants and 2.800 are packaging variants. The largest variant explosion takes place in the packing process.

The volume per product variant is high. The volume over the year at the raw material level is fairly stable and predictable, but at the product variant and SKU level the predictability is more variable.

6.1.1.2 Market characteristics

Since TINE operates both in the national and international market, the market characteristics of each market type are described below.

The Norwegian market
The largest volumes from TINE are sold in Norway, with the majority sold through grocery wholesalers who sell the products to their grocery stores (see Figure 6-6). Presently the four Norwegian wholesalers with their associated retail chains are TINE's four largest customers, representing close to 100 % of products sold through grocery stores.

The grocery retail chains, HORECA and institutions constitute 85 % of TINE's annual turnover in Norwegian kroner and 67 % of the volume. The 'other' category mainly consists of raw milk sold to other dairies as part of TINE's role as market regulator (see sub-section 6.1.1.4).

Sales per channel (NOK)

- Grocery (72 %)
- HORECA, institutions (13 %)
- Other (7 %)
- Ingredients (4 %)
- Eksport (3 %)
- Convenience (1 %)

Sales per channel (volume)

- Grocery (57 %)
- Other (25 %)
- HORECA, institutions (10 %)
- Ingredients (5 %)
- Eksport (2 %)
- Convenience (1 %)
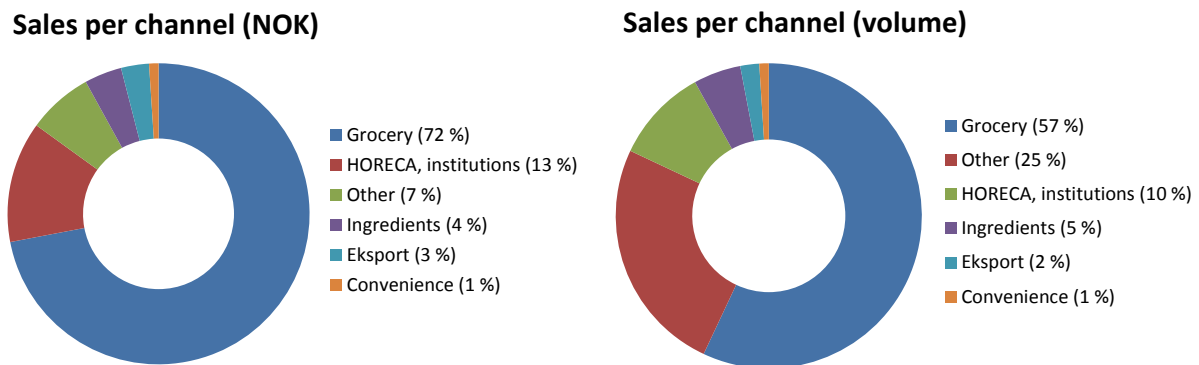
Figure 6-6: Sales per market channel, NOK and volume, 2011

TINE's distribution in the Norwegian market is a combination of direct distribution from dairies for liquid products like milk, yoghurt and fruit drinks with fairly high perishability, and wholesale distribution from one of two central warehouses for solid products with lower perishability like cheese and butter. In total, TINE delivers to approx. 25.000 delivery points per week. The two distribution channels are illustrated in Figure 6-7.
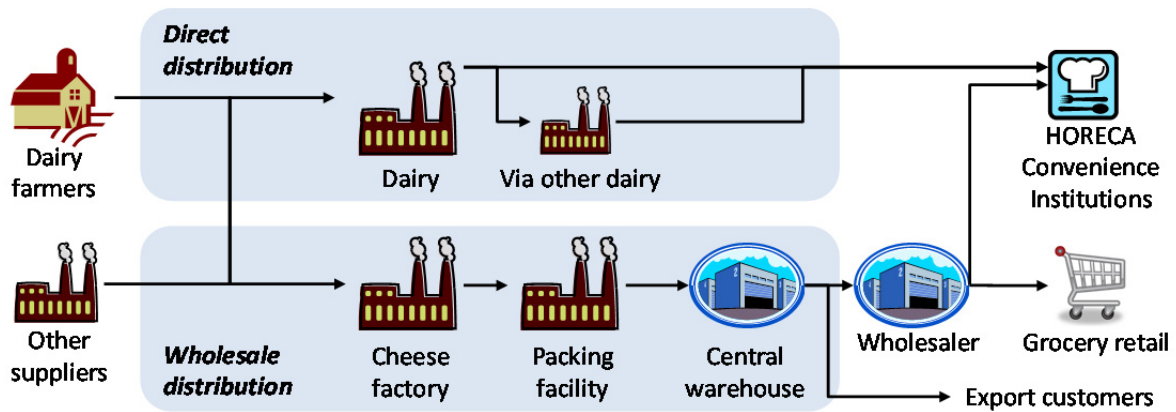
Figure 6-7: TINE's two main distribution channels (simplified)

Ordering from wholesalers is mainly periodic, where orders are placed once a day via EDI (electronic document interchange) and automatically transferred to TINE's ERP system M3 (Lawson). Other customers like HORECA and institutions place their orders less frequently using TINE's eBusiness portal, where orders are transferred into the ERP system via XML (extensible markup language).

Orders for products that are distributed directly from TINE are mainly collected from grocery stores by telephone and entered into the ERP system by TINE employees. Once received, the orders are split and distributed between TINE's different warehouse locations based on pre-defined parameters in the ERP system.

Delivery lead time to Norwegian customers is fairly stable at less than one day. Wholesalers place orders every day with same or next-day delivery, while other types of customers place orders less frequently.

Since production lead times are often longer than customers' order lead time expectations, orders are filled from finished goods inventory. In general, Norwegian wholesalers demand a service level of 97,5 % and failure to meet this can result in loss of good standing and have a negative impact on negotiations with wholesalers on prices, assortments, product introductions, joint marketing, etc. Maintaining high service levels is therefore one of the most important performance measures in TINE and large inventories of finished goods are kept in order to keep service levels high (for more on service levels, see sub-section 6.2.1.2).

In addition to large inventories of finished goods, TINE has a large amount of inventory of intermediates due to the maturation period needed for cheese products. In cases where there is an excess of raw milk, this is converted to lower-value, less perishable products like milk powder to avoid waste.

Demand uncertainty varies for different products and over the year. The largest demand uncertainty is related to:

- Market activities, where advertising campaigns, discounts and other activities are used to stimulate sales, thereby artificially amplifying demand variation.
- Newly launched products, particularly because lack of historic sales data makes forecasting difficult.
- Products with weather-dependent sales, where the lead time of production is too long for TINE to be able to respond quickly to unexpected changes in demand.

- Seasonal products, where demand varies over the year. To some extent this demand variation is predictable, particularly for products with historic sales data.

In addition, the type of listing a product has in each retail chain impacts on its demand uncertainty. The chains' headquarters determine whether or not their stores will carry the product, and if so, the listing in each store's assortment can be either compulsory (i.e. the store must carry the product) or voluntary (the store decides if it wishes to carry the product). If a product is included in a chain's compulsory product assortment, its total demand is fairly predictable. However, for a voluntary or undetermined assortment listing, there is high uncertainty since TINE does not know which retail chains and which stores will carry the product.

Volumes for campaigns and other market activities are normally agreed with retail chains six weeks in advance such that there should be little demand uncertainty related to such market activities (for more on demand uncertainty, see sub-section 6.2.1.1). However, retail chains frequently make last-minute decisions regarding campaign pricing (Huchzermeier and Iyer, 2010), thus increasing demand uncertainty for producers since price has a large impact on sales volumes.

The international market
The majority of TINE's international activities are in the US, Canada, Australia, Sweden, Denmark and the UK. TINE has production agreements with dairies in some of these countries, while the remaining demand is met through export. Jarlsberg cheese is TINE's largest export article, and in 2011, 10.860 tons were exported, amounting to approx. 60 % of all Jarlsberg produced in Norway. In addition, there is some export of the Norvegia and Snøfrisk cheeses.

Export orders are placed by TINE's overseas subsidiaries or contract partners at irregular intervals. These orders normally involve large volumes and delivery lead time allowances of several weeks or months. Export products are products with very low perishability, and while the products themselves are standard, the packing and labelling is specific for each market. Distribution to overseas countries is normally by boat, but in some cases air freight is used for rush orders.

6.1.1.3 Production system characteristics

The TINE Group is Norway's largest production network and in 1990, TINE had 190 dairies spread across the country. After a period of considerable restructuring and consolidation, TINE's network currently consists of 40 dairies and production facilities, in addition to four terminals, two central warehouses, and eight production facilities related to other activities (as per November 2012).

TINE's production network is divided into three types, where products which require the same type of production equipment and processes are produced in the same facility:

1. Dairies – processing and bottling consumer milk, fruit drinks, and other liquid products with high perishability
2. Cheese factories – producing cheese in bulk which is used as input to packing facilities. In addition, some of the cheese factories produce and pack butter products of low to medium perishability.
3. Packing facilities – cutting and packing cheese into finished end products with low to medium perishability

All facility types operate with MTS as the overall PPC approach and receive their weekly production plans from a centralised planning unit (see sub-section 6.1.2 for more details on PPC). Facilities are compared with similar types of facilities in the network based on the same performance indicators. The facility types differ with respect to product variants and the products' degree of perishability and completeness (intermediate and finished products).

Processing lead times vary among facilities and products, from a few minutes to several hours. In addition, cheese products require maturation, from a few weeks up to 15 months. The cutting, packing and labelling of a product takes only a few minutes. A cooling-down period of up to four days must be added to the production lead time of products where heat is generated during the cutting and packing process.

Each facility type has different production technology, processes and equipment. In general, the facilities have mainly integrated and continuous production processes. Machinery is capital-intensive and specialised, with setup times ranging from a few minutes to several days for both processing and packing equipment. Changeover costs are fairly high and to some extent sequence-dependent since equipment must be cleaned when switching between certain products.

6.1.1.4 Supply characteristics

The scope of the study is on demand-side uncertainty. However, some supply characteristics are also included in order to provide a general understanding of how supply-side aspects impact on operations and PPC.

Milk is TINE's most important raw material. The Norwegian agricultural sector is regulated by the Norwegian Agricultural Authority (NAA). Important objectives for the Norwegian agricultural policy include increasing consumer orientation, food safety and the multifunctional character of agriculture, enhancing rural development, and protecting the cultural landscape and biodiversity (OECD, 2007). As part of the policy, TINE has been appointed regulator for the Norwegian milk market. This means that the company determines the price of raw milk, must take delivery of all milk produced by Norwegian milk farmers, regulate fluctuations in the milk supply in the short and medium term, and supply milk to competing dairies.

The amount of milk produced by Norwegian cows and goats varies both over the year and geographically, with variations related to calving/lambing periods, grazing conditions, etc. The weekly variation in incoming raw milk over the year for 2010-2012 is illustrated in Figure 6-8. This variation represents important challenges for raw material management and PPC since demand must be met throughout the year, irrespective of the level of incoming raw milk.
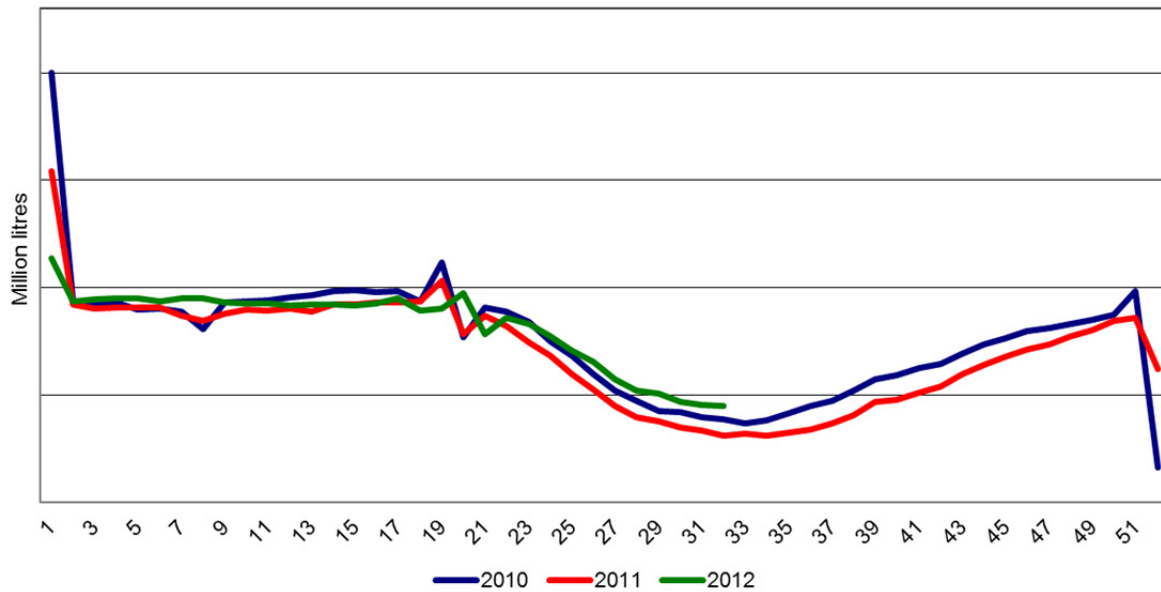
Figure 6-8: Variation in incoming raw milk per week, 2010-2012

Other key production inputs come from suppliers of ingredients and packaging materials. Delivery lead times from these vary from a few days to several months. However, lead times are generally fairly stable and predictable.

6.1.1.5 Summary of supply chain characteristics

Table 6-2 summarises TINE's key supply chain characteristics.

Table 6-2: TINE's key product, market and production characteristics

Characteristic	*Description*
Product characteristics	
Product perishability and shelf life	Mainly between 11 – 91 days. 3 % of products have a shelf life of less than one week and 16 % less than one month.
Product complexity	Mixing-process product structure where 3.800 different input factors (1.000 raw material variants and 2.800 packaging variants) are used to make 840 product variants.
Product variety	840 product variants, 1.300 SKUs.
PLC, innovation, new product development	Strong focus on product development and frequent product launches, with 50-80 new products launched annually. Steady increase in variants.
Product volume and volume variability	High volumes which are fairly stable and predictable at raw material level but more variable at the product variant and SKU levels.
Market characteristics	
Delivery lead time and lead time variability	Fairly stable and fixed at less than one day for the national market. Longer and partially negotiable for export.
Demand uncertainty	Varies among products and markets, mainly related to market activities, product launches, seasonal and weather-dependent products and assortment listings with retail chains.

Inventory management	Periodic ordering. Large inventories of finished goods and intermediates. High service levels. Excess raw material and intermediates converted to lower-value, less perishable products to avoid waste due to perishability.
Production system characteristics	
Production or MTO lead time	Processing lead time varies from weeks to 15 months, packing lead time from hours to four days. Low degree of postponement, mainly MTS.
Plant, processes and technology	Plant, machines, equipment and processes adapted to low product variety and large batch sizes. Set-up times generally around a few hours for processing and packing equipment.
Supply uncertainty	Supply of raw milk fairly predictable, with some seasonal and geographical variations. Long internal lead times for intermediate cheese products due to maturation. Fairly stable lead times from suppliers of other inputs.

From the table and the descriptions above, it can be seen that TINE's supply chain characteristics are fairly similar to the general characteristics of the food sector as described in section 4.2. This means that TINE's market and product characteristics push for responsiveness, while the production system is focused on scale benefits through its design for high production volumes and low product variety. It is therefore reasonable to assume that TINE is facing the same misalignment as the one identified in section 4.2 between product and market characteristics on the one hand, and production system characteristics on the other.

Further, it can be concluded that TINE appears to be representative of the sector in that PPC is constrained by the lack of strategic fit between external product and market requirements and the capabilities of the production system. Thus, TINE is a good candidate for investigating how differentiated PPC can enable the production system to achieve the level of responsiveness required by the external factors in an effective and resource-efficient manner.

6.1.2 Case facility; TINE Heimdal

This section introduces the case facility TINE Heimdal and describes how planning and control is performed in TINE's production network, with particular focus on the PPC of packing facilities.

6.1.2.1 Facility and physical processes

TINE Heimdal is one of three TINE facilities that transform bulk cheese into consumer packages. In addition, the facility is one of two central warehouses in the TINE network, thus receiving and distributing wholesale-distributed products produced at other facilities or bought from other producers for resale (see Figure 6-9).

Figure 6-9: TINE Heimdal packing facility and central warehouse

TINE Heimdal produces 83 different product variants of sliced, grated and blocked cheese. The shelf life of the facility's products varies from 56 to 365 days, and 60 % of the products have a shelf life of 91 days.

TINE's cheese factories produce bulk cheese in 10 and 20 kg blocks (size varies with each factory's production equipment). Different cheeses require different maturation periods and during maturation the bulk is normally stored at the cheese factory. However, in cases where factories do not have enough storage capacity, the maturation is completed in the central warehouse at TINE Heimdal.

After maturation, the bulk is transferred to the buffer inventory at the packing facility. Before production, bulks are transported to the start of the production line, where the protective plastic is removed before start of production, see Figure 6-10.
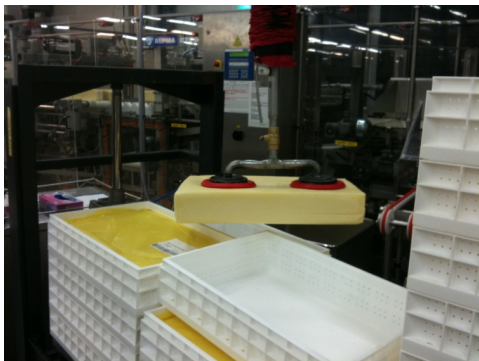
Figure 6-10: Bulk cheese in front of packing line

Processing is done on highly automated and continuous production lines which integrate the three main physical processes of;

1. Sizing, consisting of either slicing, grating or cutting
2. Packing
3. Labelling

Figure 6-11 shows a production line which cuts and packs individual slices of cheese into consumer packaging.
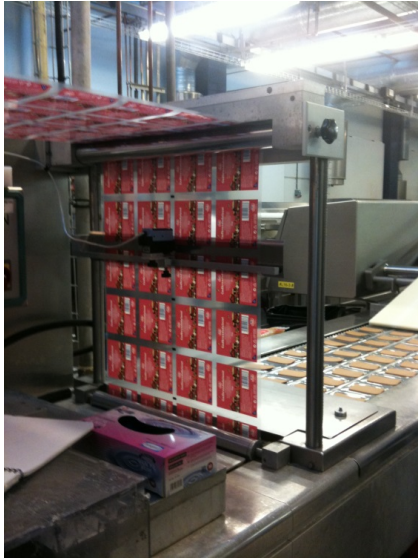
Figure 6-11: Packing of individual slices of cheese

After processing, the finished products are packed in distribution packages and transported to the refrigerated finished goods warehouse. Before they can be sold, some products have to stay in inventory for up to four days until they have reached a temperature of 0-4 ^{0}C. The duration of the cooling down period varies between products, with grated cheese requiring the longest cool-down period.

The material flow and production processes of TINE Heimdal are illustrated in Figure 6-12.
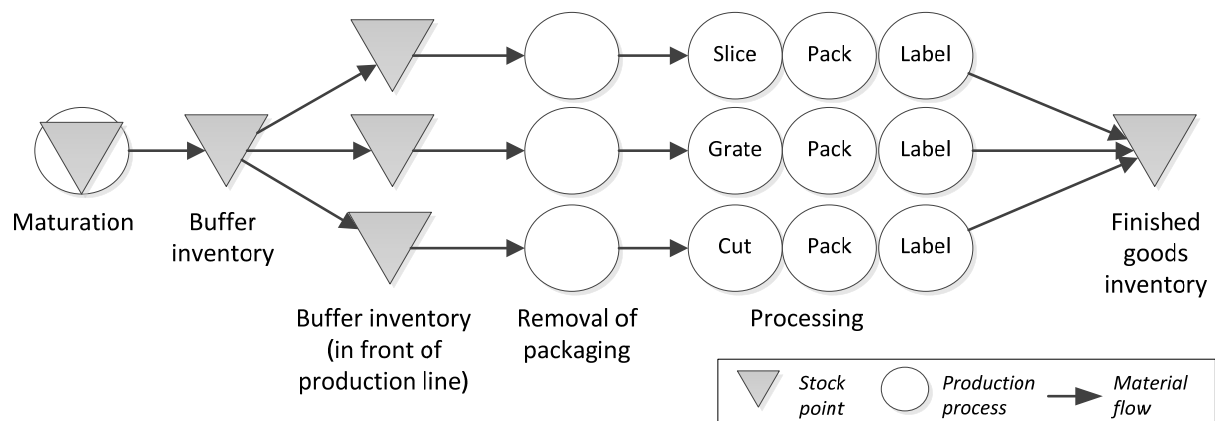
Figure 6-12: Production processes and material flow in TINE Heimdal

TINE Heimdal has 14 production lines, divided in three types;

1. Six lines which slice cheese
2. Four lines which grate cheese
3. Four lines which cut bulk into blocks

Production lead time varies between one and four days depending on the required cooling down time for the different products. Delivery lead time to national customers is one day.

The facility operates with 47 full-time equivalent employees. Operations are organised in 6-hour shifts, with two shifts Mondays to Thursdays and one shift on Fridays[10].

6.1.2.2 Overall planning and control

The main planning and control principle in TINE is forecasting and MTS. The main argument for this is that in many cases the total production lead time is longer than customer order lead time expectations. There is also a need to build buffer inventories because of the seasonal variations in milk supply. This means that the focus in periods of raw material shortage is on production of high perishability products (e.g. milk and cream), while products with low perishability (e.g. butter, cheese and milk powder) are produced and buffered before the shortage occurs.

Planning and control of production and inventory is performed at both the central and local level in TINE. Central planners are organised in TINE Supply chain management's Replenishment function, which is further organised into three teams:

- Raw material planning; responsible for planning of raw material-related products and operational replenishment of all facilities in the production network
- Requirements planning; responsible for forecasting, planning of all production (except consumer milk), coordination of product launches, and purchasing of all commodity goods for resale
- Delivery service centre; responsible for distribution of finished goods between production facilities, and customer and delivery follow-up

The organisation of the replenishment function is illustrated in Figure 6-13.
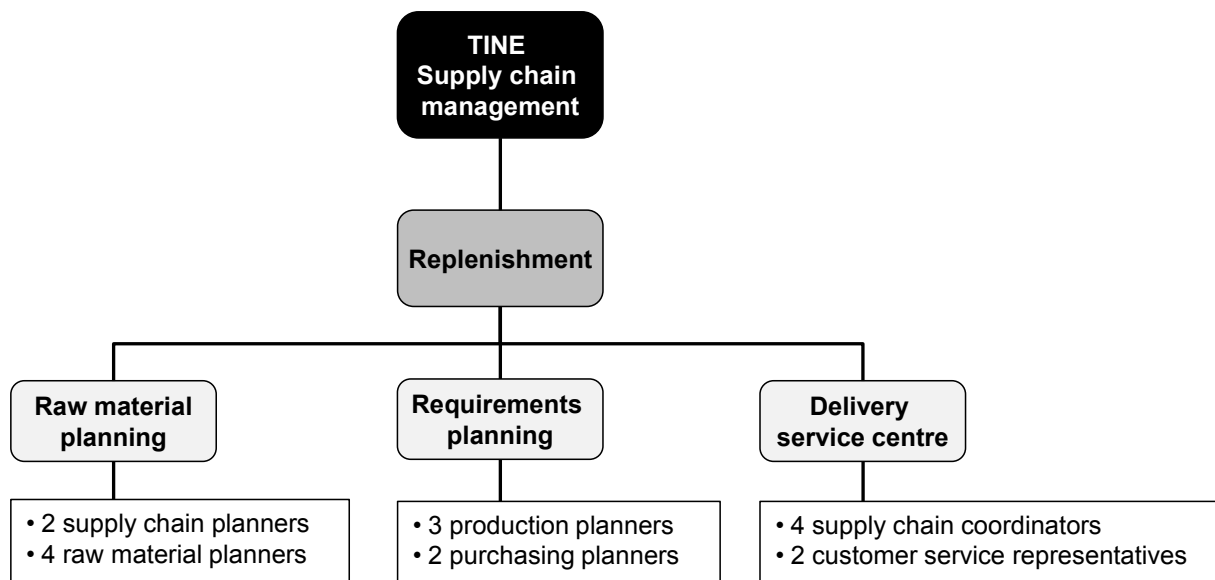
Figure 6-13: TINE Supply chain management's replenishment function

The production planners in the requirements planning team are responsible for coordinating the interface between central and local planning. Each planner has a portfolio of products to

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[10] TINE Heimdal implemented 6-hour work days in 2007, resulting in improved job satisfaction and a 30 % increase in productivity.

plan and control, and the number of products in each portfolio depends on the degree to which the planning can be automated.

One of the three central production planners is responsible for planning the weekly production for all three packing facilities. This enables coordination among the facilities and the planner has dedicated contact persons at each facility who are responsible for performing the local planning and control. At TINE Heimdal, local PPC is performed by two supervisors.

TINE uses cyclic planning where different planning activities are performed on specific days of the week, see Figure 6-14.

Continuously	**Wednesday**	**Thursday**	**Friday**	Horizon	Time bucket
Forecasting				104 weeks	Week
	Replenishment			1-4 weeks	Day
	Production (central)			1-4 weeks	Week
	Production (local)		*Production re-planning*	1 week	Day
		Raw material replenishment		1 week	Day
			Transport scheduling	1 week	Day
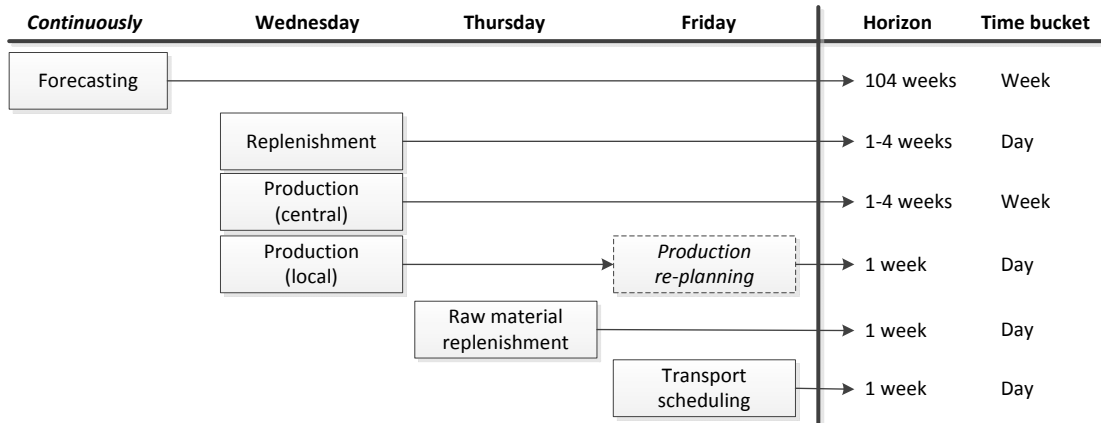
Figure 6-14: Timeline of key planning activities in the TINE Group

Sales forecasts are updated continuously by the central production planners. Forecasts are generated on an SKU level with a planning horizon of 104 weeks.

Replenishment planning takes place on Wednesday and is performed by the raw material planning team of the replenishment function. The activity includes planning of daily distribution of finished goods between production facilities for onward distribution to customers.

Production planning is also performed on Wednesday. The planning is performed at both the central and facility level. Central planning for packing facilities takes place on Wednesday for the following week. Local planning also takes place on Wednesday with daily time buckets for the following week. If needed, the production plan for the packing facilities is updated on Friday.

Raw material replenishment planning takes place on Thursday and is the responsibility of TINE Raw material management. The activity weekly plans replenishment of milk to facilities based on planned production volumes on a day level for the following week.

Transport scheduling is performed on Friday by TINE Distribution and involves the planning of daily transport between facilities on a weekly horizon.

An important condition for PPC in TINE is that dairies and cheese making factories cannot influence the amount of incoming milk due to TINE's role as market regulator. Thus, all milk collected from farmers and delivered to these facilities must be processed. The biggest PPC challenge for dairies is therefore related to converting the raw milk into processed products

within 36 hours of arrival at the facility and sequencing and scheduling production on the production lines.

6.1.2.3 PPC of packing facilities

Forecasts are generated continuously based on historic sales over the past three years[11]. The production planner supplements this with market information (campaigns and other planned activities) before the forecast is returned to TINE's ERP system. Export orders are entered into the ERP system with the due date agreed with customers and released for production on the latest possible date to meet the due date. Based on the forecast, known orders and inventory levels, the ERP system calculates net requirements and generates:

- Purchase order proposals for packaging materials, ingredients and raw milk
- Work order proposals for production per facility
- Distribution order proposals for transport of raw milk between TINE facilities

Work order proposals are generated by the ERP system on Wednesday, with expected weekly demand distributed evenly between the weekdays. The key elements in the work order proposals are:

- Number of items to be produced per product
- Production start date
- Production end date

The work order proposals are transferred to a Microsoft Excel spread sheet where the production planner makes manual adjustments in order to take overall facility production capacity into consideration. The adjusted orders are then transferred back to the ERP system, where they are locked and made available for local facility planning.

Later the same day, the local facility planners export the production work orders into simple Excel spread sheets, where the weekly orders are broken down to a day-level based on:

- Available production line capacity in the upcoming week
- Available staff
- Effective utilisation of planned shifts

The sequence of production on each production line is determined based on the planned delivery date. The main objective for local planning is to maximise capacity utilisation to keep unit costs down. While the central level determines the products and volumes that each facility will produce in the coming week, the facility uses the day-level work orders to determine:

- Sequence of production runs
- Run sizes within a 1-2 week horizon

Thursday there is a coordination meeting between the central planner and the local planners at all three packing facilities to discuss the production plans for the following week. In this meeting, information which impacts on available capacity is addressed, e.g. planned downtime for maintenance, varying raw material quality and other local issues. In addition, other new information can be considered, such as changes in sales forecasts or problems with ser-

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[11] Forecasting is done in a customised IT application using the Lewandowski algorithm

vice levels in the current week. If necessary, the production plan for the following week is adjusted and re-frozen on Friday. If the adjusted workload is not within the available capacity of the individual facility, the most common corrective actions include moving production or inventory between facilities or increasing capacity through use of overtime.

The central and local production planning activities per weekday are summarised in Table 6-3.

Table 6-3: Overview of central and local packing facility planning and control activities

Planning level	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
Central	Re-planning if required	Update of sales forecast	Planning of following week's production	Coordination meeting	Plan for following week frozen
Local			Planning for following week	Coordination meeting	Re-planning for following week if required
	Detailed planning of Tuesday	Detailed planning of Wednesday	Detailed planning of Thursday	Detailed planning of Friday	Detailed planning of Monday
	Reporting daily production	Reporting daily production	Reporting daily production	Reporting daily production	Reporting daily production

6.1.2.4 Summary of key planning and control aspects

The key design aspects of the current PPC system for TINE Heimdal are summarised in Table 6-4.

Table 6-4: Planning and control of production at TINE Heimdal

Design aspect	*Description*
PPC approach	MTS, with some degree of MTO for export orders
Planning principle	Periodic forecasts which trigger production and logistic activities
Inventory policy	Centralised inventory, weekly review
Delivery frequency	Daily to wholesalers' delivery points, less frequent to other customers
Centralisation of planning and control	Centralised planning and control of inventory and production volumes per week per facility. Local daily sequencing, lot sizing and timing of production based on available capacity.
Planning frequency	Weekly, with centralised planning in weekly time buckets and local planning in daily time buckets.

Using the supply chain planning matrix of Fleischmann et al. (2008) from sub-section 3.2.2, the tasks and responsibilities of the central and local planning levels are summarised in Figure 6-15. While the centralised PPC tasks are performed by the replenishment function, local PPC is performed by production supervisors at each facility.
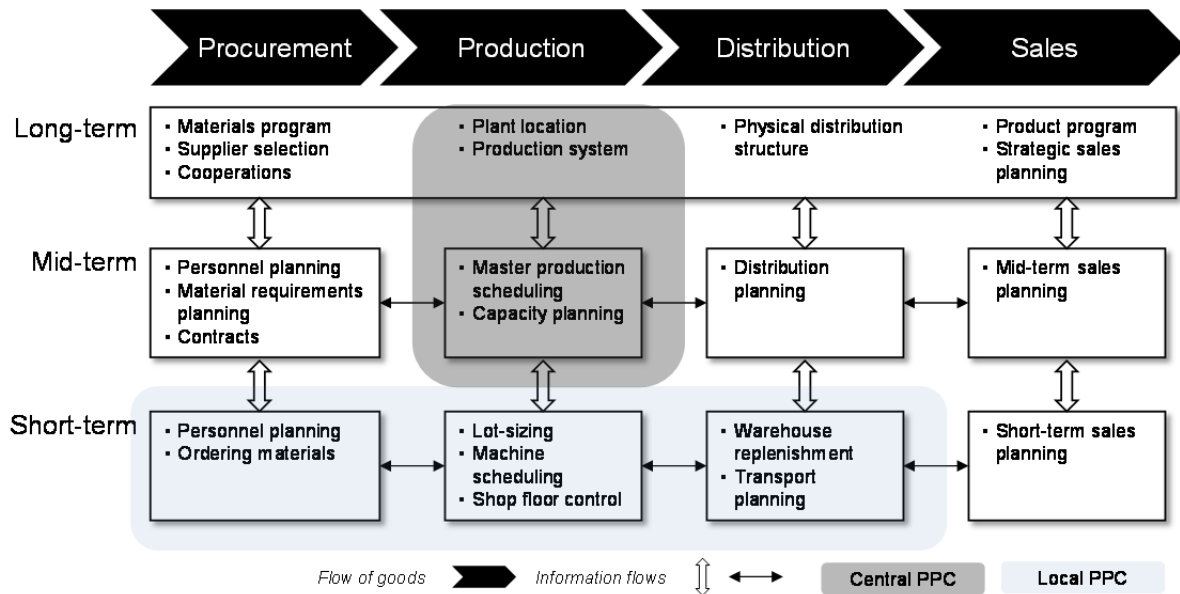
Figure 6-15: Central and local supply chain planning in TINE (based on Fleischmann et al., 2008, p. 87)

6.2 Analysis of current planning and control

In this section, TINE Heimdal is analysed with particular focus on PPC performance and the current degree of differentiation. The findings from the analyses are subsequently used as inputs to the design of new PPC solutions in section 6.3.

6.2.1 PPC performance

The performance of a PPC system is the result of how the company has designed its PPC system, as well as a number of external conditions and circumstances beyond the company's control. In order to identify key PPC challenges and improvement potentials, a number of quantitative and qualitative analyses were performed. The specific analyses were inspired by the list of indicators and aspects presented in sub-section 3.3, and the list was amended based on discussions with company representatives about relevant parameters, the performance indicators already used in the company, and the analyses that could be carried out with the available data and computational resources. The analyses of PPC performance were grouped into:

1. Demand uncertainty (sub-section 6.2.1.1)
2. Service level and delivery reliability (sub-section 6.2.1.2)
3. Inventory turnover (sub-section 6.2.1.3)
4. Capacity utilisation (sub-section 6.2.1.4)
5. Qualitative aspects (sub-section 6.2.1.5)

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[12]. In order to keep the amount of data at a manageable level, a number of products were strategically selected for detailed analysis. The following criteria were used to select the products, ensuring that they captured the most important aspects of the products produced at the facility with regards to product, market and production system characteristics:

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[12] See Appendix 1 for details on how the quantitative data collection and analyses were performed.

- Process type; all three process types represented (block, grate and slice)
- Volume; at least three products representing the largest volumes per process type
- Forecast accuracy; at least three products with low accuracy and three with high accuracy
- Shelf life; at least three products with medium and three with long shelf life[13]
- Markets; at least three export products
- New products; at least three products launched during the year

A total of 15 SKUs were selected (henceforth called reference products), constituting 18 % of TINE Heimdal's SKUs and 54 % of the total production volume in 2011. The 15 reference products and their key characteristics are listed in Table 6-5.

Table 6-5: Reference products selected for detailed analysis

ID	Product type	Process type	Average forecast accuracy	Shelf life (days)	Market	Launch*
1	Norvegia	Block	63 %	91	Norway	
2	Jarlsberg	Block	77 %	91	Norway	
3	Jarlsberg	Block	86 %	91	Norway	
4	Grated cheese original	Grate	79 %	91	Norway	
5	Norvegia	Grate	53 %	91	Norway	
6	Norvegia/Jarlsberg	Grate	51 %	91	Norway	
7	Norvegia	Slice	73 %	91	Norway	
8	Jarlsberg	Slice	72 %	91	Norway	
9	Norvegia	Slice	83 %	91	Norway	
10	Jarlsberg	Block	73 %	275	Export	
11	Jarlsberg	Slice	65 %	275	Export	
12	Jarlsberg	Slice	44 %	275	Export	
13	Burger cheese	Slice	-76 %	91	Norway	L2
14	Norvegia	Block	78 %	91	N	L1
15	Norvegia	Slice	76 %	91	N	L1

* Launch period; L1 = 1 January, L2 = 1 April

6.2.1.1 Demand uncertainty

Good predictions of future demand are essential for tactical and operational planning and control in MTS environments. High demand uncertainty can be buffered against through finished goods inventory or high degrees of flexibility in order to be able to meet customer demand in a timely manner. For this reason, many companies invest in forecasting software and in improving their forecasting processes in order to produce good forecasts which can be used as input to production and inventory planning.

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[13] None of TINE Heimdal's products can be considered to have short shelf life since the shortest shelf life is 91 days.

Through discussions with TINE personnel, a number of factors which impact on their products' degree of demand predictability were identified. These were grouped into three main categories according to the products' stage in the PLC;

- Newly launched products
- Established products
- Casual or one-off orders or orders for customer-specific products

For newly launched products, the product's degree of innovation affects demand predictability. For products with a low degree of innovation, historic demand data from the launch of similar products is used to as a template to generate fairly good forecasts. The quality of the historic data of the existing product is also important since lack of data or other weaknesses can reduce its usefulness to predict demand for the new product.

Another important factor for newly launched products is assortment listing with wholesalers and retail chains. For forecasting and planning purposes, it is essential to know which retail chains and which stores that will carry the product. If the listing in a particular chain is not confirmed, the demand predictability associated with that chain is considered low. Further, if a retail chain has confirmed that it will carry the product in its assortment, there is a need to know whether the product will be part of stores' compulsory or optional assortment. Knowing how many (and in certain cases knowing which) stores will carry the product improves the quality of the forecast and thus the demand predictability.

For established products, an important determinant of predictability is whether or not the product will be subjected to market activities in the planning period. A product's historic forecast accuracy during periods with and without activities can be used to assess a product's demand predictability. Further, if a product's demand is highly sensitive to weather and seasonality, the demand is considered less predictable than for products with more stable sales. In addition, a product's sales and demand predictability can be affected by market activities related to other company products or indeed by competitors' market activities. Such factors are however very difficult to predict and take into consideration in production planning, and these were therefore not included in the study.

In addition to the two more standard types of demand above, TINE receives casual or one-off orders which can consist of standard or customised products and packaging, for instance related to export, specific events or other extraordinary market activities. The inability to predict the timing, volume and specific content of such orders means that these are associated with low demand predictability.

Demand uncertainty can be measured and expressed in a number of ways. TINE measures the quality of its sales forecasts in terms of forecast accuracy. The forecast accuracy compares actual sales with forecasted demand, and in TINE this is calculated as mean absolute percentage error (MAPE), expressed as a percentage and calculated as 1-MAPE[14]. The further below 100 % the forecast accuracy, the larger the difference between the forecast and actual sales.

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[14] Calculated as absolute value of forecast minus number of items picked, divided by number of items picked. Forecast accuracy is communicated in percent as 1-MAPE. For simplicity, very large deviations are set to a fixed number to avoid extreme negative forecast accuracy values. The accuracy is measured as an average percentage per week.

Products with high forecast accuracy (i.e. close to 100 %) have a relatively small standard deviation, indicating that the quality of the forecast over time is fairly stable.

Forecasts in TINE are continuously updated with new information, and in order to track forecast accuracy, forecasts are captured at five different points in time; 1, 4, 6 and 10 weeks before actual sales. A comparison of forecast accuracy at these different time lags for the reference products showed that there was relatively little change in forecast accuracy in the interval from 10 weeks (lag 10) to 1 week (lag 1) before actual sales – where the best forecast accuracy for five of the products was at lag 1, three at lag 4 and four at lag 10[15]. However, the analysis indicated that the manual fine-tuning of forecasts which is often done in the weeks leading up to actual sales in some cases actually reduced the quality of the forecast.

For the purposes of PPC, the accuracy four weeks before actual sales is of most value since this allows a suitable period of time to perform workforce planning and purchase raw materials and other production inputs. In the analyses of forecast accuracy for the reference products, the four week lag was therefore used. Forecasts for export products are updated every eight weeks and for these, forecast accuracy at the eight week lag was used. Table 6-6 shows the average and low/high forecast accuracy for the reference products in 2011, and the average accuracy is presented graphically in Figure 6-16.

Table 6-6: Forecast accuracy, reference products

ID	Product type	Average (%)	Low (%)	High (%)
1	Norvegia	63 %	-139 %	100 %
2	Jarlsberg	77 %	-307 %	100 %
3	Jarlsberg	86 %	37 %	100 %
4	Grated cheese original	79 %	-13 %	100 %
5	Norvegia	53 %	-1247 %	100 %
6	Norvegia/Jarlsberg	51 %	-14 %	100 %
7	Norvegia	73 %	-31 %	99 %
8	Jarlsberg	72 %	-33 %	99 %
9	Norvegia	83 %	40 %	100 %
10	Jarlsberg	73 %	20 %	100 %
11	Jarlsberg	65 %	-100 %	100 %
12	Jarlsberg	44 %	-119 %	100 %
13	Burger cheese	-76 %	-1463 %	98 %
14	Norvegia	78 %	19 %	99 %
15	Norvegia	76 %	-4 %	99 %

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[15] Export products are forecasted separately from ordinary products and forecast accuracy at different lags for export products was therefore not available for this analysis.
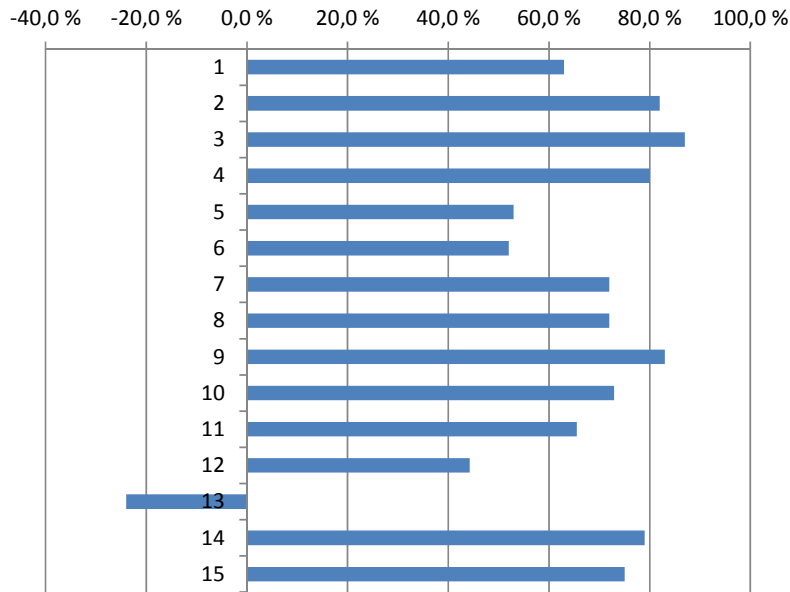
Figure 6-16: Average forecast accuracy, reference products

The average forecast accuracy for the 12 reference products in the national market was 68,5 %, varying from -76 % to 86 %. The average for the three export products was 62 %, varying from 44 % to 73 %. In TINE, an average forecast accuracy of 70 % is considered high and from Table 6-6 it can be seen that nine products can be classified as having high accuracy, while the remaining six had low forecast accuracy.

In section 4.2, market activities were found to be a major contributor to demand uncertainty in food supply chains. In order to confirm that this effect is also present in TINE, the forecast accuracy in weeks without activities was compared to forecast accuracy in weeks with activities for the 12 reference products sold in the national market[16]. The average accuracy in weeks without and with market activities, and the respective number of weeks, is listed in Table 6-7. Here we see that for the eight reference products which were subjected to market activities in 2011, the forecast accuracy for products 1, 2, 4 and 15 was higher in weeks without market activities than in the weeks with activities. For products 7 and 8 the difference is minimal, while for products 9 and 13 the number of weeks with activities was too low to draw any conclusions. Thus, the general tendency of market activities increasing demand uncertainty seems to be present in TINE.

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[16] Export products are not subjected to market activities initiated by TINE

Table 6-7: Forecast accuracy and market activities, reference products

ID	Product type	Average (%)	Without activities	Weeks[17]	With activities	Weeks[17]
1	Norvegia	63 %	83 %	14	55 %	37
2	Jarlsberg	82 %	82 %	44	78 %	7
3	Jarlsberg	87 %	87 %	51		0
4	Grated cheese original	80 %	84 %	11	78 %	40
5	Norvegia	53 %	53 %	51		0
6	Norvegia/Jarlsberg	52 %	52 %	45		0
7	Norvegia	72 %	72 %	13	73 %	38
8	Jarlsberg	73 %	72 %	15	73 %	35
9	Norvegia	83 %	83 %	50	97 %	1
10	Jarlsberg	73 %	73 %		////	0
11	Jarlsberg	65 %	65 %		////	0
12	Jarlsberg	44 %	44 %		////	0
13	Burger cheese	-24 %	-30 %	13	41 %	1
14	Norvegia	79 %	79 %	49		0
15	Norvegia	75 %	80 %	32	65 %	17

In addition to forecast accuracy, the coefficient of variation (COV) is commonly suggested in literature as an appropriate measure for describing demand uncertainty (see e.g. Godsell et al., 2011, Aitken et al., 2005, Christopher et al., 2009). The COV is defined as the ratio of the standard deviation to the mean, and a COV > 0,4 can be considered high variation in terms of demand (see e.g. Godsell et al., 2011, D'Alessandro and Baveja, 2000). The COV of all products produced at TINE Heimdal was calculated, and using the 0,4 cut-off, 46 % of the products were classified as having high demand uncertainty; see Figure 6-17.
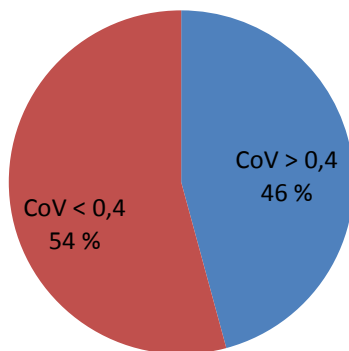
Figure 6-17: Coefficient of variation (COV) for all products produced at TINE Heimdal

In summary, the analyses on demand uncertainty show that there are a number of factors which impact on the predictability of the demand for the products produced at TINE Heimdal. Some of the factors are quantifiable, while others require qualitative evaluation. The forecasting and planning process is based on the use of sophisticated forecasting software. In addition, the process is highly reliant on the experience and knowledge of the production planners who make a lot of manual adjustments to the forecasts. Thus, it would be beneficial to know; 1)

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[17] Due to an error in TINE's forecasting data, one week of data was dropped from the analysis

which of the products that can benefit from more manual follow-up of forecasts, and 2) which of the products that can be forecasted automatically using the forecasting software.

There seems to be a lot of knowledge in the organisation about the different factors which impact on demand uncertainty. However, the current planning is almost entirely based on forecasts and there is a lack of a structured and formalised process for taking other factors into consideration in the PPC process.

The analysis of the COV revealed that 46 % of TINE Heimdal's products can be considered to have high demand uncertainty. However, putting such a large number of products into the 'focus box' for PPC does not contribute to reducing much of the complexity in the PPC task. Also, it does not capture any of the qualitative aspects affecting demand predictability and is not forward looking enough for it to be of much value for planning purposes. Thus, the COV may not be the best variable to use to differentiate how products are planned and controlled in TINE.

6.2.1.2 Service level and delivery reliability

Service levels express how well a company or facility satisfies customer demand. In order to evaluate how well each facility performs, TINE measures service level performance out from facilities instead of in to customers since a customer order can be filled from several facilities.

Service levels are measured according to the Norwegian grocery sector standard, defined as number of delivered units divided by number of ordered units. There may be some weaknesses associated with this performance indicator since undelivered items are not backordered but rather added to the order for the following day.

Norwegian wholesale customers require a service level of 97,5 % from TINE. On the facility level, the average service level for all products delivered from TINE Heimdal in 2011 was 95,8 %. The actual service level to customers was however probably higher since deliveries are often supplemented from other TINE facilities in local stock-out situations.

The average service level per process type was 97,1 % for blocked products, 95,4 % for grated products, and 95,7 % for sliced products. Thus, none of the process types achieved a service level above the customer requirement of 97,5 %. The average and low/high service levels for the reference products are summarised in Table 6-8. Service levels for export products were not measured since these were MTO in 2011.

Table 6-8: Service level, reference products

ID	Product type	Low (%)	High (%)	Average (%)
1	Norvegia	77,0	100	98,6
2	Jarlsberg	29,2	100	95,1
3	Jarlsberg	67,7	100	97,1
4	Grated cheese original	68,8	100	98,6
5	Norvegia	44,5	100	95,3
6	Norvegia/Jarlsberg	88,9	100	99,8
7	Norvegia	90,3	100	99,5
8	Jarlsberg	86,1	100	99,5

ID	Product type	Low (%)	High (%)	Average (%)
9	Norvegia	94,5	100	99,9
10	Jarlsberg			
11	Jarlsberg			
12	Jarlsberg			
13	Burger cheese	0	100	76,4
14	Norvegia	20	100	97,2
15	Norvegia	20	100	98,1

From Table 6-8, it can be seen that the average service level for seven of the national products were above the requirement, while five were below.

While the average service level expresses how well a company performs on average, the variation in service level says something about how reliable the delivery from the facility is. The average service level for the reference products varied from 76,4 % to 99,9 %, where the lowest delivery performance during the year was 0 % and the highest 100 %. The lowest service level was associated with reference product 13 which was launched in January but was later discontinued because it did not succeed in the market.

Service levels for all the reference products varied over the year. There was no clear pattern in the variation over the year among the products. However, four of the reference products (1, 2, 3 and 5) had clear drops in service levels between weeks 19-25. Company reports quoted a combination of lack of packing material and technical problems as the main reasons for the delivery problems in these weeks. No clear link was found between service levels and market activities for these products in this period. However, a comparison between service levels and forecast accuracy per week (lag 4) suggests a link between the two drops, where poor forecast accuracy seems to have coincided with poor service levels (although poor service levels did not necessarily coincide with poor forecast accuracy). A potential explanation for this finding is that forecasts are used to generate purchase orders for packaging materials a few weeks before product starts – and that poor forecast accuracy at the four week lag could have resulted in a lack of these input factors to satisfy actual demand in week 0. Demand for input factors and finished products might have been satisfied by consuming from the safety stocks – but when this coincided with a period of technical problems in the facility, the levels of inventory at the facility were perhaps not sufficient to meet actual demand.

In several cases where the facility was unable to deliver 100 % of a customer order, the delivery was supplemented from other facilities. This required increased communication and coordination between facilities, which would again have reduced the efficiency of the PPC resources on the central and local level. In addition, this required additional transport and may also have resulted in a need for re-planning at the supplying facility, further reducing the efficient use of PPC resources.

In summary, the analyses of service levels indicate that the facility is fairly effective in meeting customer requirements. However, this is achieved despite varying forecast accuracy, technical problems and other delivery issues – which increase the need for buffer inventories and flexibility, and results in additional transport costs, inefficient use of PPC resources, and disturbances to PPC at other facilities.

6.2.1.3 Inventory turnover

As mentioned, TINE's main PPC approach is MTS and orders are therefore mainly delivered from inventory. Because of the fairly large variations in forecast accuracy and demand, inventories are used to buffer against demand uncertainty. Safety stocks are used to ensure availability when demand is greater than expected and the level of safety stock is currently manually set in the ERP system on an SKU level.

A Norwegian industry standard determines how much of a product's shelf life each supply chain actor can consume before the product must be sold to the next actor in the supply chain[18] (STAND001, 2006). Currently, producers can consume a maximum of 1/3 of a product's shelf life, and this represents an internal 'sell-by' date for TINE. Products with shorter remaining shelf life can still be sold and this requires additional efforts by the sales team and usually involves offering the products to customers at discounted prices. This may also have negative effects on the sales of the full-price items to these customers in the subsequent period.

The inventory turnover rate expresses the number of times inventory is turned over in a period. In TINE, this is calculated as the total number of items sold per month divided by the average number of items in inventory in the same period. The turnover rates for the reference products are presented in Table 6-9. In addition, the average number of days in inventory for the products in the national market was calculated and compared to the number of days of shelf life TINE can consume according to the Norwegian industry standard.

Table 6-9: Inventory turnover, reference products

ID	Product type	Inventory turnover (month)	Inventory turnover (year)	Average days in inventory	Days available to TINE	% of available time consumed
1	Norvegia	3,9	47,0	8,8	30	29 %
2	Jarlsberg	8,1	97,4	4,6	30	15 %
3	Jarlsberg	7,7	92,4	4,4	30	15 %
4	Grated cheese original	7,3	87,6	4,6	30	15 %
5	Norvegia	5,5	65,5	6,6	30	22 %
6	Norvegia/Jarlsberg	3,2	38,9	10,3	30	34 %
7	Norvegia	5,6	67,8	6,2	30	20 %
8	Jarlsberg	4,5	54,3	7,3	30	24 %
9	Norvegia	4,0	48,4	7,8	30	26 %
10	Jarlsberg	3,7	44,0	10,1	/////	/////
11	Jarlsberg	2,4	29,2	14,6	/////	/////
12	Jarlsberg	2,3	27,3	11,9	/////	/////
13	Burger cheese	1,4	16,9	26,0	30	86 %
14	Norvegia	5,2	62,8	6,9	30	23 %
15	Norvegia	4,0	48,4	7,9	30	26 %

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[18] For products with a shelf life of between 17-150 days, the shelf life is currently distributed with 1/3 each for producers, distributors/wholesalers, and retailers and consumers combined.

Average inventory turnover per month for the reference products was 4,6 (55,2 for the year), varying from 1,4 for a newly launched product[19] to 8,1 for one of the high-volume products. On average, the products consumed 25 % of the time available to TINE in inventory, varying from 15 % for the fastest-moving products to 86 % for the slowest moving product.

The limited shelf life of food products means that products which expire before they are sold to customers must be scrapped. In addition to product expiry, the internal 'sell-by' date deter-mines the number of days of shelf life a product must have remaining when it is sold to wholesalers, thus further reducing the amount of products available for sale. In cases of ex-cess inventory, TINE's main options are to (in order of priority):

1. Offer discounts to wholesalers in order to increase sales
2. Sell the products as animal feed, inputs to other food producers or other lower-value products
3. Dispose of the products

In 2011, scrapping costs were recorded for only four of the reference products (2, 8, 14, 15), representing a very small proportion of the total volume. The most used alternative in TINE is to offer discounts to wholesalers, and therefore inventories are continuously monitored with regards to products approaching their 'sell-by' date and options found to avoid scrapping. However, the value loss of selling products at discounted prices, as animal feed or as inputs to other types of food production is not recorded.

Although the analyses were unable to quantify the full costs and value losses related to excess inventory, the general impression is that this is a relevant issue – evidenced by the fact that there is a formal process for monitoring and managing products approaching their 'sell-by' date. In addition, this approach is consuming sales and administrative resources, as well as generating disposal costs for products that cannot be sold.

In summary, the analyses of inventory show that TINE currently to a large degree uses inven-tory to buffer against demand uncertainty. Given the fact that forecast accuracy is fairly low and variable, and that perishability limits the amount of time products can spend in inventory, determining the right inventory levels is challenging. The result is value loss, reduced product quality in terms of remaining shelf life when products are sold to customers, and some scrap-ping.

6.2.1.4 *Capacity utilisation*

TINE calculates the capacity utilisation of production lines as hours produced on each line compared to available manpower[20]. Figure 6-18 shows the capacity utilisation per production line in 2011.

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[19] The very low turnover of this product is probably due to the fact that the product was not removed from the ERP system when it was delisted. Thus, the product generated inventory data even though it was not available for sale.

[20] Calculated as number of hours produced per line per week divided by available hours manpower per line per week
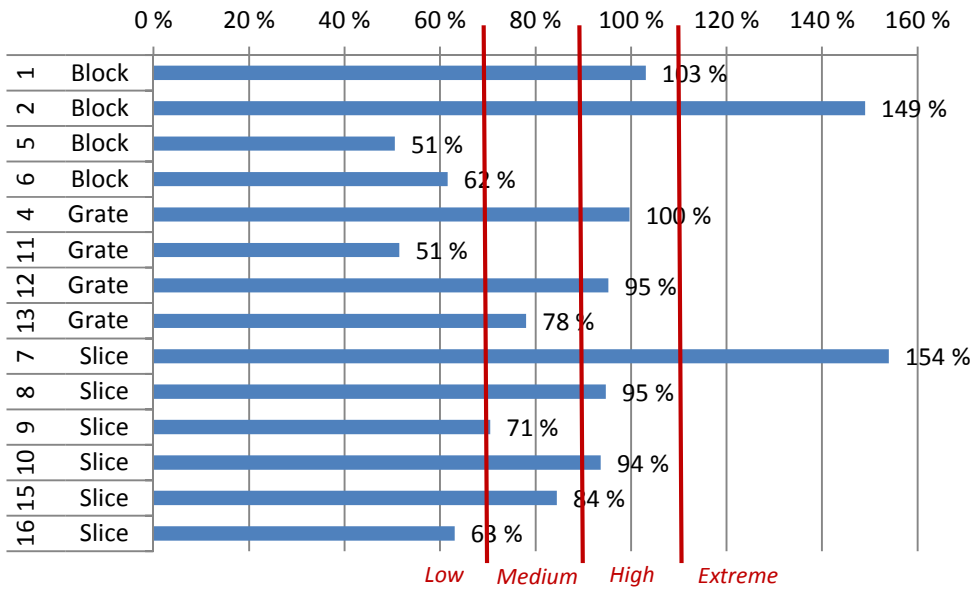
Figure 6-18: Capacity utilisation per production line, 2011

Utilisation above 100 % in Figure 6-18 signifies that overtime has been used. The figure shows that two of the lines can be classified as having achieved extreme capacity utilisation (>110 %), six had high utilisation (90 % -109 %), two medium (70 % -89 %) and four low capacity utilisation (<70 %). The average utilisation per line type was 91 % for blocking lines, 81 % for grating lines and 93 % for slicing lines.

High-volume industrial sectors like food generally have fairly high capacity utilisation rates and TINE Heimdal appears typical in this respect.

Wholesalers in Norway impose very high service level requirements on their suppliers, and failure to fulfil orders can have serious negative consequences. Therefore, large efforts are made by TINE to meet the requirements. In cases where the weekly plan received from the central production planner exceeds available capacity at TINE Heimdal, the facility's inventory can either be supplemented from other facilities or capacity can be increased through the use of overtime.

Overtime is only registered in personnel files and exact data on the extent and timing of the use of overtime was not available for the study for confidentiality reasons. However, consumed machine hours per production line are registered on a day level and therefore any production on Saturdays and Sundays can be classified as overtime; see Figure 6-19.
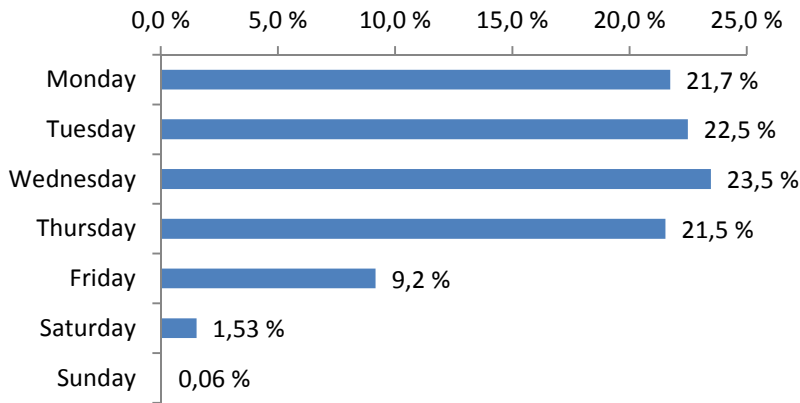
Figure 6-19: Consumed machine hours per weekday at TINE Heimdal, all products

From Figure 6-19, it can be seen that 1,59 % of the total machine hours in 2011 were consumed during weekends. In total, overtime was used on 15 Saturdays and two Sundays, constituting use of overtime every 3,5 weeks on average. In addition there is often overtime on weekdays, but this could not be quantified due to the confidentiality issues related to personnel files.

Although the need to use overtime can also be the result of machine breakdowns, unscheduled maintenance and other factors not related to PPC system performance, the central and local planners confirm that overtime frequently is used to avoid stock outs and to fulfil customer orders. The fact that weekend overtime is used at least every 3,5 weeks indicates that the current PPC system is not efficient in meeting customer requirements, i.e. that fulfilling demand effectively requires more than the planned expenditure of time and effort.

Figure 6-19 also shows that most machine hours are consumed on Tuesdays and Wednesdays. From a logistics point of view this is not optimal. Producing larger volumes closer to the weekend would enable much of the non-value adding cool-down time to take place during the weekend such that the products could be released for sale early in the following week. One of the possible explanations for this less than optimal solution is the facility's policy of 6-hour work days and the number of available shifts per day agreed with labour unions (two shifts Monday to Thursday, one shift on Friday).

In summary, the facility appears to have enough capacity to meet demand. However, the balancing of capacity with available manpower and demand uncertainty is challenging. The fairly high capacity utilisation means that increasing flexibility through smaller batch sizes and more frequent changeovers is likely to increase costs – and conversely that higher capacity utilisation may reduce the degree of flexibility.

6.2.1.5 Qualitative aspects

PPC performance depends on how the system is designed in terms of policies, rules, and procedures to guide the PPC process, as well as the information systems and tools that are available to support decision making. During the data collection and quantitative analyses, a number of qualitative aspects were uncovered which are thought to have had an impact on the performance of the PPC system.

On an overall level, TINE's PPC system to a large degree appears to be the result of traditions and procedures that have developed over the years. There is a more or less formalised planning process in place but this does not appear to have been the result of a holistic design process aiming to maximise the overall performance of the PPC system across planning levels. In their daily work, planners naturally focus mostly on operations and the short and medium term challenges of meeting customer demand and internal performance targets. It is unclear who is responsible for the overall design of the PPC system and following up its performance in a holistic perspective. The task of planning and controlling production at TINE Heimdal is also characterised by a large degree of human decision making at both the central and local level. The result is that the PPC task is fairly resource demanding, involving one central production planner, two raw material replenishment planners and two local planners.

The current PPC system is characterised by great dependence on individual employees and a lot of manual decision making. The fact that the weekly planning for the three packing facilities is performed based on one production planner's experience and knowledge makes the system highly vulnerable to absenteeism, employee turnover, etc. – particularly since there is no formalised process for how forecasts and other types of information is used in the centralised planning process. The local planning at TINE Heimdal is performed by two PPC resources, although there are several employees with experience from daily PPC which somewhat reduces the vulnerability at the local level.

Although there is a lot of knowledge in the organisation about the different factors which impact on demand uncertainty, the exchange and use of this information for PPC purposes is not formalised to any large degree. The central planner stated that he often feels he does not have access to all relevant information from the sales teams or the individual facilities when developing the weekly plans. There are examples of informal guidelines for reducing demand uncertainty. Newly launched products are for instance 'protected' from market activities in the first few months. This allows the product's sales and production processes to stabilise before additional demand uncertainty is introduced. However, the decision about when a launched product can be subjected to market activities is not formalised or based on quantitative analysis of for instance demand variation.

The decoupling of central and local planning processes increases the risk of mistakes and reduces the efficiency of PPC resources since it requires additional coordination and communication. This challenge is further reinforced by the use of different planning and decision support tools at the central and local level.

A number of weaknesses and errors in master data were revealed during the data collection and analysis. It was for instance discovered that the ERP system was not set up to count Saturday and Sunday as part of production lead times. This added unnecessary cool-down time for products produced before a weekend, where products could potentially have been released for sales two days earlier – with two days of 'extra' shelf life. Such errors in master data and local planning tools can reduce the quality of the information on which PPC decisions are made.

The fact that local production planners only have access to information on forecasts for the upcoming week means that it is difficult to spread production over more than one week to increase capacity utilisation or build inventory in preparation for scheduled downtime related to for instance maintenance of production equipment. Market activities are for instance normally planned by the sales team in collaboration with retail chains six weeks before a cam-

paign but there is a 1-2 week delay in the communication of this information to facilities. Also, export orders with several weeks or months order lead time allowances are only visible to the facility in the week where they need to be produced to meet the agreed delivery date – and the facility is therefore not able to spread the production of such large orders over more than one week. In addition, the export orders are usually given priority over production for the national market because the order must be complete 'when the boat is scheduled to leave'. In many cases, this leads to overtime and re-scheduling at the facility.

A number of KPIs are used to follow up PPC performance at the central and local level. In some cases employees experience these as conflicting and leading to sub-optimisation. There is for instance a general understanding that export orders should have top priority in production. Thus, such orders for products with low perishability and long customer order lead time allowances are usually prioritised over ordinary production, reducing the stability of plans and disturbing the ordinary production.

6.2.2 Differentiation

Differentiation can take many forms at different levels of an organisation. Below, the current differentiation at TINE's strategic, tactical and operational levels is described and discussed in terms of the relevance for PPC.

6.2.2.1 Strategic level differentiation

As mentioned, TINE has three main production facility types; dairies, cheese factories and packing facilities. Thus, at the strategic level, the production network is currently differentiated according to product types – where products requiring the same type of production equipment and processes are produced in the same type of facility. This in theory allows the PPC function to see several facilities of the same type as one such that production planning can be based on the total capacity in the network. This principle is to a certain extent used for the packing facilities where one planner is responsible for the weekly production planning of all three facilities. There are plans to implement the same model for dairies and cheese factories as well but currently this is not the case.

The recent reorganisation of the TINE Group was also carried out in order to further strengthen the existing structural differentiation. Instead of organising the operations function according to geographic location, facilities are now organised according to facility type. This means that facilities producing liquid products are organised and managed together, while facilities producing solid products are managed together. This new organisation enables more knowledge-sharing and increased organisational learning across facilities.

In addition to the structural differentiation, distribution is differentiated at the strategic level so that low-perishability products are distributed through wholesalers while high-perishability products are distributed directly to customers (e.g. retail stores, HORECA customers and institutions).

6.2.2.2 Tactical level differentiation

The current overall PPC approach in TINE is MTS. However, the tactical determination of how different products are managed is based on a number of supply and demand related factors.

TINE's role as market regulator of raw milk means that the company has an obligation to receive all milk produced by Norwegian milk farmers, as well as regulate fluctuations in the milk supply in the short and medium term. This means that PPC decisions are highly influenced by the amount of incoming raw material and how this can be managed and distributed among the different products. For this purpose, TINE has developed a differentiation framework for how different products should be planned – where some are supply focused, i.e. candidates for regulating incoming raw material through buffering, while others are more demand focused where the aim is to balance supply with demand. In addition, product perishability is considered.

Bulk cheese is a good example of a supply focused product. Its low perishability and long maturation periods makes this a suitable product for buffering milk in periods where supply is higher than the total demand for milk. This is also done in anticipation of periods where demand exceeds supply, i.e. when the available milk must be used to meet the demand for consumer milk and other highly perishable products. Another key buffering product is low-fat milk powder. The production of cream requires extraction of fat from the raw milk and the remaining milk powder is then used to store the remaining usable raw material. The powder has low perishability and is used as input in TINE's own yoghurt production, and in cases of excess, sold to other food producers as raw material. Butter is another product that is suitable for buffering since it can be frozen without any considerable quality loss, and then defrosted and sold in periods where demand is higher than the supply of milk.

At the other end of the scale are the more demand focused products. These are products which are not suitable for buffering, and PPC therefore aims to balance supply with demand. Examples include consumer milk, yoghurt and consumer packaged cheese.

The differentiation between supply and demand focused products is linked to the drivers of PPC decisions. As previously mentioned, the main driver for all of TINE's product categories is forecasts. However, in addition to this, product perishability is considered. This means that for the more perishable products (bottom half of Figure 6-20), the amount of incoming raw material is an important factor for supply focused products, while for demand focused products production volumes are adjusted during the day based on incoming demand signals/orders. For the less perishable products (top half of Figure 6-20) some time in inventory is possible and here the PPC focus is therefore on maximising capacity utilisation. In addition, for the supply focused products, PPC must ensure that input factors are buffered in times of excess raw materials or in anticipation of periods where demand is expected to exceed milk supply.

Examples of supply and demand focused products and their PPC drivers are shown in Figure 6-20.
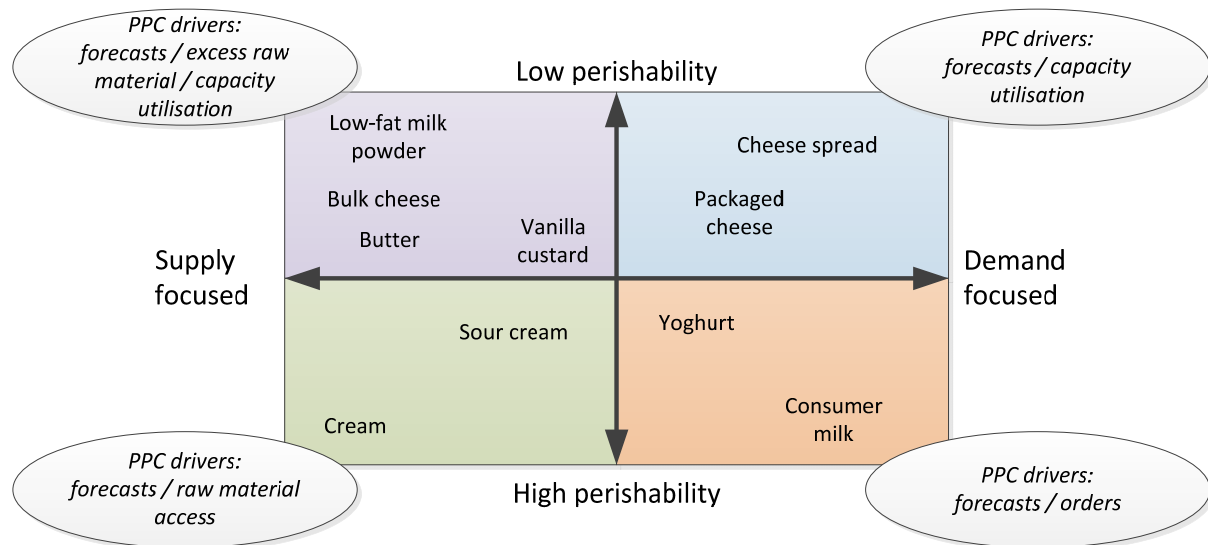
Figure 6-20: Current tactical level differentiation in TINE

6.2.2.3 Operational level differentiation

The products produced at TINE Heimdal are all located in the top right-hand box of Figure 6-20. This means that production is demand focused and the current drivers for PPC are therefore forecasts and maximising capacity utilisation. At the operative facility level there is very little differentiation in the way products are planned and controlled.

In addition to the PPC differentiation described above, there is also some differentiation related to how export orders are managed. Production (i.e. packing) of export items at TINE Heimdal was in 2011 based on orders instead of forecasts. Export customers usually allow long lead times for their orders, and since these orders usually involve large volumes, customers accept that one individual delivery can consist of products with different expiry dates since production has to be spread over several days. However, in terms of PPC, export orders are entered into the ERP system with the due date agreed with the customers and added to the ordinary sales forecast for weekly planning. In this way the export orders are included in the MRP calculation and production is scheduled to start as late as possible to meet the agreed due date.

6.2.2.4 Summary on current differentiation

From the above descriptions, we see that there is some degree of differentiation at the structural level in the TINE network. The grouping of facilities into dairies, cheese factories and cheese packing facilities has allowed TINE to decouple the cheese making process at the bulk level. Since maturation periods for cheese are fairly long and variable due to the biological nature of the products, and cheese can be stored in bulks, the decoupling of the cheese making process from the packing process seems appropriate. The use of forecasts as a basis for PPC for the production of bulk cheese also seems appropriate since the lead time of the production process far exceeds the customer order lead time expectations, making an MTO approach to PPC impossible in most situations. On the other hand, the decoupling represents an opportunity to use an MTO approach for the packing process since this in many cases is within the cus-

tomer order lead time allowance. Thus, for TINE Heimdal, differentiated PPC with a mix of MTS and MTO approaches is feasible[21].

The PPC decisions in the two left-hand boxes of Figure 6-20 are driven by incoming raw material. Thus, differentiated PPC combining MTS and MTO based on differences in customer order lead time and demand uncertainty is not relevant. The products in these boxes are typically made at dairies and cheese making factories, providing additional support for the decision to cut case 2 (dairy) and 3 (cheese factory) from the study. Thus, as long as TINE has the market regulator role, the differentiation based on supply and demand focused products seems appropriate.

On the other hand, the products in the two right-hand side boxes of Figure 6-20 appear to be good candidates for differentiated PPC since this can assist the company in balancing supply and demand for these products. Currently, TINE Heimdal is producing nearly all its products using the same PPC approach – despite there being considerable variation in customer order lead time allowances, product perishability and demand uncertainty.

6.2.3 Summary; challenges and improvement potential

The analysis of TINE and TINE Heimdal resulted in a number of key findings with regards to food sector characteristics and the way food production is currently planned and controlled.

The analyses largely support the assumptions and findings from chapter 4 on food sector characteristics. At the company level, the mismatch between supply chain characteristics was confirmed, with market and product characteristics pushing for responsiveness, while the production system favours large batch sizes and economies of scale. This mismatch impacts on PPC in the way that the TINE Heimdal facility must meet the market demand for high responsiveness mainly through large finished goods inventories.

The analyses further confirm the trend of growing complexity in PPC stemming from increasing product proliferation and demand variability. This trend is making it increasingly difficult for PPC resources to plan and control the entire range of products in an effective and efficient manner. Differentiation of PPC was in chapter 3 identified as a potential solution for meeting these challenges – enabling companies to identify the 'focus box' for PPC. However, the case study showed that although there is some differentiation at the strategic and tactical level in TINE, there is limited differentiation of PPC.

The analysis of PPC performance found that although TINE Heimdal'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. Thus, the fairly low and varying forecast accuracy means that large inventories are used to buffer against demand uncertainty – leading to high inventory carrying costs, scrapping costs for expired products, and income loss due to price reductions for products with short remaining shelf life. There was also considerable use of overtime to meet higher than forecasted demand, as well as transport between TINE facilities

[21] In TINE Heimdal's case, the most relevant PPC approaches are packing to stock or to order, but for simplicity these two options are in the case study referred to as MTS and MTO respectively.

and disturbances to PPC at other facilities. In sum, it can be concluded that although the company's current MTS approach appears effective in meeting customer requirements in terms of service levels, this comes at the expense of efficiency in production, inventory and PPC performance.

TINE does practice differentiation of PPC when it comes to export orders. However, the current backward scheduling of these orders means that they are incorporated into the MTS schedule in a way which does not enable the facility to exploit these orders' favourable characteristics to provide flexibility. The export orders are also prioritised over ordinary production, leading to frequent rescheduling.

Related to the difficulty in identifying the products which could benefit the most from additional focus in the PPC process, the COV proved to be of little value since nearly half of the products were classified as high demand variability products. Although the COV could assist PPC resources in prioritising their time and attention to the products that are the most difficult to plan, the traditional 0,4 cut-off seems fairly arbitrary. Instead, demand predictability appears to be a better variable for identifying products requiring particular attention in PPC.

Another interesting finding is that although TINE agrees with customers on the volumes of market activities several weeks in advance, the volumes related to such activities cannot be considered to have high demand predictability. The data indicates that market activities reduce the forecasting accuracy despite the advance volume agreements with customers.

Finally, the analyses revealed that the current PPC process involves a lot of manual decision making, making the PPC task resource demanding and exposed to risks of human errors. Also, although there is considerable knowledge in the organisation on PPC and factors which impact on demand uncertainty, the exchange and use of information from different functions in TINE is not very formalised or standardised.

6.3 New solutions for planning and control

The purpose of the analyses in the previous sections was to identify improvement opportunities for PPC in TINE. This section firstly outlines the overall process that was followed to redesign the PPC system. Next, the concept and framework from chapter 5 are operationalised and the results used to design the new solutions. Finally, some reflections on the potential benefits of the proposed solutions are presented.

6.3.1 Design process for differentiated planning and control

TINE at an early stage of the study showed an interest in the potential for differentiating their PPC approaches and actively participated in investigating possible avenues and discussing potential solutions. For TINE, the design of a new PPC solution had three main purposes:

- Simplify the PPC process and reduce the number of manual decision making tasks
- Standardise and validate the planning process
- Identify the 'focus box' for PPC, i.e. the products that should be allocated the most time and resources in central and local PPC

The first step in the design process was a mapping of the company's strategic priorities and objectives to identify the objectives for the solutions to be developed. The most important

performance measure was identified to be customer service levels. This meant that any new solutions would have to maintain or increase the facility's current service level performance.

Step two was to investigate if there were any other important internal or external aspects which constrained the solution possibilities. In brief, these included the variable milk supply (see sub-section 6.1.1.4) and the current strategic and tactical level differentiation in the company (see sub-section 6.2.2).

Step three was the mapping and analysis of the current performance of the company's PPC system. This enabled the identification of challenges and opportunities for improvement. The results of this step are documented in section 6.2, where the main conclusion was that although the case facility may be effective in meeting external requirements in terms of service level, there appears to be a potential for increasing the efficiency in how the internal production and inventory processes are planned and controlled.

In step four, the differentiation concept and framework from chapter 5 were used as exemplars to design the new PPC solution, thus identifying the most appropriate PPC approach for each of the reference products and the associated techniques which should be used to buffer against demand uncertainty. This step required a number of quantitative and qualitative analyses and involvement of experts from different functions and planning levels in the company. The outcome of this step is documented in the next sub-section.

6.3.2 New solution for differentiated planning and control

In order to design the new PPC solution for TINE Heimdal, the supply chain configuration of each reference product had to be identified before the new PPC approaches and relevant buffering techniques for each product could be determined.

6.3.2.1 *Identifying TINE Heimdal's supply chain configurations*

The first principle in the concept for differentiated PPC is to match supply chain configurations with the most appropriate PPC approaches, i.e. MTS or MTO. In order to do this, the differentiation framework developed in section 5.2 provides the dimensions of product and market characteristics which need to be mapped to identify the configurations of each of TINE Heimdal's products. Based on the framework, each of the 15 reference products were mapped according to the three key dimensions; product perishability, customer order lead time allowance, and demand predictability.

Product perishability was easily determined since each of TINE Heimdal's products has a fixed shelf life which starts counting when packing starts. All the 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 TINE Heimdal 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. Initially the COV with a cut-off of 0,4 was used to group the products into predictable and unpredictable. How-

ever, it was decided that this variable did not capture enough of the complexity of demand predictability (see sub-section 6.2.1.1). Instead, a more comprehensive analysis was required to determine each product's demand predictability. As a result, a decision tree was developed to capture 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 and communication with experts from different parts of TINE (central and local PPC, sales, marketing, ICT, managers at the strategic, tactical and operational level, etc.) in order to identify factors, determine data requirements, perform analyses, determine cut-off limits, and interpret findings.

The demand predictability was operationalised into a number of qualitative and quantitative factors and resulted in a decision three that could be used in the evaluation process.

The first aspect to determine is the product's stage in the PLC in the coming planning period, i.e. whether the product is still within the first three months of its launch, an established product with historic demand data, or part of a more casual, one-off or customised order.

For newly launched products, the product's degree of innovation must be determined. This is a qualitative evaluation which must be performed by resources with expert product and market knowledge. If the degree of innovation is high, the product must be classified as having low demand predictability since any forecast would be associated with a high degree uncertainty. On the other hand, if the product's degree of innovation is low, there may be historic demand data for similar existing products that can be used as a template to generate a good forecast for the new product. Next, whether or not the product has been listed with the different retail chains and wholesalers must be determined. If the listing has not been confirmed for all major customers, the product must be classified as having low demand predictability. If the listing has been confirmed, the quality of the historic demand data of the reference product(s) which will be used to generate the forecast must be evaluated. If the data quality and historic forecast accuracy of the comparable product is low, the new product must be classified as having low demand predictability. If the quality is deemed satisfactory, the new product's type of listing with each retail chain must be investigated. If the product will not be part of chains' compulsory assortment, the demand predictability is considered low since TINE does not know which and how many shops will carry the product. If the listing is compulsory, the demand predictability can be considered high.

The demand predictability of established products is mostly affected by the presence of market activities. If the product will be subjected to market activities in the planning period, the forecast accuracy for the product related to previous and comparable market activities must be evaluated[22]. If the historic forecast accuracy of market activities is below 70 % (see justification below), the demand predictability is considered low. Although this is mainly a quantitative evaluation, there needs to be a qualitative assessment to ensure that the product has been subjected to enough comparable market activities in the past for the historic forecast accuracy to be relevant. If the product will not be subjected to market activities, the historic forecast accuracy of ordinary sales must be evaluated (i.e. historic accuracy in weeks without market activities). If this is below 70 %, the demand predictability is considered low. Finally, the

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[22] The analyses of demand uncertainty found that some of the reference products actually had higher historic forecast accuracy during market activities than during ordinary sales. Demand related to market activities should therefore not automatically be classified as low predictability and an evaluation of the product's historic forecast accuracy in periods with comparable market activities is therefore relevant.

product's sensitivity to other factors which are thought to impact on demand predictability for the company's products must be considered. This is a qualitative evaluation which must be performed by expert resources with knowledge of how the product's demand is affected by weather, seasonality, public holidays and other known circumstances. If the sensitivity is high, demand predictability is classified as low.

The final PLC stage is relevant for casual, one-off special orders related to export, specific events or other extraordinary market activities. Since the company usually does not know when such orders will arrive, for which products and in which quantities, there is low demand predictability associated with these products.

Figure 6-21 summarises the decision tree for the determination of a product's demand predictability.
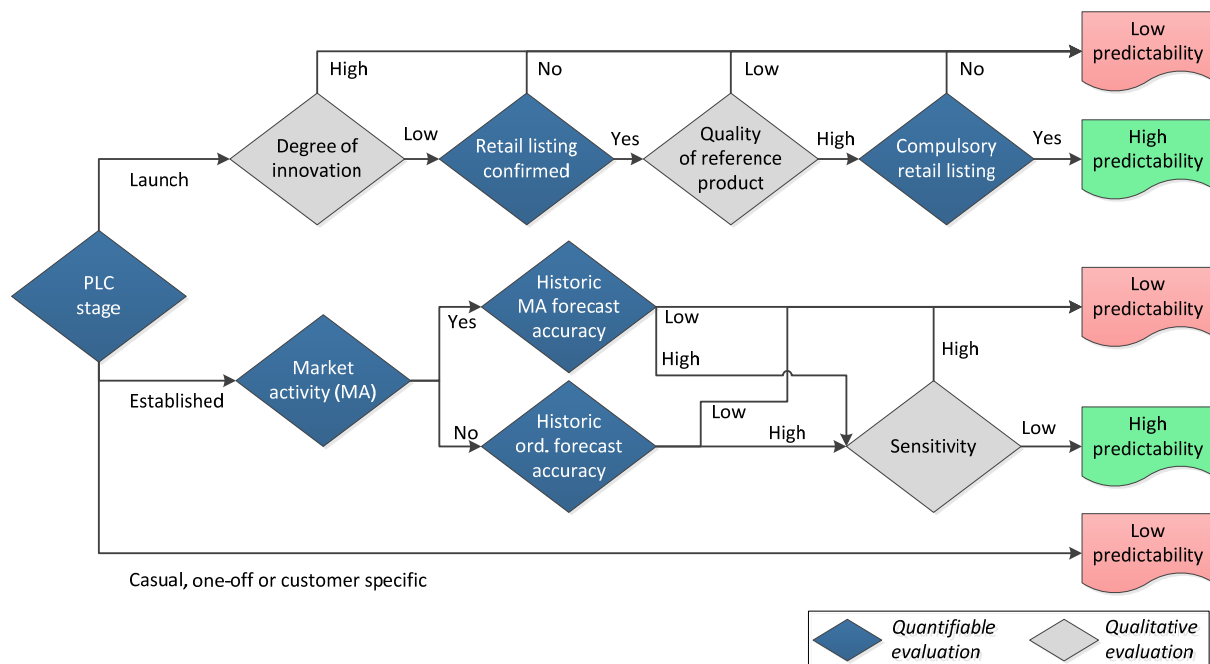
Figure 6-21: Decision tree for evaluation of demand predictability

The 70 % cut-off limit for forecast accuracy in the decision tree was determined in discussions with TINE representatives and was based on a combination of factors. One aspect is that since TINE does not have very many customers, the timing of for instance orders and price changes can have artificial effects on forecast accuracy. Further, since customer orders are highly affected by manual decisions made by purchasers, the order sizes contain an element of irrationality. In addition, TINE has limited information about the demand pattern of consumers, which means that TINE's demand variability is artificially amplified by wholesalers and retailers. Further, while TINE's base forecast is automatically calculated using the algorithm defined in the forecasting software, the forecast is manually adjusted by planners and thus another element of irrationality is introduced. In total, the above factors mean that TINE currently considers 70 % forecast accuracy to be satisfactory.

In Table 6-10, the data required to evaluate the demand predictability of the 15 reference products is shown.

Table 6-10: Data for evaluation of demand predictability, reference products

ID	Product type	PLC	Degree of inno-vation	Forecast accuracy	
				Ordinary sales	Market activity
1	Norvegia	Established		High	Low
2	Jarlsberg	Established		High	High
3	Jarlsberg	Established		High	Low[23]
4	Grated cheese original	Established		High	High
5	Norvegia	Established		Low	Low[23]
6	Norvegia/Jarlsberg	Established		Low	Low[23]
7	Norvegia	Established		High	High
8	Jarlsberg	Established		High	High
9	Norvegia	Established		High	Low
10	Jarlsberg	Export (casual)			
11	Jarlsberg	Export (casual)			
12	Jarlsberg	Export (casual)			
13	Burger cheese	Launch	Low		
14	Norvegia	Launch	Low		
15	Norvegia	Launch	Low		

For the established products, the evaluation of sensitivity to other factors was not possible to recreate and forecast accuracy was therefore used to determine the degree of demand predict-ability[24]. In cases where the number of weeks with historic market activities was very low, the demand predictability was classified as low.

The three export products were all classified as casual orders and therefore associated with low demand predictability since the timing and volume of such orders are difficult to forecast. The analyses did on the other hand show that product 10 had a forecast accuracy of 73 % which is fairly high.

For the three products that were launched in 2011, the degree of innovation was low since all three were extensions of existing product lines. Information on confirmation and type of retail listing and the quality of relevant reference products was not possible to recreate.

Based on the above, the 15 reference products were located in the configuration framework based on their perishability, customer order lead time allowance and demand predictability, where:

- Low perishability was defined as products with a shelf life of more than 11 days

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[23] For these products, there was no or not enough historic data to determine forecast accuracy for market activi-ties. These were therefore classified as low predictability.
[24] Although some of the evaluations in the decision tree were difficult to carry out on the historic data, the classi-fication of the different products was validated with TINE representatives and considered to represent the reality fairly well.

- Long customer order lead time was defined as customers allowing more than one day delivery time
- Demand predictability was determined using the data in Table 6-10

Below, the configurations are illustrated graphically, where Figure 6-22 shows the relevant configurations for periods with ordinary sales and Figure 6-23 for periods with market activities.
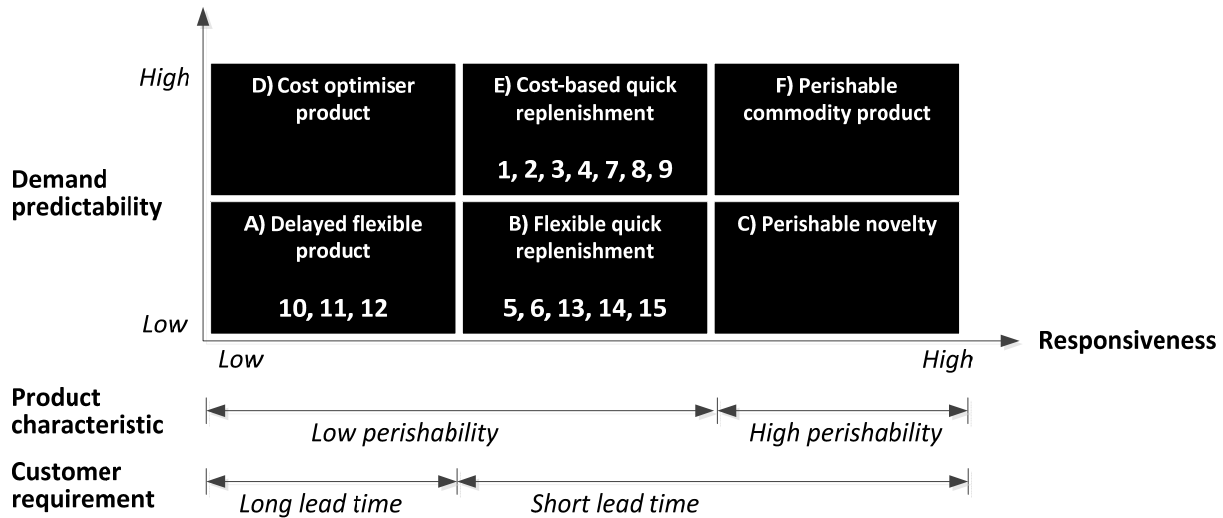
Figure 6-22: Mapping of configurations for reference products, ordinary sales
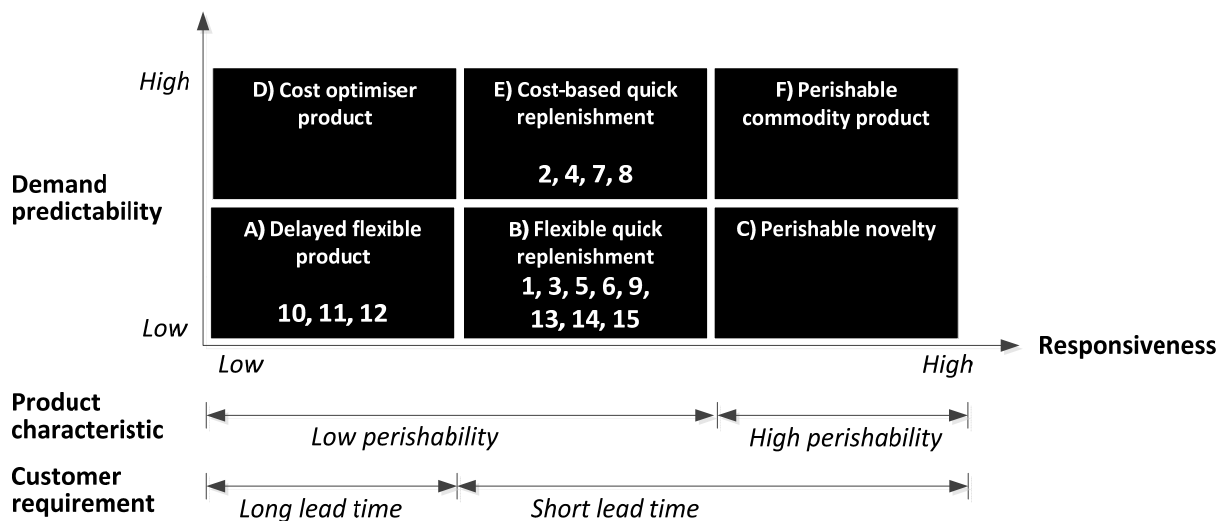
Figure 6-23: Mapping of configurations for reference products, market activities

The figures above show that for the 15 reference products, three configurations are relevant;

- Configuration A – delayed flexible product supply chain
- Configuration B – flexible quick replenishment supply chain
- Configuration E – cost-based quick replenishment supply chain

It was found that three products (1, 3 and 9) would change configurations from E to B in periods with market activities compared to periods with ordinary sales.

6.3.2.2 *Proposed PPC approaches and buffering techniques*

The previous sub-section addressed the first principle of the configuration concept; identification of supply chain configurations as input to a differentiated PPC solution. Once the configurations of the 15 reference products had been identified, the framework from section 5.2 was used to design the new PPC solution. Firstly, the appropriate PPC approaches which can exploit the favourable characteristics were identified (principle 2), and secondly, the types of slack resources to be used to buffer against demand uncertainty were determined (principle 3).

The resulting current and proposed PPC approaches of the reference products in periods with ordinary sales situations and during market activities are shown in Table 6-11.

Table 6-11: Current and proposed PPC approaches, reference products

ID	Product type	Current	Proposed	
			Ordinary sales	*Market activities*
1	Norvegia	MTS	MTS	MTO
2	Jarlsberg	MTS	MTS	MTS
3	Jarlsberg	MTS	MTS	MTO
4	Grated cheese original	MTS	MTS	MTS
5	Norvegia	MTS	MTO	MTO
6	Norvegia/Jarlsberg	MTS	MTO	MTO
7	Norvegia	MTS	MTS	MTS
8	Jarlsberg	MTS	MTS	MTS
9	Norvegia	MTS	MTS	MTO
10	Jarlsberg	MTO	MTO	MTO
11	Jarlsberg	MTO	MTO	MTO
12	Jarlsberg	MTO	MTO	MTO
13	Burger cheese	MTS	MTO	MTO
14	Norvegia	MTS	MTO	MTO
15	Norvegia	MTS	MTO	MTO

Table 6-11 shows that 12 products are currently MTS while the three export products are MTO. In the proposed solution, five of the reference products change from MTS to MTO in ordinary planning situations (two established products and the three newly launched products), while in periods of market activities, another three established products change from MTS to MTO.

The changes in the mix of MTO and MTS approaches from the current to the proposed solution are illustrated graphically in Figure 6-24.
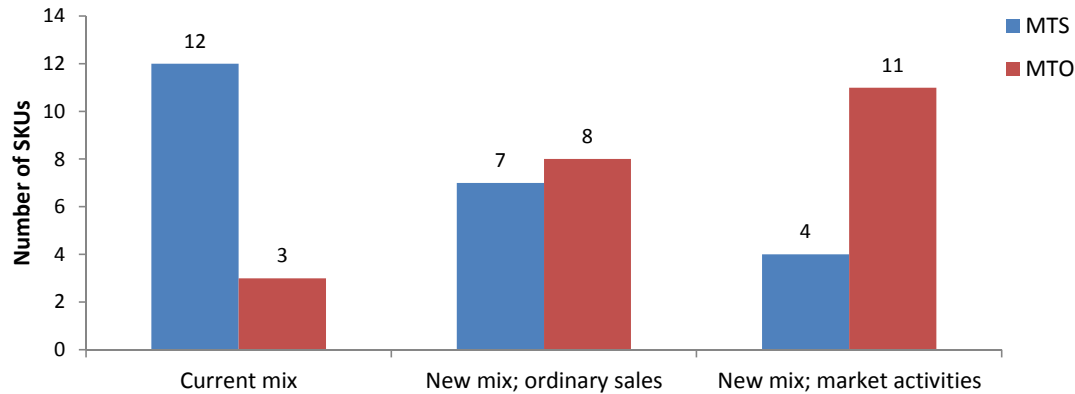
Figure 6-24: Current and proposed mix of MTO and MTS, reference products

The mapping of the current PPC system found that the main buffering technique for addressing demand uncertainty in TINE is finished goods inventory. In addition, there is some buffering in terms of time through MTO for export items. In addition to the application of more MTO production, the differentiation concept means that the facility should move from a focus on finished goods to also planning with excess capacity and use inputs and intermediates to buffer against demand uncertainty.

For export products in configuration A (products 10, 11 and 12), the main buffering technique should be time through the MTO approach and inputs in terms of intermediates and packaging material. Buffering capacity will make it possible to postpone the start of production, which will reduce the risk of obsolescence since it keeps raw materials in a neutral state, allowing them to be used for several customer orders. Also, it postpones the start of consumption of the products' shelf life and eliminates the potential waste of resources consumed to produce products that are not sold. The buffering of inputs ensures that production does not have to wait for these to be ordered and delivered before the customer order can be put into production. Since these products have low perishability they can also be used to level production.

The newly launched products (products 13, 14 and 15) all belong to configuration B, where the main buffering technique should be time through the MTO approach, capacity, and intermediates and packaging material. Again, postponing the start of production requires a capacity buffer and can reduce the risk of obsolescence since it keeps raw materials in a neutral state and postpone the consumption of the products' shelf life. The buffering of inputs ensures that production does not have to wait for these before the order can be put into production. In addition, production should focus on reducing changeover times to make sure the product can be produced within the short customer order lead time.

For the established products in configuration E, buffering should take place through finished goods inventory in a situation of ordinary sales. This allows focus on economies of scale through maximisation of capacity and resource utilisation, and the finished goods inventory buffer enables the facility to meet the requirements for shorter customer order lead time.

For the established products in configuration B, buffering should be through capacity, inputs and time.

In situations with market activities, the established products 1, 3 and 9 move from configuration E to configuration B, meaning that in periods of market activities, the facility should re-

place the finished goods buffering with excess capacity and buffering of inputs and time for these products.

The buffering techniques in the proposed solution are summarised in Table 6-12.

Table 6-12: Buffering techniques in proposed solution, reference products

Configuration	*Buffering technique*	*Ordinary sales*	*Market activities*
A Delayed flexible product	Inputs and time	10, 11, 12	10, 11, 12
B Flexible quick replenishment	Capacity, inputs and time	5, 6, 13, 14, 15	1, 3, 5, 6, 9, 13, 14, 15
E Cost-based quick replenishment	Finished goods	1, 2, 3, 4, 7, 8, 9	2, 4, 7, 8

Above, the new principles for how the individual products of TINE Heimdal should be planned and controlled were described. In order to achieve the full benefits of the proposed solution, some changes to the overall PPC system of TINE may also be appropriate.

To be able to exploit the long customer order lead time allowances, it may be appropriate to make the planning horizon for local planning longer. This will increase the information visibility for local planners, enabling them to spread production volumes over a longer time period. Also, the current policy of backward scheduling for MTO items should be reviewed, at least for products with low perishability, since the current policy makes the production system highly vulnerable to machine breakdowns, product quality problems, and other unexpected factors which currently disrupt production.

During the case analysis, it was also revealed that the level of safety stock for all products in TINE is currently manually determined and not based on any established rules or policies. Thus, a revision of how safety stock levels are determined should be included in the implementation of a new PPC system.

Further, TINE could benefit from taking a more holistic approach to PPC design. The redesigned PPC system should enable better integration of central and local planning, as well as ensure that information sharing across organisational functions is built into the PPC process. The new system should also be supported by integrated PPC decision support tools and be less based on manual decision making, thus enabling the PPC function to better support operations and more effectively and efficiently achieve the goals set in the operations strategy.

6.3.3 Potential benefits

In the case analysis, it was concluded that at the "one size fits all" approach to PPC in TINE does not appear to provide TINE Heimdal with sufficient flexibility to meet customer requirements in an effective and efficient manner – evidenced by the fact that although customer service levels are high, there are inefficiencies in production, inventory and PPC performance.

In sub-sections 6.3.1 and 6.3.2, a new PPC solution was designed to meet the need for increased flexibility in TINE's production system. The differentiation approach to how products are planned and controlled can enable the facility to better respond to variability in demand –

while still delivering the requested product variants, in the quantities required and within customer order lead time expectations.

Ideally, the new PPC solution should have been implemented as part of this research so that the benefits of the proposed design could have been measured and verified. Unfortunately such a research strategy was not possible within the mandate and available time and resources of the study. Instead, expected benefits were substantiated through a combination of logic reasoning and joint reflections with case representatives.

Below, some of the expected benefits of the proposed solution are outlined, structured according to the typical performance objectives for the operations function (see also sub-section 3.3).

Quality

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 for such items will enable shorter response times in the production system. Export items are currently prioritised in PPC, mainly due to inflexibility in outgoing shipping time schedules. Although these products are already MTO, the current backward scheduling makes the production vulnerable to machine breakdown, product quality problems, and other unexpected factors which currently reduce service levels. By extending the planning horizon in PPC and moving away from backward scheduling, the facility will be able to exploit the long customer order lead time allowances associated with these products, and thus have more time to react to potential changes in order volumes. 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. In total, the proposed solution is expected to lead to increased customer satisfaction, goodwill and brand loyalty.

Speed

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. Frequency of delivery and delivery response times are not within the scope of the study since the scope was to enable the production system to meet these customer requirements, not change them. Physical throughput time will also remain unchanged since the proposed solution does not change any of the production process characteristics. 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. This will again reduce the total scrapping and inventory devaluation costs. The inventory of unpacked bulk products associated with MTO items will increase, but the risk of obsolescence of these intermediates will be lower than for the current finished good inventory for these products.

Dependability

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 on the other hand this need will also be buffered against through slack resources in the form of capacity and inputs. The redesigned and formalised PPC system is likely to introduce more predictability and clearer policies for how MTO items should be incorporated into the MTS schedules and improve plan stability, which might reduce the total need for re-planning and changeovers. The proposed solution is also likely to reduce the number of disruptions to PPC at other facilities since there will be fewer out of stock situations at TINE Heimdal.

Flexibility

Flexibility is about the ability to change an operation in some way, e.g. what, how or when. The main scope of the study is on the volume flexibility of the production system, and the proposed PPC solution is expected to increase volume flexibility by enabling the exploitation of long customer order lead time allowances, low product perishability and high demand predictability. In addition, a longer planning horizon is expected to enable more level production, thus improving capacity utilisation and reducing the need for overtime and unscheduled changeovers.

Cost

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 with regards to the efficiency of PPC resources in the proposed solution. Further, inventory carrying costs are expected to be reduced, cost savings related to disposal of expired products are expected, as well as less value loss related to selling obsolete or excess inventory at reduced prices or as animal feed instead of for human consumption.

Performance of PPC function

In addition to the effects described above, an important objective for TINE was that the new PPC solution should improve the performance of the PPC function. The implementation of the new PPC solution should therefore also include a review and redesign of the PPC function and processes. Important expected benefits from this include:

- Simplification, formalisation, standardisation and validation of PPC processes
- Development of a PPC function and processes based on a holistic perspective to PPC, which improves the integration of central and local planning and is based on thought-through principles
- Increased automation of PPC and reduced number of manual decision making tasks, reducing the risk of human errors
- Increased efficiency and effectiveness in PPC processes, thus making PPC less resource demanding and freeing up central and local resources to focus on more value-adding activities

Table 6-13 summarises the benefits that can potentially be achieved with the implementation of the proposed PPC system in TINE.

Table 6-13: Summary of potential benefits of proposed PPC system

Category	Benefits
Quality	- Improved service levels - Reduction of stock outs for MTS items - Better product quality - Increased customer satisfaction
Speed	- Shorter production response times - Increased inventory turnover rates
Dependability	- Improved delivery reliability - Better due-date adherence - Increased re-planning frequency but also more predictability and clearer PPC policies which might reduce need for re-planning - Reduced number of disruptions to PPC at other facilities
Flexibility	- Increased ability to deal with changes in volume - Improved capacity utilisation - Reduced need for overtime and unscheduled changeovers
Cost	- Increased efficiency of PPC resources - Reduced inventory carrying costs - Reduced costs for disposal of excess inventory - Reduced value loss for obsolete or excess inventory
Performance of PPC function	- Simplification, formalisation, standardisation and validation of PPC processes - Better integration of central and local planning - Reduced manual decision making and risk of human errors - Less resource demanding PPC

7 DISCUSSION AND CONTRIBUTIONS

In this chapter, the study's main findings and contributions are outlined and discussed. The chapter firstly addresses each of the four research questions which were defined in section 1.3. For each question, the study's findings are summarised and subsequently discussed with regards to existing literature and other studies, as well as transferability, weaknesses, limitations and rival explanation of findings. Next, some reflections are presented with regards to the study's contributions towards substantive theory, before the chapter concludes with some reflections on research methodology in terms of quality and limitations.

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┌─────────────────────────────────────────────┐
│ RQ1; findings, discussion and contributions  │──┐
├─────────────────────────────────────────────┤  │    ┌──────────────┐     ┌──────────────┐
│ RQ2; findings, discussion and contributions  │──┤    │   Towards    │     │ Reflections on│
├─────────────────────────────────────────────┤  ├──→ │  substantive │ ──→ │   research    │
│ RQ3; findings, discussion and contributions  │──┤    │    theory    │     │  methodology  │
├─────────────────────────────────────────────┤  │    └──────────────┘     └──────────────┘
│ RQ4; discussion and suggestions              │──┘
└─────────────────────────────────────────────┘
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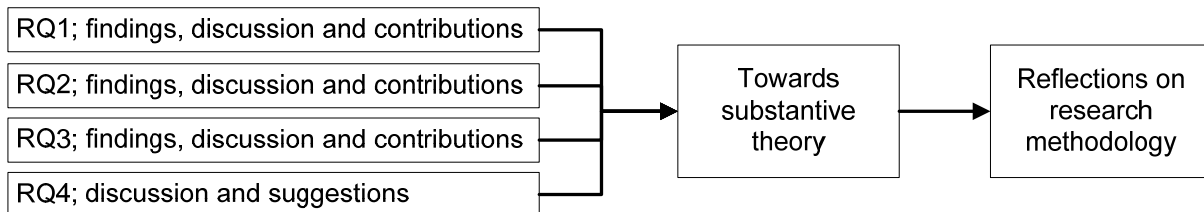
Figure 7-1: Structure of chapter 7

7.1 RQ1: Food supply chain characteristics

This section outlines and discusses the study's key findings related to RQ1.

7.1.1 Findings on RQ1

The first objective of the study was to identify the challenges of current PPC in the food sector. This objective was addressed through RQ1: *What are the characteristics of food supply chains?*

In sub-section 3.1.3, a framework for characterisation of supply chains was developed through a literature study. This was subsequently used in section 4.2 to collect and structure empirical data from literature. The characteristics' impacts on the supply chain requirements facing food producers were then logically derived.

In brief, the following key characteristics of food supply chains were identified:

- Products are characterised by:
  - Product perishability, large volumes, high and varied product complexity and increasing product variety, decreasing PLC and high pace of product innovation, and increasing variety from the processing to the packing stage
- Markets are characterised by:
  - Demands for short delivery lead times and frequent deliveries, high and increasing demand uncertainty, limited possibilities to keep inventory, and high stock-out rates
- Production systems are characterised by:
  - Long production lead times, large batch sizes, low degree of postponement, technology, equipment and processes designed for high production volumes and low product variety, supply uncertainty related to seasonality, and variability in quality and price of raw materials

The analysis found that the market and product characteristics require responsiveness from food producers, while the production system is mainly focused on efficiency through exploitation of scale benefits. Thus, there is 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 means 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.

In addition, most producers are using only one approach to plan and control their products, even though they may be facing a variety of external requirements. The findings therefore indicate that a differentiation approach to PPC may be appropriate to better meet the complexity in external requirements and enable higher efficiency in internal processes.

The findings from the literature study were also confirmed in the subsequent case study of TINE.

7.1.2 Discussion of findings and contributions from RQ1

In order to map food supply chain characteristics, a generic framework for supply chain characterisation was developed as a tool both to identify the aspects that should be mapped and to structure the description. The framework extended existing frameworks by also including aspects of the production system. Further, the characteristics' requirements for PPC were logically derived. This methodology provided a tool which can be used to link characteristics to requirements in a simple, systematic and visual manner.

Through the application of the framework in both the literature study on supply chain characteristics and the case study, the study illustrated how the framework can be used to increase understanding of an industrial sector and the requirements exerted upon producers and their PPC systems. The methodology showed how different characteristics drive supply chains towards different requirements. The lack of alignment between the requirements exerted by market and product characteristics on the one hand and the characteristics of the production system on the other could not have been found using the traditional product-market characterisation/configuration frameworks like Fisher (1997) or the lean/agile/leagile concepts (see e.g. Mason-Jones et al., 2000, Bruce and Daly, 2004, Naylor et al., 1999) since these do not consider production system characteristics. Despite being developed specifically for a food sector context, the developed characterisation framework is more comprehensive than existing frameworks since it also includes production system characteristics and may therefore also be of value in other sectors to identify mismatches between characteristics, requirements, capabilities and PPC system design.

The literature study of food supply chain characteristics provided increased understanding of the food sector and the environment within which PPC is performed. The study started out with the assumption what there was a gap between the requirements that external characteristics put upon food producers and the internal capabilities of the production system, and this assumption was confirmed. Although the mismatch between characteristics has been observed in previous studies (see e.g. van Wezel et al., 2006, Soman, 2005, van Donk, 2001), the study contributed to explaining in more detail the source of the misalignment and provided a tool and a methodology for detecting such mismatches.

In addition to the sector-level lack of strategic fit between external requirements and internal capabilities identified in the literature study, the case study of TINE provided a more in-depth understanding of PPC in a food production environment. The case study showed how customer responsiveness and production system flexibility are not only constrained by the characteristics of the production technology, equipment or production processes, but also to a high degree by the organisational procedures and principles used to plan and control production. This is in line with findings from a study by van Wezel et al. (2006) who found that planning practices in food processing industries are often not able to make the most of the available flexibility in the production process. Although their study focused on small and medium sized enterprise (SME) food producers, the findings from the TINE case study indicate that this problem exists also for larger producers, possibly because several of the planning and control tasks are performed locally and with limited support from advanced planning software. On the other hand, the analysis by van Wezel et al. (2006) showed that ERP systems and advanced planning systems (APS) can only partly resolve the planning flexibility bottleneck, illustrating that the problem may not only be related to the availability of sophisticated computer resources but just as much to how the PPC system is designed with regards to information flow, work processes, planning principles and other organisational mechanisms.

There seems to be a general agreement in literature that a company's performance is affected by the strategic fit between the company's competitive strategy and its supply chain strategy (Chopra and Meindl, 2010). Selldin and Olhager (2007) tested Fisher's framework through a survey of Swedish production firms and the results gave some support to Fisher's model in that there were more companies with a match than a mismatch between product types and supply chain design types. However, the study was unable to prove that companies that had a match between products and supply chains performed better than companies with mismatches. As a potential explanation for this finding, the authors suggest that all production companies may not have the opportunity or resources to create a perfect supply chain for their products but rather have to manage within the existing supply chain structures. The authors also introduce the notion of a supply chain frontier for describing the best attainable combination of efficient and responsive attributes for firms performing much better than competitors. As a potential explanation for the identified mismatches between product types and supply chain design types, the authors suggest that limited resources and continued cost focus have constrained producers' ability to adapt internal processes and equipment/technology to external market and product requirements. This may also explain why the food processing sector over time has not adapted its production system to market and product requirements.

In a similar study to Selldin and Olhager (2007), Wagner et al. (2012) investigated industry differences with regards to supply chain fit and financial performance. The study concluded that the food and beverages industry has a potential for better adjusting their supply chains to their products – which supports the findings of this PhD study. However, the Wagner et al. (2012) concluded that food and beverages manufacturers should aim for higher efficiency in their supply chain strategy – breaking with the findings from RQ1. A possible explanation of the difference may be found in weaknesses in the survey's design. Firstly, the producers in the survey were asked to consider only their main product line, defined as the product line with the largest contribution to revenues. This means that the study did not consider the trend towards increasing product variety, nor did it capture the complexity of managing a variety of products with different market and product characteristics. Thus, an efficiency strategy may have been appropriate for the characteristics of the companies' main product lines. Further, the survey only asked about external supply and demand related characteristics and ignored

internal production system characteristics. Although this may not have affected the study's conclusion, it is nevertheless a weakness and simplification which ignores a critical real world constraint.

Both the Fisher (1997), Selldin and Olhager (2007) and Wagner et al. (2012) studies are indicative of much of the existing research on supply chain fit and design in that they are based on the idea that a company should select one single "right" supply chain strategy. Considering that most companies today are facing a situation with increasing product variety and diversity in customer requirements, this "one size fits all" approach to operations strategy and managing the way the company interacts with the market does not seem to reflect the challenges facing decision makers. It is perhaps no surprise that there are mismatches between requirements and capabilities if only one or a few product lines are used to determine one main strategy which is then used for all products. Another relevant question is whether the survey methodology is suited for investigating such complex and messy real-world issues.

In conclusion, RQ1 identified that food producers are producing a large and increasing variety of products with differing characteristics. This is significantly complicating PPC, and the traditional PPC approaches reduce the efficiency of production, inventory and PPC performance since mainly finished goods are used to provide the responsiveness required by external factors. The analysis of characteristics and current performance in the TINE case study also demonstrated how the differences in product and market characteristics are leading to such internal inefficiencies.

7.2 RQ2: Differentiation of PPC in food production

This section outlines and discusses the study's key findings and contributions related to RQ2.

7.2.1 Findings on RQ2

RQ2 asked: *How can PPC be differentiated according to food supply chain characteristics?*

This second research question contributed towards the attainment of objectives 2 and 3:
- Develop a framework for differentiated PPC in the food sector
- Conduct a case study to identify current PPC challenges, develop new solutions and investigate the potential benefits of differentiated PPC

RQ2 was the most comprehensive research question as it addressed the scientific core of the study. The main results from RQ2 were abductively developed through the successive modification of original frameworks, combined with ideas based on theoretical and empirical insights from literature and the case study.

A concept for differentiated PPC was developed, consisting of the following principles:
1. Favourable product and market characteristics should be exploited to provide flexibility to the production system
2. PPC approaches should be differentiated according to food supply chain configurations
3. Slack resources in the form of inventory, capacity and time should be used to buffer against demand uncertainty

Then, a framework for determination of PPC approaches and buffering techniques was developed, see Figure 7-2.
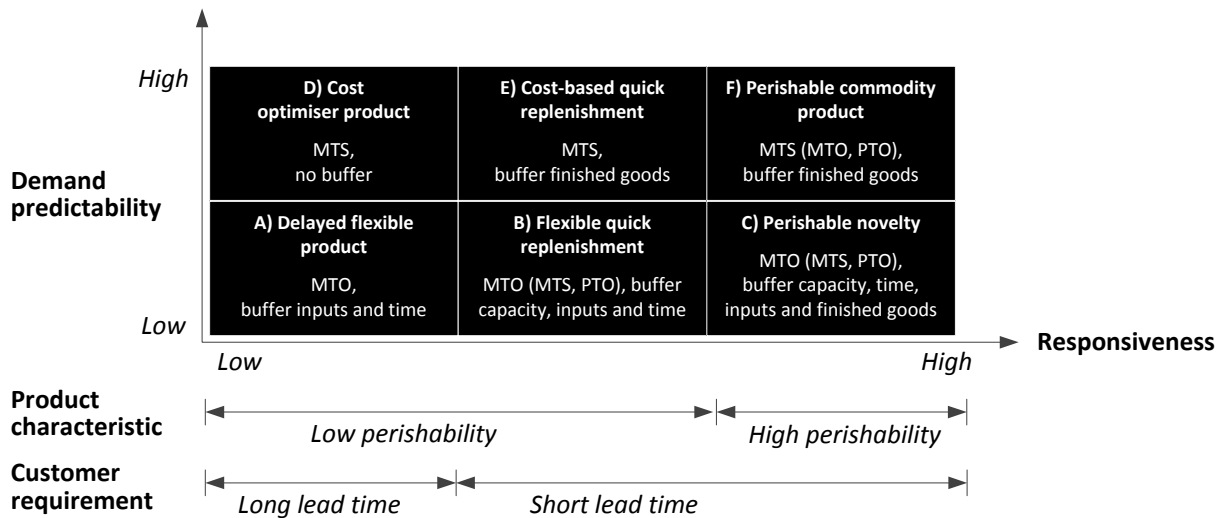
Figure 7-2: Framework for differentiated PPC in food production (adapted from Kittipanya-ngam, 2010, p. 110)

The case study illustrated how the concept and the framework could be used to design a new PPC system for a food producer. The analysis and solution development part of the case study revealed a number of challenges related to the operationalisation of both the concept and the framework. The activity was therefore put into a broader context where the design process took into consideration the company's strategic priorities and assessed a number of external and internal aspects which constrained the design of the new PPC solution. In addition, a decision tree was developed in order to capture and structure the most important quantitative and qualitative factors that impact on a food product's demand predictability.

7.2.2 Discussion of findings and contributions from RQ2

Below, the main findings and contributions from RQ2 are discussed and reflected upon. Firstly, the motivation for the study in terms of the need to differentiate PPC in food production is discussed. Secondly, the developed concept and tools are discussed, before some reflections on the use and applicability of the tools are presented.

7.2.2.1 The need to differentiate PPC in food supply chains

A starting point for RQ2 was the difficulty associated with using the Fisher (1997) framework for determining product types and selecting supply chain strategies in the food sector. Already four years after Fisher's seminal article was published, van der Vorst et al. (2001) asked the question of which strategy a food supply chain should follow when its products have mainly functional characteristics but are sold in markets associated with innovative characteristics like high demand uncertainty and a requirement for high responsiveness from suppliers. On a similar note, van Donk (2001) looked at factors influencing the localisation of the CODP in food production and called for more cases that elaborate on the decision rules for CODP placement in the food sector.

Although the literature on CODP, supply chain strategies and PPC approaches differs in how food products should be classified, the underlying idea is that aligning strategies and process-

es to market requirements is a way of achieving service improvements to customers at less cost (Christopher and Gattorna, 2005), and further, that companies should differentiate the way they manage products in their supply chain. The essential question is then; on what should this differentiation be based? And secondly; how can companies identify the products which require most the attention in planning and control?

Sharman (1984) was one of the first, if not the first, to write about the need for taking the external product and market characteristics into consideration when designing a company's logistics system. In the article 'The rediscovery of logistics', he links the order penetration point with what he calls 'logistics configurations', i.e. selecting between strategies based on MTO, MTS, ATO, etc. Since then, there has been a plethora of studies investigating the phenomenon under a host of different labels (see sub-section 3.4.2). There does not seem to be a general agreement on the terminology to use or the variables which should be taken into consideration when determining how the company's products should be managed and planned. The fact remains that this PhD study and others have observed that a lack of strategic fit between the external requirements put upon food producers and the internal capabilities of their production system still exist in practice today. Although this mismatch may also be attributed to limitations in production technology and processes, organisational issues, companies' overwhelming reliance on ERP systems and MRPII logic, supply chain power struggles, etc., this study has shown that there is reason to believe that practice is still in need of tools and frameworks which are easy to use and that provide some rules or logic which can be used to guide such strategic design decisions. The results from this PhD study are timely contributions in that respect.

7.2.2.2 Concept and tools for designing a differentiated PPC system

Below, the concept, framework and decision tree developed in the study are discussed.

Differentiation concept
An early investigation into the differentiation of PPC approaches in the food sector was undertaken by van der Vorst et al. (2001). Through a conceptual discussion, the authors suggested the application of a hybrid leagile strategy in a poultry supply chain in order to bring the CODP closer to the point of the variant explosion. Although the characteristics of the specific empirical context limited the opportunities for realisation of the proposed solutions, the article found some merit in the concept in a food supply chain setting. A weakness in the study was however that it was based on determining one strategy for all the company's products – thus not addressing the fact that the increasing product variety in the food sector is exerting a number of different requirements on the supply chain, thereby complicating PPC. The differentiation concept developed in this PhD study meets this weakness by taking a product-by-product approach to differentiation.

An interesting example of a study that does consider different supply chain strategies for different products is the case study of a large European technology company reported by Payne and Peters (2004). Here, a segmentation and selection model was developed and implemented based on clustering of products with similar attributes and assigning each to the most fitting of three supply chain strategies; a dispersed stock model with finished goods held in more than one European distribution centre, a central stock model with finished goods stock held only in one European distribution centre, and an MTO model with no finished goods held in stock anywhere. Although the study focused on differentiation of inventory models and not PPC approaches, it is a good example of a differentiation model that was implemented in

practice and which realised substantial benefits (including 32 % reduction in supply chain costs and 22 % reduction in inventory investments) – thus demonstrating the merit of differentiating supply chain strategies according to external requirements[25]. The PhD study has shown that there is reason to believe that a similar approach is also relevant for the production stage of the supply chain, particularly since this is where the main variant explosion takes place.

There is a study described in literature which specifically addresses the same challenge as this PhD study. The quantitative model developed by Soman (2005) provides a tool for selecting between an MTO and an MTS approach on a product-level in the food sector (see sub-section 3.4.2). The simplicity of the model is attractive. However, there are some weaknesses related to some of the simplifications and assumptions that had to be made in the decision process. The model is for instance based on economic order quantity (EOQ) and assumes constant demand, which is unrealistic. In addition, Soman did not include consideration of qualitative factors which may impact on the MTO-MTS decision (e.g. market activities, seasonality and retail listing), nor could it be used for determining how new products should be planned. In this respect, the differentiation concept and framework developed in this PhD study can be said to be both more realistic and comprehensive. However, the two studies are similar in that they both rely on access to high-quality historic data on sales and forecast accuracy. In addition, both are based on the involvement of company management and experts in the design process, although this involvement is more limited in Soman's model since it is mostly based on quantitative calculations.

An important difference between many similar previous studies and this PhD study is the focus on production volume vs. product variety. As mentioned in sub-section 5.1.2, the relationship between volume and variety has traditionally been used to determine PPC approaches in the food sector in order to reduce changeover times and costs. The proposed concept and framework do not consider this issue on the strategic design level of PPC. However, the handling of the subsequent issues on the tactical and operational PPC levels is addressed in RQ4 (see section 7.4). In addition, advances in production technology and equipment are continuously reducing changeover times, which means that the differentiation concept will become even more relevant as production becomes less reliant on producing large batches and limiting changeovers to keep costs down.

Framework and supply chain configurations
The framework for differentiation links each of the six configurations in the Kittipanya-ngam (2010) framework with the most appropriate PPC approaches. Naturally, there are some weaknesses related to this strategy since the configuration framework is based on a simplification of reality and only considers a limited number of characteristics and only the most important supply chain requirements exerted on food producers. The six configurations do for instance not capture supply chains characterised by high perishability and long lead times, which could be imagined for instance related to highly perishable products that are planned and ordered for a market activity in the local market several weeks in advance. However, the underlying assumption of all configuration research is that taxonomy classifications are a meaningful way to capture the most essential complexities of organisational reality (Ketchen Jr and Shook, 1996). And while configurations are not theories per se, they are a critical part of theory development (Bacharach, 1989). Thus, taxonomies like the Kittipanya-ngam (2010)

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[25] The article had only 37 citations on Google Scholar per 14 September 2013, indicating that the results have not been widely built on in more recent research

framework can be highly valuable for initially classifying data before subsequent analysis (Ketchen Jr et al., 1993). The Kittipanya-ngam (2010) framework further provided an understanding of the complexity of food supply chains and the variety of requirements that food producers are facing. From this insight grew the notion that meeting the different requirements of the six configurations with one single PPC approach may not be the best way to align the capabilities of the production system with the external product and market requirements. Thus, although there may be some weaknesses related to the configuration framework, there is still merit and logical consistency in the idea of linking configurations and PPC approaches.

Decision tree

Before the differentiation framework could be used to determine a new mix of PPC approaches in the case study, the facility's products had to be located within the configuration framework of Kittipanya-ngam (2010). Although the configuration framework is attractive in its simplicity, this exercise proved to be more complicated than expected since the demand predictability of each product could not simply be collected from the company's ERP or other ICT systems. From the differentiation framework, it can be seen that the main determinant for the selection between MTO and MTS is demand predictability. This differentiation between decisions made under certainty and decisions made under uncertainty of customer demand was identified by Wikner and Rudberg (2005) as a key issue in operations strategy and SCM. Both the Wikner and Rudberg study and the PhD study use the CODP to identify this distinction, which means they are both limited in that they are based on classifying demand into one of two categories with regards to uncertainty. However, by using the decision tree to arrive at the classification, as well as using human involvement in the evaluation of the cut-off limits between the classifications, the differentiation framework overcomes some of these issues.

Discussions with case representatives revealed a number of factors which should be taken into consideration in this evaluation, and consequently, a decision tree was developed to structure the evaluation process. The decision tree consists of a combination of quantitative analyses and qualitative evaluations, and requires involvement of managers and resources at different levels. Although the quantitative model developed by Soman (2005) also requires some human decision making in the determination of high-low limits for product volume and variance in the demand analysis, the decision tree involves more human decision making and captures more of the essential aspects which impact on demand predictability, e.g. products' stage in the PLC, historic forecast accuracy, retail listing and sensitivity to other factors. The decision tree can therefore be said to provide a more accurate and comprehensive demand analysis than existing frameworks and models since it is not based on mere personal beliefs or assumptions, but rather driven by actual data and systematic evaluation of defined quantitative and qualitative factors.

Another weakness of existing frameworks and tools like Fisher and Soman's model is that these are exclusively based on the use of historic data and therefore only backward looking. In today's fast-paced world, looking in the rear-view mirror when planning for the future does not seem like the best strategy. The decision tree is able to consider future events and circumstances. The frequent and growing use of market activities to stimulate sales is for instance a key market characteristic of food supply chains. Such activities introduce additional demand uncertainty and must therefore be taken into consideration when determining a product's demand pattern. The decision tree does however not take into consideration how a product's demand predictability is affected by market activities the company is running on other products – but qualitative and quantitative assessment of this could easily be added to the decision

tree. The impact of competitors' actions would on the other hand be more difficult to incorporate, both because they are beyond the company's control and the fact that the awareness of for instance competitors' market activities typically occurs too late to be of much value for the short-term planning and control of production.

Although the decision tree was developed specifically for the TINE case, there is reason to believe that it can be of use also for other food producers and other industrial sectors. The evaluation of retail listing may be sector and Norway specific. However, the evaluation of PLC, degree of innovation and quality of reference products for newly launched products, and evaluation of historic forecast accuracy in periods with and without market activities are factors which may be transferable to other industrial contexts.

7.2.2.3 Reflections on the use and applicability of the design tools

The case study demonstrated how the concept and framework could be used to re-design a PPC system. The findings from the mapping and analysis of supply chain characteristics (RQ1) and early versions of the concept and framework sparked interest and attention at several management levels in the company. The simplicity and intuitive nature of the tools and the accompanying graphical illustrations helped to provide an understanding of the problems and sold the idea of differentiated PPC to decision makers. However, the operationalisation showed that large amounts of data and a number of human evaluations of both qualitative and quantitative data were needed to drive the development of the case-specific solutions.

Another complicating factor was the determination of cut-off values for distinguishing between the high and low/short and long dimensions in the supply chain configuration framework and the decision tree. The operationalisation required in-depth knowledge of the company's operations, products and markets. In addition, the quantitative analyses required high quality and integrity in master and transactional data in the company's ICT systems – the lack of which resulted in a need to manually structure, clean and analyse large amounts of data, as well as actions to correct identified weaknesses and errors in master data. The human involvement in the use of the decision tree does however not necessarily mean that the future PPC process would be time consuming. Rather, the decision tree should be used to determine the principles used to plan and control production, and these can subsequently be integrated into the ERP system and any other relevant planning systems. Further, tolerance levels can be defined in the ICT systems to detect when a re-evaluation of a product's classification is appropriate, for instance when the forecast accuracy for a newly launched product has improved sufficiently to stop using the reference product's demand history to predict future sales. This way the developed tools can assist in automating, enriching and standardising planning resources' work.

The concept and framework were developed as tools to guide an organisation's decision making in the design of its PPC system in order to give the production system the desired characteristics and capabilities. The design is therefore a key process in the realisation of the company's operations strategy. Several authors have maintained that supply chain configuration is strategically driven by product and market or demand characteristics (Childerhouse et al., 2002, Christopher et al., 2006, Fisher, 1997, Lamming et al., 2000, Pagh and Cooper, 1998). On the other hand, the case study shows how a number of other aspects constrain the available alternatives, e.g. competitive strategies, physical network structure and current strategic differentiation – thus emphasising the importance of putting the PPC design process into a broader strategic context. Based on the experiences from the case study, a generic process or

methodology for designing a differentiated PPC system can therefore be derived, see Table 7-1.

Table 7-1: Methodology for design of a differentiated PPC system

Step	*Description*	*Purpose*
1	Map strategic priorities	• Identify objectives for new PPC system
3	Map other constraints	• Identify other constraints for PPC system • Select scope for improvement project
2	Analyse current PPC performance	• Identify current challenges • Identify opportunities for improvement
4	Design new PPC solution	• Identify supply chain configurations • Determine new mix of PPC approaches • Determine new mix of buffering techniques

Although the methodology was developed for a food production context, the steps are generic and can be used to develop a differentiated PPC approach for any industrial sector.

The purpose of the differentiation concept and framework was to classify products according to the six supply chain configurations in order to determine the appropriate PPC approaches. By doing this on a product-by-product level, each product is planned and controlled based on its own specific product and market characteristics. Given that the six configurations capture the most important characteristics of food supply chains, this concept of linking the configurations with different strategies and approaches may also be useful for other purposes, for instance inventory management, distribution strategies, forecasting techniques, and supply chain information sharing and collaboration models.

A weakness of the developed framework and decision tree is that they do not consider the ratio between production lead times and delivery lead time (P/D ratio). If the production lead time is longer than lead time allowance from customers, an MTO approach is not feasible and one might therefore argue that the P/D ratio should be performed before the framework and decision tree are used. On the other hand, the decision tree enables planners to identify the products with low demand predictability as these are traditionally the most difficult to plan and control. Thus, even if an MTO approach is not feasible, other actions may be initiated for these products, e.g. promoting information flow with customers to improve forecasting, more frequent follow-up and demand analysis, and working closer with operations to enable greater flexibility and reduce lead times in the physical production processes.

7.3 RQ3: Potential benefits of differentiated PPC

This section outlines and discusses the study's key findings related to RQ3.

7.3.1 Findings on RQ3

RQ3 asked: *What are the potential benefits of differentiated PPC?*

This question contributed to the achievement of part three of objective 3 – the investigation of the potential benefits of differentiated PPC.

RQ3 was mainly addressed through the case study where a new solution for differentiated PPC was designed and the types of benefits expected from the new solution substantiated and discussed.

The benefits were structured into six categories, with the following expected effects:

1. Quality; improved service levels, reduction of stock outs for MTS items, better product quality and increased customer satisfaction
2. Speed; shorter production response times and increased inventory turnover rates
3. Dependability; improved delivery reliability, better due-date adherence, more predictability in PPC policies, and reduced number of disruptions to PPC at other facilities
4. Flexibility; increased ability to deal with changes in volume, improved capacity utilisation and reduced need for overtime and unscheduled changeovers
5. Cost; increased efficiency of PPC resources, reduced inventory carrying costs, reduced inventory disposal costs, and reduced value loss related to excess inventory
6. Performance of PPC function; improvements in PPC processes, improved planning integration, reduced manual decision making and less resource demanding PPC

7.3.2 Discussion of findings and contributions from RQ3

Below, the main findings and contributions from RQ3 are discussed and reflected upon. Firstly, the limitations related to the lack of implementation are discussed, secondly some reflections on the measurability of effects are described, thirdly some reflections on the scope of the case study are outlined, and finally some concluding remarks on RQ3 are presented.

7.3.2.1 Strategies to overcome lack of implementation

As mentioned, RQ3 was mainly addressed through the case study of TINE and the TINE Heimdal facility. Ideally, the new PPC solution would have been implemented in order for the benefits of the new design to be measured and verified. Unfortunately such a research strategy was not possible within the mandate and available time and resources of the study. To mitigate the effects of this weakness, alternative strategies were designed into the study to substantiate the potential benefits.

Firstly, a research strategy was chosen which enabled close collaboration between researchers and company representatives. The company was involved in the research design, analyses, solution development and reflections on potential effects. This helped to identify and frame a problem that was relevant from both an academic and industrial perspective, as well as ensure that the proposed solutions in fact targeted a relevant challenge and that there was realism in the proposed benefits.

Further, the collaborative solution development means that practitioners consider the proposed concepts and solutions both feasible and relevant for solving the identified challenges. The proposed solutions were also at several occasions discussed with company representatives at the strategic, tactical and operative levels, including resources who had not been involved in the design, analyses or solution development. This further strengthened the trustworthiness of the findings.

Another strategy was to use literature to generate a working list of potential effects which was used to structure and inspire how effects could potentially be measured. Literature thus provided a theoretical frame for logically deriving potential benefits. The abductive logic of al-

ternating between theory and the empirical world meant that the investigation of potential benefits was not an isolated and one-off activity, but rather an integrated part of the initiation, design, analysis and evaluation of the case study.

Finally, the entire PhD project and the findings and conclusions from the case study were regularly presented and discussed at academic and industrial conferences, seminars and workshops. This ensured academic relevance of the work, and provided valuable feedback and inspiration for further work.

7.3.2.2 *Measuring effects*

The lack of implementation was a weakness in the study. However, even if implementation had been included, the full effects and benefits of an implementation would have been difficult to identify, isolate and measure. The scope of the overall study was on investigating the relationship between differentiated PPC and the external requirements for responsiveness and efficiency. Responsiveness is in itself a complex phenomenon, for which there is still a lack of a precise definition and measurement instruments. In addition, the definition and scope of PPC can be ambiguous. Thus, identifying and isolating the effects of implementing a differentiated PPC system into a large production network like TINE would be very difficult.

From the experiences in the case study, there are however some effects which theoretically[26] could have been measured had the solutions been implemented. Some of the measurements would have required some changes to the ERP system and the types of data registered in the company but theoretically these effects could have been captured without too much effort. One of the largest changes in the proposed PPC system was the increased use of MTO for products with low demand predictability, thus eliminating the inventory of finished goods and the amount of excess and obsolete inventory of such items. The effects of this could have been measured through inventory turnover rates, inventory investment costs and value loss associated with offering discounts to customers or selling excess inventory as animal feed instead of for human consumption. In addition, it could be possible to measure quality improvements for instance as the number of days of shelf life remaining when products are sold to customers, and service levels for MTS products. Further, the expected improvement in plan stability could be measured in terms of the number of changes to the weekly or daily plan after it has been frozen. Further, the improved plan stability and longer planning horizons are expected to reduce the use of overtime, which could have been measured before and after implementation. The most measurable effect on the performance of the PPC function would be the number of hours spent on PPC at the central and local level.

In addition to the measurable and quantifiable effects above, a number of qualitative and other effects which are more difficult to measure are expected. These include customer satisfaction, disruptions to PPC at other facilities, costs of supplementing orders from other facilities in cases of stock outs, less risk of obsolescence for finished goods, more formalised and automated planning process, reduced risk of human errors, and better integration of central and local PPC.

In Table 7-2, the potential effects are summarised, indicating whether each effect is mainly quantitative and thus measurable, or qualitative and therefore more difficult to isolate and measure.

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[26] Irrespective of whether or not the effects could be isolated

Table 7-2: Potential effects of differentiated PPC and their measurability

Category	*Benefits*	*Quantitative*	*Qualitative*
Quality	• Improved service levels	X	
	• Reduction of stock outs for MTS items	X	
	• Better product quality	X	
	• Increased customer satisfaction		X
Speed	• Shorter production response times	X	
	• Increased inventory turnover rates	X	
Dependa-bility	• Improved delivery reliability	X	
	• Better due-date adherence	X	
	• Increased re-planning frequency but also more predictability and clearer PPC policies which might reduce need for re-planning	X	
	• Reduced number of disruptions to PPC at other facilities		X
Flexibility	• Increased ability to deal with changes in volume		X
	• Improved capacity utilisation	X	
	• Reduced need for overtime and unscheduled changeovers	X	
Cost	• Increased efficiency of PPC resources	X	
	• Reduced inventory carrying costs	X	
	• Reduced costs for disposal of excess inventory	X	
	• Reduced value loss for obsolete or excess inventory	X	
Perfor-mance of PPC func-tion	• Simplification, formalisation, standardisation and validation of PPC processes		X
	• Better integration of central and local planning		X
	• Reduced manual decision making and risk of human errors		X
	• Less resource demanding PPC	X	

7.3.2.3 *Limitations related to case study scope*

A confounding factor in the estimation of benefits was the fact that the scope of the case study was not only on investigating a differentiation approach to PPC, but also included an evaluation and redesign of other aspects of TINE's PPC system. An improvement initiative consisting only of changing the principles of PPC seems neither realistic nor practical, particularly since previous studies have found that responsiveness in the food processing industry is constrained by broader organisational aspects such as work processes, planning principles and information flow (van Wezel et al., 2006). The effects described in Table 7-2 are therefore a combination of effects expected from differentiated PPC and effects from the redesign of the PPC system.

The investigation of effects was based on the findings from the analysis of the performance of the existing PPC system in the case company – in which identifying cause and effect relationships was fairly complicated and thus represented a potential source of errors. An example is that the findings suggest that the varying service levels may have been the result of poor fore-

cast accuracy. However, other potential causes of varying service levels include technical problems, high levels of sick leave, problems with the quality of raw materials, low service levels from suppliers, etc. Similarly, the analysis found a gap between the external market and product requirements and the internal capabilities of TINE's production system – and suggested this was due to weaknesses in how the current PPC system was designed and the overwhelming reliance on the MTS approach. Although this assumption has logical consistency, there is reason to believe that other factors may have contributed to this gap as well. Other potential causes include the continued cost focus in food production which will have favoured MTS as the best option to achieve scale benefits and thus reduce the cost per unit. Another factor is that the inflexibility of the technology and equipment for food production has limited the possibilities for using other PPC approaches. Further, the strong focus on product quality and food safety in food production may have led to an organisational culture which prioritises these issues over efforts to better align supply with demand and responding quickly to changes in customer demand. In addition, similar to the findings in the study of van der Vorst et al. (2001), the perishability of raw materials or intermediates will in many cases limit the applicability of postponement strategies like producing or packing to order.

7.3.2.4 Concluding remarks on RQ3

Despite the difficulties in isolating effects and the limitations related to the scope of the case study, in a broad perspective the qualitative and quantitative analyses together point towards it being reasonable to believe that the gap between external effectiveness is achieved at the expense of internal efficiency in production, inventory and PPC performance – and that this is affected by the current PPC design in the case study. The findings from the analyses were also confirmed by company representatives at the strategic, tactical and operative levels.

Although the proposed PPC system was not implemented in the case company, the solution has logic consistency in that that it is reasonable to believe that the differentiation approach to PPC, as well as a redesign of the PPC system, would in fact provide increased flexibility and reduce the facility's exposure to demand uncertainty. This is not to say that making changes to PPC is the only or perhaps even the best way to increase flexibility and close the gap between external requirements and internal capabilities. However, for the case company, implementing the proposed PPC system may be one of the most cost effective ways of improving the current situation. The solution does not require any major investments in new production equipment or technology since it is mainly based on changing planning principles and work processes (for more on requirements for implementation, see sub-section 8.3.1).

7.4 RQ4: Tactical and operational challenges of differentiated PPC[27]

The scope of the study was on the strategic determination of the principles which should be used to plan and control production. As mentioned, food production systems are commonly classified as applying either an MTS or an MTO approach. An outcome of RQ2 was a framework for determination of PPC approaches based on the concept of combining MTO and MTS in the same facility. The resulting hybrid production environment considerably compli-

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[27] Parts of this section is based on the following publication: ROMSDAL, A., ARICA, E., STRANDHAGEN, J. O. & DREYER, H. C. 2013. Tactical and operational issues in a hybrid MTO-MTS production environment; the case of food production. *In:* EMMANOUILIDIS, C., TAISCH, M. & KIRITSIS, D. (eds.) *Advances in production management systems; Competitive manufacturing for innovative products and services.* Springer.

cates the task of planning and control on the tactical and operational level (Porter et al., 1999, Schönsleben, 2012), particularly in a food production context where a variety of market and product characteristics must be taken into consideration.

Most of the existing PPC literature focuses on a single type of production environment, and a number of methods and techniques that are appropriate for tactical and operational planning decisions in MTS and MTO environments have been identified (see e.g. Stevenson et al., 2005, Jonsson and Mattsson, 2003). However, there is much less research on methods and techniques applicable for addressing the particular challenges and complexities involved when these two approaches are applied in combination, and a literature review by Soman et al. (2004) concluded that the research into such hybrid MTO-MTS production environments is still in its infancy. In particular, the authors found that existing literature was characterised by limitations and pre-requisites that do not hold true for the particular product and market characteristics of food supply chains. Further, previous literature was assessed to have limited applicability for real-life situations and for handling the trade-offs resulting from the fundamental interactions between two types of orders competing for a shared capacity and the use of time and quantity buffers.

Based on the above, there is a need for more research investigating combined MTO-MTS situations and the food sector represents an interesting and relevant sector in this respect. This led to the formulation of the fourth and final research question: *What are the tactical and operational challenges of differentiated PPC?*

Since the main focus of the study is on the strategic determination of PPC approaches, the aim of RQ4 was not to provide solutions to the highly complex tactical and operational PPC issues involved in hybrid production environments. Rather, the purpose of was to highlight and discuss some of the most critical decisions and challenges that the proposed differentiation concept imposes on these lower planning levels. The discussion is based on insights from theory, the case study of TINE and other industrial research projects.

7.4.1 A hierarchical approach to PPC in hybrid MTO-MTS environments

Some work has been done on outlining the issues and decisions involved in PPC in hybrid MTO-MTS food production environments, e.g. Soman et al. (2004), Soman (2005) and van Wezel et al. (2006). Based on the frequency of typical planning activities and events, Soman et al. (2004) developed a hierarchy of decisions for such hybrid environments, see Figure 7-3. At the highest level, the overall PPC approach is typically determined, e.g. whether MTO, MTS or a combination of MTO-MTS is to be used for PPC. In addition, product families are determined, target service levels are set and long-run capacity planning is performed.
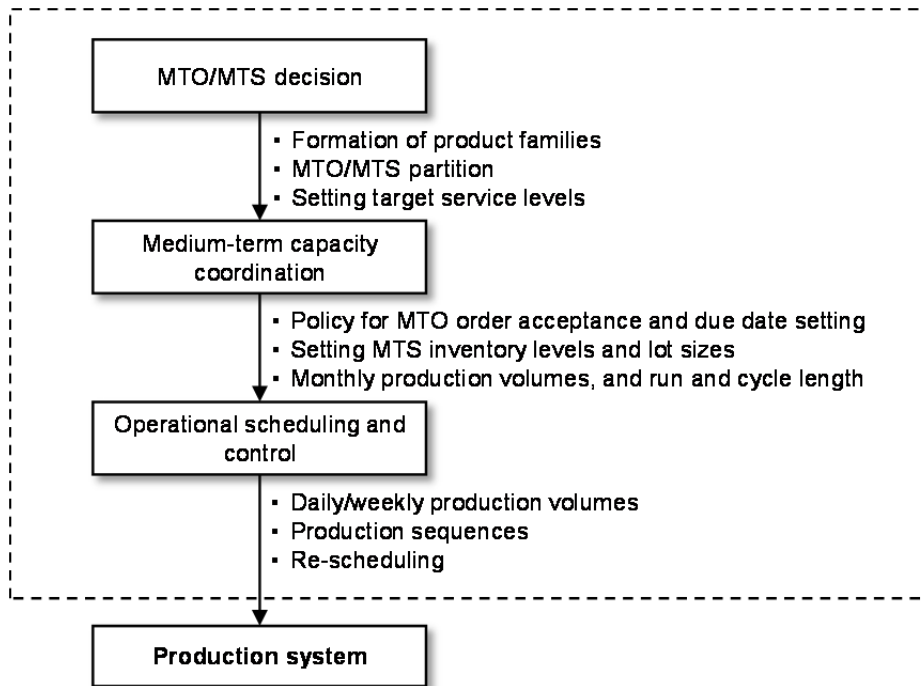
Figure 7-3: Simplified approach to MTO-MTS problem (adapted from Soman et al., 2004, p. 23)

In cases where a combination of MTS and MTO is found to be the most appropriate solution, there are several critical issues and trade-offs which must be thoroughly evaluated and incorporated into the lower PPC levels, i.e. capacity coordination and operational scheduling and control. A key question in this respect is how to deal with MTO items in the MTS schedule - particularly with regards to planning methods and techniques for accommodating the uncertainty related to the volume, timing and mix of MTO items. This question is therefore the focus of the discussion in the following sub-sections.

7.4.2 Medium-term capacity coordination

The tactical mid-term planning level deals with two main tasks;

1. Planning of production volumes
2. Material planning determining the quantity and timing of components needed to produce the required volumes of end-items

For MTS items, the tactical planning level involves determination of inventory levels and lot sizes, as well as production volumes, and run and cycle lengths. A number of methods for materials planning exist to support these decisions in an MTS environment, including the re-order point system, runout-time planning, and MRP (Jonsson and Mattsson, 2003). The most common method currently used in food production is MRP, implemented through an ERP system. The MRP method is well suited for production of standardised product components produced in batches and with predicable demand, and MRP has been found to be effective for reducing operating costs (Koh and Saad, 2003).

In an MTO environment, this tactical level must determine the policies for accepting orders and setting due dates. Jonsson and Mattsson (2003) suggest that MRP is an appropriate planning method for tactical planning also in an MTO environment. However, Stevenson et al. (2005) argue that MRP may not be the best method since it does not consider capacity at the

point of order/job entry and order release. Stevenson et al. (2005) instead suggest that Workload Control (WLC) may be appropriate since it ensures high due date adherence and considers capacity simultaneously. WLC is a planning method that uses a pre-shop pool of orders consisting of a series of short queues where jobs are released if workload levels will not exceed pre-set maximum limits. Simultaneously, WLC ensures jobs do not stay in the pool too long, thereby reducing WIP and lead times (Stevenson et al., 2005).

However, before MRP and WLC can be applied in a hybrid MTO-MTS environment, the differences in the production rates in MTS and MTO environments need to be considered. The differentiation concept developed in this study is based on the majority of production being run using the MTS approach (i.e. for products with high demand predictability), thus requiring a standardised method like MRP to reduce operating costs. In addition to the production of MTS items, MTO orders will be received occasionally, requiring a focus on strict adherence to specified due dates. Based on the above, a possible solution for the hybrid environment is to combine the MRP method with WLC, where MRP is used as the backbone of the system.

Before the WLC method can be applied at the point of new MTO order entry, the materials planning must be tailored and supported with some additional techniques which accommodate the uncertainty associated with the quantity and timing of future demand for MTO items in the material plans. Consequently, in order to ensure consistency between the tactical and operational levels, the tactical level must contain some approaches which consider such uncertainties and provide the required flexibility. Although some studies have been conducted on how to incorporate MTO products into an MTS planning environment (see e.g. Federgruen and Katalan, 1999, Soman et al., 2006), the studied approaches only considered a narrow selection of food supply chain characteristics. There is therefore a need to investigate a broader set of techniques that consider more of the food sector characteristics.

In general, supply chains can buffer against uncertainty using inventory, capacity and time. MTS environments use inventory and capacity as buffers – where safety stock is used to ensure availability when demand is greater than expected, while safety capacity allows for stock to be duly replenished. However, in food production differences in product and market characteristics like perishability, order lead time allowances and demand predictability may limit the types of techniques that can be applied to buffer against uncertainty. For instance can safety stock be useful to ensure availability when demand is greater than expected for products with low perishability since these can be stored for a certain period of time. On the other hand, if product perishability is high, safety capacity may be more appropriate since it reduces the risk of products expiring while in inventory, particularly in cases where the perishability of raw materials or intermediates is lower than for the finished product. Further, safety lead time to tackle uncertainty in timing can be a more appropriate technique than safety stocks when demand is stable (Buzacott and Shanthikumar, 1994), thus representing a useful approach for products with low perishability and high demand predictability since it reduces the risk of obsolescence and product expiry for finished goods while in storage. Uncertainty in product yield is another uncertainty factor and for products with internal error-prone characteristics such as cheese which requires maturation periods as part of the production process hedging and overproduction may be useful techniques (Koh et al., 2002).

In summary, MRP in combination with WLC seems to be a promising approach for material planning in a hybrid MTO-MTS environment – supported by additional techniques to ac-

commodate uncertainty and provide flexibility for relevant food product and market characteristics.

7.4.3 Operational scheduling and control

The operational level involves determining in the short term:

1. Which product to produce next?
2. When to produce?
3. How much to produce?

At this level the production orders are sequenced and scheduled on machines and other resources within the planning period, determining the set of production orders to be accomplished in the bottleneck, the sequence of production orders, and the production orders' run length and start times (Soman et al., 2007).

Developing daily/weekly plans and schedules for production volumes, as well as sequencing orders on the shop floor, is not a substantially challenging task in a stable MTS environment. However, in a hybrid production environment, several types of customised orders for MTO products may be received during the execution of the schedules. Such changes may trigger the rescheduling of production orders and revision of priorities given to the shop floor (Jacobs, 2011).

Once the required flexibility and uncertainties are accommodated at the intermediate tactical planning level, the capacity-based WLC method can be an appropriate approach to fit MTO products into the operational schedule, while also incorporating the customer order entry level.

In summary, a combined MRP-WLC approach may improve the effectiveness of schedules in hybrid environments also at the operational level. The operational performance of the schedule can then be measured on its ability to meet due dates for MTO products, minimise time jobs spend in the process, reduce WIP inventory for MTS products, and minimise set-up costs and waste.

7.4.4 Suggested approach for incorporating MTO into MTS schedules

Based on the above, this sub-section conceptually describes how WLC can be used to support MRP in a hybrid production environment in a step-by-step planning process spanning both medium-term tactical, and more short-term operational planning tasks.

Step 1: Setting due dates
For both MTS and MTO items, the due date must be determined – in other words the date on which the products must be available for dispatch to the customer. For both types of items, the due date can either be:

- Fixed, for instance in TINE's case where wholesalers demand a maximum of one day delivery
- Negotiable, for instance in TINE's case of international customers who allow a lead time of several weeks or months

For MTS items, the due date is automatically calculated in the MRP netting process.

For MTO items, the due date must be set depending on the capacity status at order entry. Certain product characteristics like long customer order lead time allowances and negotiable due dates can be exploited to provide flexibility to the production.

Step 2: Setting order release dates
Workstation lead time can be assumed stable in this highly controlled process-type environment and thus order release dates are determined by deducting planned workstation lead time from the due date. For MTS items, the order release date is determined in the ERP system as part of the MRP calculation.

For MTO items, a number of aspects need to be considered before the start date can be determined. Firstly, the available capacity must be considered. Depending on the existing and required workload for the new MTO order, the order is added to the sequence of MTS products being released in that period.

If the total workload for MTS and MTO items is within the workstation load limit, the plan is feasible. However, if the total workload exceeds the load limit, the order release date for the MTO item should be moved to earlier periods, evaluating the available capacity until the present period. By this approach, the system nervousness and cost of rescheduling can be avoided.

However, before the MTO item can be moved to earlier periods, some product characteristics must be considered as this option may not be feasible for products with high perishability and short customer order lead time allowances. Thus, if the product cannot be moved to earlier periods, there are three other options to consider;

- Rescheduling the pool of jobs at the point of order release
- Increasing capacity for instance through overtime
- Renegotiating the due date for MTO items

Once a feasible schedule of order release dates has been found, the total load of MTO and MTS items can be sequenced on the workstation.

Step 3: Setting job sequences
The priority setting and order sequencing according to order release dates is regarded as one of the advantages of the WLC concept as the performance of order release simplifies the shop floor dispatching process (Stevenson et al., 2005). However, in a food production environment this might lead to high sequence-dependant set up costs. The final step is therefore to determine a sequencing rule that considers the trade-off between order priorities and set-up costs for the total workload of scheduled MTS and MTO products.

The three-step process is illustrated in Figure 7-4.
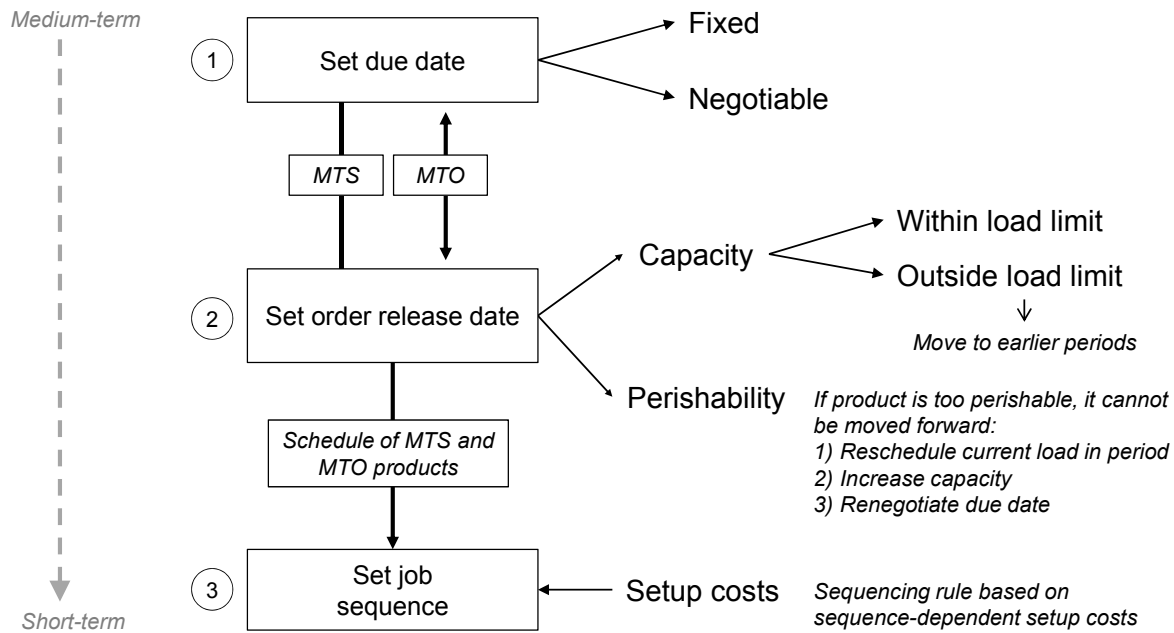
Figure 7-4: Incorporation of MTO in the MTS schedule

7.4.5 Concluding remarks on RQ4

Although MRP is very widely used, its evolutionary process has still not come up with solutions for effectively dealing with the key characteristics of an MTO environment (Stevenson et al., 2005). The characteristics of food production seem to indicate that MRP and ERP will continue to be the backbone of PPC for this sector – given the standard products and well-known product routings. On the other hand, for supply chain configurations with low demand predictability, MTO production is likely to grow in importance. This study supports the view of Stevenson et al. (2005) that MRP and ERP may continue to be seen as a potential solution for at least some of the concerns of the MTO sector. For the other concerns, WLC has been suggested as a possible way forward. However, more case studies, simulations, pilots and real-life testing are required to investigate if the combined MRP-WLC approach is effective in an operational food production environment.

7.5 Towards substantive theory on responsiveness and differentiation

This section contributes towards the development of substantive theory through reflections and synthesis of the findings and insights from the study. The discussion links the study to the broader theoretical discourse on key concepts and refines the original design proposition.

The section firstly revisits the scope of the study. Then, reflections are presented on:
- Responsiveness
- Responsiveness and differentiation
- Differentiation and product variety
- Differentiation and the COV

7.5.1 Revisiting the study's scope

In their literature review, Bernardes and Hanna (2009) pointed out the need to study responsiveness and the factors leading to responsiveness in order for research to develop prescriptive theories which could provide guidance to practice. This study took that challenge by aiming to generate prescriptive theories with implications for managerial practice in the food production context. By doing this, the study aimed to contribute to closing the gap between theory and practice in OM.

In the empirical setting, the responsiveness concept was studied in terms of customer responsiveness, defined as the business level performance capability of a system to react on market knowledge in a timely and purposeful manner. In this setting, flexibility was understood as a key operating characteristic and system property which enables operations to achieve the required performance and meet customer expectations by absorbing disturbances and variability stemming from both the internal and external environment. Within the scope of customer responsiveness, flexibility was further limited to volume flexibility required to deal with demand-side variability – with the aim of enabling the production system to deliver the requested product variants, in the quantities required and within customer order lead time expectations. Mix flexibility was indirectly addressed since considerations were made on an SKU level, fitting different market and product combinations with the appropriate PPC approach in different situations. Also, the scope was on how PPC can provide flexibility to handle the mix as specified by incoming orders within the existing capacity. Product and delivery flexibility were out of scope since the study addressed the issue of producing already existing products and meeting customer orders with the existing production equipment and capacity, within the lead time defined by the customers. Further, flexibility was viewed as an internal mechanism within the broader system contributing to overall system responsiveness, and thus represented an availability of choices which may be used to respond to changes (Bernardes and Hanna, 2009). The study looked at one such choice; PPC – and how differentiated PPC can enable the required responsiveness stemming from product and market characteristics.

7.5.2 Reflections on responsiveness

Implicit in the aim of meeting external product and market requirements is the OM phenomenon of responsiveness which as mentioned has been recognised as one of the most important capabilities needed for firms to achieve competitive advantage. Thus, there is little doubt that this is a phenomenon which deserves attention both in practice and research.

In sub-section 3.1.4, it was seen that in literature responsiveness is often related to efficiency, where increases in costs in order to increase responsiveness reduces efficiency (Chopra and Meindl, 2010). Further, an underlying premise in the OM world has been that any uncertainty and variability is threatening and counter-productive. This has led to push-based production strategies that enable companies to produce against long-term stable forecasts, supported by strategic supply chain initiatives like information sharing models, advance contracts, contract production, etc. to eradicate or at least reduce the variability, prevent dynamic distortions like the bullwhip effect and spread the operational risk (Christopher and Holweg, 2011). The key objective in this setting was therefore to reduce costs through increased control. There is however considerable evidence that supply chains will experience increasing turbulence in the future and companies will need to develop supply chain models suitable to meet these challenges (Christopher and Holweg, 2011). Thus, there is a need for a better understanding of both the responsiveness concept and how responsiveness can be achieved.

In terms of the content of the responsiveness phenomenon, this study provided some insights on the phenomenon in a food supply chain context – demonstrating how both product and market characteristics increase the need for responsiveness. Further, the study looked at the relationship between external responsiveness to customer requirements, demonstrating how effectiveness in meeting external requirements can come at the expense of internal efficiency in production, inventory and PPC performance. In the terminology of Reichhart and Holweg (2007) this can be understood as a gap between the demonstrated responsiveness and the potential responsiveness in the way that responsiveness is achieved, in other words that the production system is currently not delivering the required external responsiveness in a resource-efficient way. An example of this is that the case facility appeared fairly effective in meeting external customer requirements in terms of service levels and remaining shelf life. On the other hand, the analysis also revealed large inventories – which can offer a false sense of security while hiding problems in the underlying processes (Griffiths and Margetts, 2000).

The study provided some insights on how responsiveness can be enabled through increased volume flexibility based on a differentiation of PPC approaches and using different buffering techniques to protect operations against demand variability. The study further proposed a process for analysing market and product characteristics and used the findings to design an appropriate organisational response. Responsiveness further requires an external sensing capability with mechanisms that trigger reactive internal behaviour (Bernardes and Hanna, 2009). In the proposed solution, this sensing capability is represented by the continuous monitoring of demand uncertainty in the redesigned PPC process, while the mechanism that triggers reactive internal behaviour is represented by the application of the differentiation framework which links configurations with PPC approaches and buffering techniques.

Another contribution of the study is the illustration of how efficiency and responsiveness is not necessarily a question of selecting one or the other strategy. Rather, the study demonstrated how different degrees of the two are appropriate in different contexts. Thus, the differentiation concept and framework can assist companies in determining a mix of the two that is suited for their particular product and market mix. These tools enable companies to identify the requirements exerted upon them by product and market characteristics, and these insights can then be used to identify the operational capabilities needed to meet the requirements. By applying different PPC approaches in different supply chain configurations, a company can be both efficient and responsive because it responds to the set of external requirements with a strategy consisting of an appropriate mix of PPC approaches.

7.5.3 Reflections on responsiveness and differentiation

Below, the study's contributions towards knowledge on responsiveness and differentiation are outlined and discussed from two perspectives; from a design proposition perspective and from a critical realist perspective.

7.5.3.1 *Insights from a design proposition perspective*

The overall scientific goal of the study was to contribute to increased understanding of how differentiated PPC can enable food producers to meet external product and market requirements in an effective and efficient manner. A key issue in this respect was the link between responsiveness, efficiency and PPC. Initially, the practical problem was formulated as a lack of strategic fit between external requirements and the capabilities of food producers' production system, based on the assumption that there was a need to increase food producers' responsiveness. The initial design proposition for the study was therefore that:

- If you want to increase the responsiveness of a food producer, differentiate the way production is planned and controlled

Although there may be a need to increase the responsiveness of food producers in general, the TINE case study demonstrated that this may not necessarily be the biggest challenge – at least not when customer responsiveness is defined as the capability to meet customer requirements. Rather, it was found that TINE is highly effective in meeting customer requirements on time and in the quantities ordered. However, the analyses concluded that this effectiveness is achieved at the expense of internal efficiency in production, inventory and PPC performance. Thus, the operating characteristics of the company do not enable production to deliver the customer responsiveness in a resource-efficient manner.

This reframing of the practical problem did not change the underlying problem; how to achieve a better fit between external requirements and the capabilities of the production system, such that operations would be able to meet the external requirements in both an effective and efficient manner.

Through an abductive approach, the study linked the responsiveness concept with the concept of differentiation and investigated how a differentiation approach to PPC could enable volume flexibility in the production system. The insights from the literature studies and the case study of TINE led to a revision of the initial design proposition with a more detailed description of the involved mechanisms and expected outcomes of the proposed intervention. Based on this, the revised design proposition is that:

- If you want to improve the strategic fit between external requirements and the capabilities of food producers' production system, differentiate the way production is planned and controlled according to product and market characteristics

The mechanism on which this proposition is based is related to the principles of the differentiation concept. Firstly, the proposition is built on the concept of differentiation – and a key question is then; on what should the differentiation be based? The first principle of the differentiation concept addresses this from a supply chain configuration perspective. From previous research it was found that food supply chains consist of configurations with different product and market characteristics. This insight means that favourable characteristics can be exploited in PPC to provide flexibility to the production system, i.e. using long customer order lead time allowances to enable postponement and flexibility in the timing of production, taking advantage of low perishability to keep products in inventory and thereby provide flexibility in the timing of production, and separating demand into high and low predictability to enable more efficient use of PPC resources since these can be focused on the most challenging products.

The second principle targeted the question of which PPC approach to use in which situation. Again, the supply chain configuration framework was used as a starting point. Since the scope was on demand-side issues, demand predictability was identified as the most important factor for determining PPC approaches. Thus, for configurations with low demand predictability an MTO approach is most appropriate because it reduces operations' dependency on forecasts and the exposure to demand variability. MTS is suitable for configurations with high demand predictability since this allows for a focus on operational efficiency.

The third principle addressed the question of which buffering techniques to use to protect operations against uncertainty in the different configurations. Buffering of inventory work was

identified as an appropriate option well when perishability is low, buffering of capacity can be appropriate in situations where customers allow long delivery lead times, and in cases where demand predictability is low, buffering of time through an MTO approach may be appropriate.

Based on these insights, the CIMO logic of the initial design proposition from sub-section 2.2.2 was revised; see Table 7-3.

Table 7-3: Components of the study's revised design proposition

Component	*Description*
Context (C)	The context is industrialised food production, with a main focus on handling demand variability resulting from downstream actors. The institutional setting is a single production facility which produces a given number of product variants on a limited number of production lines.
Intervention (I)	The proposed intervention is a redesign of the PPC system based on differentiation of the principles used to plan and control production. An operational prerequisite is that production processes can be decoupled.
Mechanism (M)	Differentiated PPC can improve the strategic fit between external requirements and production system capabilities – based on exploiting favourable supply chain characteristics, differentiating PPC according to product and market characteristics, and using slack resources to buffer against demand uncertainty.
Outcome (O)	The expected outcome of the intervention is higher volume flexibility and less exposure to demand variability – which in turn enables simultaneous internal efficiency in production, inventory and PPC processes, and high responsiveness to customer requirements.

7.5.3.2 Insights from a critical realist perspective

Another way of expressing the study's contributions towards knowledge on responsiveness and differentiation is through the critical realist approach. A key strength of a case study is the ability to reach the causal depth required for revealing the structures and mechanisms underlying actual events in practice and performance (Aastrup and Halldorsson, 2008). The findings and insights from the study can therefore be summarised using the causal structure of Sayer (2010), see Figure 7-5. Sayer's model links generative mechanisms and actual events or outcomes in a causal analysis, where the causal powers represent an object's ability to activate a mechanism, whereas liabilities represent inherent limitations to do so. This is different from the traditional view of causality as a relationship between discrete events (e.g. 'cause and effect'). Instead, the CR view maintains that powers and liabilities exist whether or not they are being exercised and their activation is dependent on contingent conditions, i.e. objects that have their own causal powers and liabilities (Sayer, 2010). Thus, an object's causal power to achieve the events rely on both the physical and social elements of the object's structures and is affected by the power and liabilities of the conditional circumstances (Aastrup and Halldorsson, 2008).
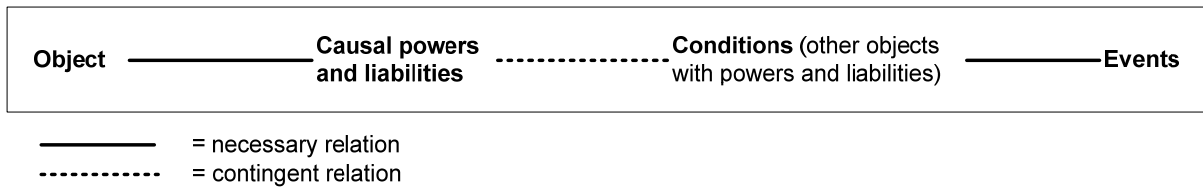
Figure 7-5: Causal analysis from a critical realist position (adapted from Sayer, 2010, p. 109)

The object under investigation in this study was PPC systems consisting of loosely coupled structures, i.e. the principles, systems, procedures and decisions of the PPC task, and social agents represented by the people who make decisions and perform the PPC task. The studied mechanism was the causal power of PPC differentiation to enable responsiveness as an event or performance, see Figure 7-6. Responsiveness in this context included the ability to provide both effectiveness and efficiency in meeting customer requirements – thus expanding the definition of responsiveness to also mean that the effectiveness in meeting customer requirements should be achieved in an efficient manner.
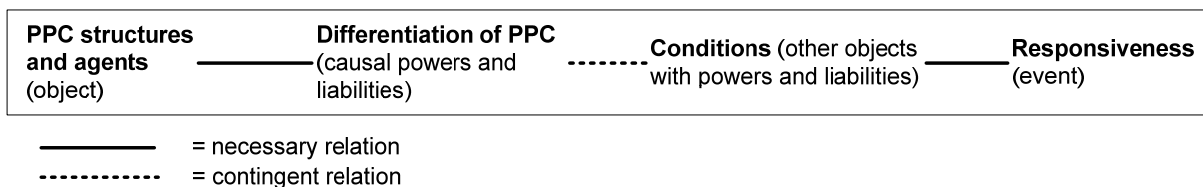
Figure 7-6: Causal analysis of relationship between PPC, differentiation and responsiveness (based on Sayer, 2010)

In the TINE case study, both quantitative and qualitative data on the physical and social structural elements of the PPC system was collected, providing a rich description and a basis for understanding both current practices and performance and how these may affect the ability of differentiation to lead to responsiveness.

The rich data and the collaborative research strategy generated insights into the conditioning powers of the physical and social structures of the PPC system; i.e. both the structural elements of rules, processes and policies of the PPC system and the social system within which decisions are made and PPC tasks performed. Based on abductive reasoning, the study posits that a number of conditions affect the ability of differentiated PPC to generate responsiveness in the food production setting. The reasoning behind this consists of two types;

- Abstract reasoning; explaining what it is about differentiation that affects the causal power to result in responsiveness
- Concrete reasoning; explaining under which conditions differentiation will result in responsiveness

The first group of conditions are generated through abstract reasoning related to the structural elements resulting from a redesign of the PPC system based on the concept for differentiated PPC. Firstly, the company should have a thorough understanding of its product and market characteristics in order to be able to exploit these in the redesign of the PPC system. Secondly, it is essential that the appropriate dimensions are used to differentiate and the study posits that in the food production setting, PPC should be differentiated according to product and market characteristics, expressed as customer order lead time allowance, demand predictability and product perishability. Thirdly, the design must incorporate the use of appropriate tech-

niques for buffering against demand uncertainty and the study suggests that this should at least include using slack resources in the form of inventory, capacity and time.

The second group of conditions are a result of concrete reasoning. Firstly, a key condition for the mechanism is the access to reliable data, both as input to the redesign the PPC system and for following up the performance of the PPC system. The study found that the PPC system should be monitored using a mix of performance indicators, including service levels, safety stock levels and frequency of out of stock situations, levels of scrapping and identification of the causes of scrapping, amounts of value loss associated with discounts and identification of causes for discounts, production response times, plan stability or re-planning frequency, due date adherence, overtime and capacity utilisation, and number of resources spent on PPC.

Further, the ability of the redesign to enable the performance is dependent on a redesign of PPC processes. This will involve a number of elements affecting the social system involved in PPC decision making, including who does what, when and based on what information. The new framework for determination of PPC approaches will for instance remove a number of the current decision making tasks involved in weekly planning, thus reducing the reliance on the planners' manual assessments but simultaneously also changing the way planners work. Thus, the question of whether or not the redesigned system will work according to the intentions will to a large degree depend on the motivation and expectations of the planners. Issues related to the social system must therefore be given particular attention in the detailed design and implementation process.

In summary, the study has inferred through abstract reasoning what it is that affects differentiation's causal power to enable responsive performance, namely:

- Exploitation of favourable product and market characteristics
- Differentiation according to customer order lead time allowance, demand predictability and product perishability
- Application of appropriate buffering techniques

Further, through concrete reasoning, the TINE case study provided insights on the conditions that are required for differentiation to enable the desired performance, including:
- Redesign of PPC processes
- Access to data
- Use of appropriate performance indicators
- A carefully designed implementation process.

These causal links between structures, practices and performance are illustrated in Figure 7-7.
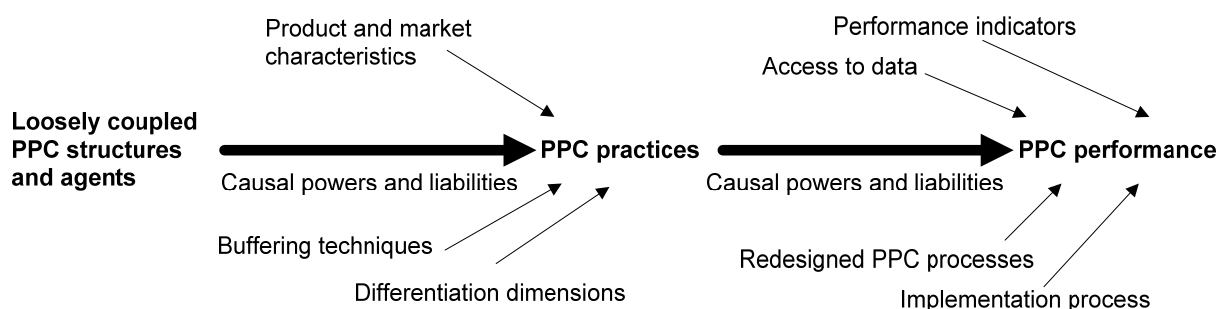

Figure 7-7: Causal links between PPC structures, practice and performance (based on Sayer, 2010, adapted from Aastrup and Halldorsson, 2008, p. 755)

7.5.4 Reflections on differentiation and product variety

The trend towards increasing product variety has a great impact on the complexity of the PPC task. Rather than producing large volumes of a few variants in a stable environment with fairly predictable demand, tomorrow's producers must deal with an increasingly larger variety of variants, ordered in smaller and smaller quantities, and produced and distributed more frequently in smaller batches.

The issue of how to deal with the increasing product variety is far from new and several authors have looked at how differentiation can be used to increase responsiveness in a supply chain setting. Already in 1995, Daugherty and Pittman (1995) investigated how companies were using differentiation in their distribution. The study found that a commonly used strategy was to differentiate between customers by customising the service offerings to the most important clients. Simultaneously, this involved a dilemma between the increased cost of customisation or differentiation and the potential benefits resulting from standardisation. Fisher (1997) looked at how companies could identify one single strategy to fit the majority of the company's products – but did not discuss how companies could deal with a variety of products with differing characteristics. A group of articles published in the early 21st century targeted this by investigating how companies could design different pipelines or supply chain strategies for different products, see e.g. Christopher and Towill (2002), Aitken et al. (2005) and Christopher et al. (2006). Similarly, Payne and Peters (2004) extended Fisher's concept with the idea of matching each product variant with the most appropriate distribution channel (see sub-section 7.2.2.2). Carrying the differentiation on a supply chain level over to the production context, authors like Naylor et al. (1999) and Bruce and Daly (2004) looked at how different strategies can be applied in the same material flow, where an efficiency strategy is used for the processes upstream of the CODP while a responsiveness strategy is applied downstream.

In this study, the ideas from the above were studies applied to PPC in food supply chains. However, a further complication is introduced in the proposed concept for differentiated PPC. In addition to applying two different PPC approaches simultaneously in the same production system, the concept will in some cases also result in different PPC approaches being applied to the same product simultaneously. How to deal with this issue in practice is an interesting avenue for further research as it has not been dealt with in existing literature.

An inherent strength of the proposed concept for differentiated PPC is that it assesses each product on a variant level and thus the research contributes to the stream of research on SKU classification or categorisation. A host of characteristics have been used in literature to classify SKUs for different purposes, and based on a review of literature, van Kampen et al. (2012) outline four main categories for SKU characteristics; volume, product, customer and timing. Below, this study's contributions towards each of the four categories are outlined.

In most studies on SKU, consideration of volume is included, particularly in the studies on production strategy. Volume characteristics often include sales volumes, order sizes, COV of demand, and volume variability. This study contributes to this category by focusing mainly on volume and how to provide increased flexibility to enable the production system to handle the volumes requested and simultaneously deal with demand uncertainty. A difference between this study and several of the others is the operationalisation of demand uncertainty into predictability, which enables planners to separate the demand variation which can easily be forecasted from the variation which is difficult to forecast and therefore requires more flexibility and should be given more focus in the PPC process. In this respect, the study is in line with

Fisher et al. (1994) who differentiated supply chain strategies based on which of the offered products that can be forecasted more accurately than others. By using less demanding strategies for easy-to-forecast products, flexible resources can be saved for the hard-to-forecast products.

Consideration of product is also found in most papers, often related to demand value and product unit cost. Product characteristics which are often considered are production or supply lead times in addition to context-specific characteristics such as perishability, commonality and substitutability. This study focused on determining PPC approaches on the product variant/SKU level in order to enable the facility to deal with a wide variety of product variants. Characteristics which were considered include the uncertainty regarding which variants that will be required. The concept added context-specific characteristics related to perishability which is one of the key characteristics that complicate PPC in the food sector. However, the study did not consider relations between products and this is an interesting avenue for further research. Since the focus was on operations and PPC, profit margins related to portfolio decisions were not considered. Further, duration of PLC is not directly considered although changes in demand predictability over a product's life cycle are captured as part of the decision tree.

Consideration of customer was found to be less used in literature although some studies have included consideration of customer criticality. The differentiation framework in this study matches products with the requirements of customers in terms of lead time and predictability of demand and thus captures differences between customer requirements. The fact that the case company has only a limited number of customers and mainly two lead time expectations (one day or several weeks) simplifies the grouping of customers for PPC purposes. Further, customer criticality is indirectly captured in the case study through the company's strategic decision to always provide high service levels to all customers.

The timing category was found to be relatively neglected in literature, even in studies on forecasting. This measure captures the frequency of orders and related time window for delivery. In this study, the time window for delivery is reflected in the consideration of customers' lead time expectations. The case company's customers mainly place orders either daily or at fixed intervals (with short lead time allowances) or infrequently (with long lead time allowances). In the application of the framework, it was decided to ignore the fact that many of the products currently have a packing lead time that is longer than the time window for delivery which makes an MTO approach infeasible. However, with investments in readily available cooling technology at the end of the production lines, the majority of the packing lead time could be eliminated, thus making MTO feasible for all products.

From the above, it can be argued that this study has taken a broader perspective than much of the reported literature on SKU classification since it addresses all four categories. The study provides additional evidence to the claim that differentiating the way products are managed in the supply chain is a way forward and there is scientific value in reporting such applications as they strengthen the evidence in favour of the differentiation proposition.

7.5.5 Reflections on differentiation and the COV

Much of the literature on supply chain differentiation has been based on the DWV^3 market characteristic criteria (see sub-section 3.4.3) which can be used to develop context-specific differentiated pipelines (see e.g. Godsell et al., 2011, Aitken et al., 2005, Christopher et al.,

2009). The third V in this model refers to variability, where demand variability is expressed in terms of the COV. The COV expresses the degree to which the demand for a product varies in a period and can be used to identify products that have a demand variation so high that forecasts should be avoided and the focus instead should be on lead-time reduction and the substitution of information for inventory. This corresponds to the identification of the 'focus box' for PPC in the differentiation concept and the application of an MTO approach in situations where demand predictability is low since this postponement strategy uses time as a buffer against demand variability.

In empirical studies, a COV > 0,4 has been considered high (see e.g. Godsell et al., 2011, D'Alessandro and Baveja, 2000). However, the COV approach has proven difficult to use in a number of studies because the number of products that have turned out to have COV > 0,4 has been too large to provide the desired reduction of products in the 'focus box'. This was also seen in the TINE Heimdal case, where 46 % of the products had a COV > 0,4. This indicates that the COV may not be the most appropriate criteria to characterise demand variation for the purposes of PPC. The cut-off limit for high and low variability in many studies reported in literature is also unclear (see e.g. Bruce and Daly, 2004, Christopher et al., 2009, Aitken et al., 2005, Aitken et al., 2003) or appears to be fairly arbitrary, where anything from COV > 0,4 to COV > 1,5 has been classified as high (see e.g. Wong et al., 2006, Soman, 2005, D'Alessandro and Baveja, 2000).

Although the COV expresses how much demand varied in a given period, not all of this variation may have been unpredictable. Some of the variation could perhaps have been forecasted, for instance seasonal variations or demand increases related to frequently used market activities. For this reason, predictability of demand was used to express demand uncertainty instead of the COV in the differentiation concept and framework. Although a decision tree had to be developed in order to evaluate the demand predictability, this approach makes it possible to include assessment of qualitative factors which impact on predictability in addition to the traditional quantitative measures.

Yet another weakness in the use of the COV approach is that it is calculated from historic data. Thus, it is not suitable for planning new or newly launched products with no historic demand data. Also, it does not capture that future demand will be impacted by planned market activities. Thus, although the COV may provide useful insights which can be used to for instance group products with similar historic demand patterns, its use for planning and control purposes appears limited.

7.6 Reflections on research quality and methodology

This section presents some reflections with regards to the quality of the research which has been conducted, the methodological choices which were made, and some limitations related to the study's methodology and theoretical scope.

7.6.1 Research quality

In section 2.2, four criteria for evaluation of research quality were presented, and below, the study's performance on each criteria is evaluated based on the definitions of Halldorsson and Aastrup (2003).

Credibility

The credibility criterion is similar to the conventional notion of internal validity but in cases where social actors and their perceptions of reality form part of the data, there can be no single objective reality. Therefore, the notion of credibility is more suitable, expressed as the degree to which researchers have succeeded in capturing and representing the constructions of the respondents, i.e. their perception of reality.

The qualitative data collected in the study came from countless formal and informal meetings, conversations, workshops, factory tours and some more formalised interviews. Although notes or minutes were not taken in all these meetings, some strategies were employed during the data collection to increase credibility, including:

1. Interviews and workshops were carried out by the PhD candidate and the key informant together, and impressions and interpretations were discussed afterwards. In cases where interviews were conducted by the key informant, field notes and impressions were shared and discussed with the PhD candidate.
2. In cases where there was a need to clarify and expand on received information, respondents were contacted again.
3. Case reports and notes from meetings were in some cases sent to respondents for commenting.
4. Case analyses performed by the PhD candidate or the key informant were collaboratively interpreted and discussed.
5. Findings from the case analyses and details of the suggested solutions were presented and discussed with company resources from the strategic, tactical and operational levels in order to ensure that the descriptions corresponded with employees' own views and impressions.

In sum, these strategies are thought to have ensured high credibility of findings and results.

Transferability

Making general claims is a crucial idea in research, and traditionally generalisation has been expressed in the form of statistical generalisation and external validity (Aastrup and Halldorsson, 2008). As an alternative, Yin (2009) suggests the use of analytical generalisation based on theoretical replication in case studies. Developing formal theory from case studies thus requires cumulating research by adding cases until theoretical saturation is reached – in other words to the point at which incremental learning is minimal because the researchers are observing phenomena seen before (Eisenhardt, 1989). A key question in generalisation is however what one is generalising in relation to; industry, organisation size, geographical location, or what? (Karlsson, 2009) The theoretical replication logic can therefore be argued to be built on the same logic as the conventional statistical generalisation, and Aastrup and Halldorsson (2008) therefore suggest using the terms transferability or contextualisation instead since both context and individuals will change over time and space.

Since the relevance of knowledge cannot be generalised beyond the specific context, the knowledge acquired in one context depends on the contextualisation. This means that it is critical to understand the context and how the knowledge was developed, and further that detailed descriptions of the context, mechanisms and process are provided such that both practitioners and other researchers can assess if the findings apply to their particular context. Transferability of findings from studies based on design science and case studies therefore relies on using the findings to 'design not copy' and 'adapt not adopt' (Godsell et al., 2011).

The transferability of the various contributions from the study was discussed in sections 7.1 - 7.6. The following elements increase the potential for transferability of the results:

- The depth of the case study enabled the production of a rich description of the external and internal contexts, the mechanisms and the expected outcomes
- The structural and social elements of the studied object and the powers of the object and other elements of its context were described and the mechanisms articulated and substantiated

As mentioned in sub-section 2.1.2, reaching stage 5 of development of formal theory in a PhD study is difficult due to practical constraints related to the available time and resources. Reaching this stage also requires beta-testing by other researchers and is therefore not included in this study. However, the detailed descriptions of the case, its internal and external contexts and the research methods used provide a good starting point for such beta-testing which can provide additional support for the transferability of the contributions.

Dependability
Dependability is similar to the conventional notion of reliability; when replication of the same or similar instruments of the same phenomenon results in the same measurements (Halldorsson and Aastrup, 2003). This means that in the conventional view, reliability is sensitive to changes in methodology, hypothesis and constructs. However, an abductive inquiry like the one used in this study rests on an emergent research design where evolving theoretical frameworks and empirical observations inspire changes in methodology and constructs. Dependability in this context can therefore be achieved by documenting the logic of process and method decisions, and clearly articulating the preconceptions and assumptions on which the study is based.

The appropriateness of the design science paradigm and the selection of research methodology were outlined in section 2.1. All major shifts in methodology have been articulated and justified in this thesis (see also sub-section 7.6.2), including the decision to reduce the number of cases from three to one, the reframing of the field problem and revision of the design proposition, and the need to carry out a considerable number of additional quantitative analyses to identify the supply chain configurations in the TINE case study.

Confirmability
Confirmability can be seen as a parallel to the conventional criteria of objectivity, i.e. that the methods used ensure that findings represent the results of the inquiry and not the researcher's bias. However, research can never be truly neural and separated from the researcher, particularly since the researcher selected and used the methods (Halldorsson and Aastrup, 2003). A way to increase an observer's trust in the integrity of the findings is to demonstrate clearly how the findings can be confirmed through the data itself such that conclusions, interpretations and recommendations can be traced back to their sources.

The study has attempted to achieve confirmability through appropriate design and reporting of the research by:

- Providing detailed descriptions of the methods used to collect and analyse data
- Including data excerpts in the thesis and articulating how conclusions were drawn based on the data
- Keeping a case study database which can be inspected by external observers

Together, these strategies are thought to have provided a good basis for the confirmability of the results.

7.6.2 Methodological choices

As mentioned, all research questions cannot be answered by all research methods and one particular method cannot answer all types of research questions. The question of which methods to use is therefore a critical one, and the fit between problem, method and contribution is often reached in an iterative manner (Karlsson, 2009).

This study was originally planned as a multiple-case study. Initially, the plan was to start off with one deep case study in TINE, followed by two more targeted case studies in other Norwegian food producers to increase the dependability of the findings across contexts. However, it was quickly discovered that TINE's production network in itself represented three different contexts and the study was therefore redesigned as a multiple-case study of three different facility types in TINE.

About one year into the first case in TINE, it was discovered that two of the facility types were not relevant for the scope of the study. At this point, the study could have been redesigned again to include comparable cases from other companies. However, reaching the same level of depth in these additional cases would have required considerable resources and time, and for practical reasons the study was therefore redesigned as a single-case study. This meant that the time allotted for cases 2 and 3 could instead be spent on case 1 – thus increasing the depth of the single case even further.

The case study methodology was not the only methodology that was considered for the study. A survey methodology could have been followed. However, this strategy was considered less appropriate since the context and variables were not very well defined at the outset of the study, which is a requirement for surveys (Forza, 2009). The survey methodology was also not found suitable for answering the research questions or for capturing the complexities involved in supply chains dealing with a variety of products with different product and market characteristics. The findings of a survey would also not have been of much value for practitioners in other contexts since it would not have provided rich enough descriptions of the contextual factors and understanding of the involved mechanisms.

Quantitative modelling was also considered. However, this strategy was also considered inappropriate for answering the research questions since the problem situation at the outset was not very clearly defined, which is a critical prerequisite for OR models (Semini, 2011). Instead, the aim was to understand the complexities and mechanisms related to PPC and the responsiveness phenomenon rather than expressing relationships by means of mathematical and logical expressions which would require simplifying assumptions and omitting qualitative factors that are difficult to quantify (D'Alessandro and Baveja, 2000).

7.6.3 Methodological limitations

All research is associated with limitations which impact on the outcomes of the study and the extent to which findings can be transferred to other contexts. A number of such limitations were discussed as part of the discussion of findings and contributions in sections 7.1 - 7.6. Below, some broader reflections with regards to the study's methodology and theoretical scope are discussed.

The study was designed to address the quality criteria described in section 2.2 and as such aimed to apply methods appropriate for the research questions. However, the design also had to take into consideration some practical limitations related to the available time frame, resources, skills, and other practical considerations such as access to cases. On the other hand, the researcher's continuous interaction with the case company and its employees through a number of related research projects since 2006 was a significant strength for the study. The close collaboration enriched the data, strengthened the researcher's credibility with informants, and provided ample opportunities to discuss current challenges, and generate and test ideas on a continuous basis.

Although the researcher was granted close to full access to the case company, there were some limitations related to the availability of data. One issue was the fact that there was too much quantitative data available from a number of information systems such that the case analyses had to be limited to 15 out of 82 products. On the other hand, some limitations in the company information systems and the types of data captured in these meant that the possibility of for instance calculating the potential effects on inventory levels was limited, as was the estimation of the value loss related to selling products to customers at a discount.

The perhaps biggest methodological weakness of the study is related to the lack of testing in a real setting in order verify that the proposed intervention would actually produce the expected outcomes. This type of testing would have involved redesigning TINE's planning and control practices and principles and initiation of a large change effort with the involvement of labour unions and management at all levels of the organisation, actions which are difficult to achieve and generally outside the scope and mandate of a PhD study. In order to alleviate some of these limitations, a number of alternative strategies were employed, including close collaboration with company representatives in all stages of the study, regular discussions with key resources at strategic, tactical and operative planning levels, and presentation and discussion of ideas, concepts and findings at academic and industrial conferences.

Another limitation is related to the lack of solutions for how the developed concept and framework can be realised on the tactical and operational PPC levels, and this is a key topic for further research.

Due to practical limitations, PhD researchers naturally need to limit the breadth and depth of the study's theoretical scope, and this was also the case in this study. Firstly, this study only focused on one type of variability facing production companies; demand variability. For many companies, other types of variability are equally important and challenging, e.g. product variability, process variability, supply variability, and workforce and equipment variability. For many food producers, supply variability is a key driver for PPC decisions, exemplified by the planned TINE cases 2 and 3. By focusing on only downstream variability, the study therefore imposed some simplifications with regards to the complexities involved in PPC in practice. However, this is not to say that the concept of differentiating PPC by supply chain configurations may not also be applicable for addressing for instance supply variability and this is an interesting topic for further research.

Further, the research only looked at two solutions for handling demand variability (see subsection 3.1.4); buffering and developing flexible operations through postponement and differentiated PPC. Thus, solutions for reducing variability itself were not considered, nor were other ways of developing flexible operations like using flexible process types and technology,

shortening setup and cycle times, cross-training of the workforce, and alternative organisational structures.

In addition to scope, there are also some limitations related to contextual factors in the TINE case. In particular two TINE-specific factors meant that the MTO approach was relevant to consider:

1. The cheese making process in TINE has already been decoupled through the separation of cheese making and cheese packing in the physical network structure
2. Cheese is a product which can be stored as an intermediate product which means that it is possible to postpone packing since the shelf life of consumer products is determined by the packing date

These two factors thus represent contextual factors which may limit the transferability of the results.

8 CONCLUSIONS

This chapter summarises some of the insights and findings from the previous chapters. Firstly, the study's key findings are summarised. Next, the study's contributions to knowledge are outlined and the study's achievement towards the objectives evaluated. Finally, some implications for practice, suggestions for further research and concluding remarks are presented.

8.1 Summary of key insights

This thesis addressed a highly relevant and timely issue faced by many food producers in today's business environment. With the realisation that responsiveness may be one of the most important capabilities needed for organisations to achieve competitive advantage comes the need to investigate how PPC can contribute to providing the internal flexibility required to achieve responsiveness in both an efficient and effective manner. The thesis demonstrated how increasing product variety and demand variability are causing problems for PPC and reducing the efficiency in production, inventory and PPC processes.

The study proposed a way of exploiting differences in product and market characteristics to provide more flexibility to the production system, as well as make PPC processes more efficient. Although the proposed solutions introduce additional complexity to the tactical and operational levels of PPC which must be investigated before the solutions can be implemented in practice, the study demonstrated that a differentiation approach to PPC has some merit in the food production context.

In addition to the case-specific solutions and the contributions to knowledge described above, the study resulted in some insights which may be useful beyond the food sector context. Firstly, the study provided evidence of and a potential explanation for the lack of strategic fit between external market and product requirements and production system capabilities. While the production system is designed for scale benefits through high volume and low variety, there are external pressures for shorter response times, higher delivery frequencies, and ability to handle increasing product variety and demand variability. The study demonstrated how a differentiation approach to PPC has the potential to improve the fit between external requirements and production system's capabilities, thus providing a basis for improved performance.

Secondly, the study demonstrated how the growing complexity and variability facing today's producers considerably complicates the PPC task and requires a focusing of PPC resources. An outcome of the study is a decision tree which can assist food producers in identifying the 'focus box' for PPC, where the manual decision making for products with high demand predictability (the majority of products) can be automated using ICT as an enabler, while PPC resources can be focused on the products with low demand predictability.

Thirdly, the case study provided evidence of how responsiveness in meeting market requirements can come at the expense of efficiency in internal processes. The study also illustrated that rather than responsiveness and efficiency being a question of either-or, a better solution can be to match different market and product requirements with different PPC approaches to achieve an appropriate mix of the two. A key in this solution is the idea that an MTO approach is not incompatible with MTS – but rather that the two approaches can be combined to provide the internal capabilities needed to meet external requirements in different supply chain configurations.

Finally, the research illustrated how practical problems can be addressed with theory. By using theoretical perspectives to design a concept and a framework that address real-life practical problems, the study showed how design science research can provide guidance to OM practice. The case study also illustrated how concepts can be used to drive solution development, while data and analytics are used to design the detailed solutions for implementation. Thus, simplified concepts and frameworks can be used sell ideas to decision makers, while data and human involvement are needed to drive development and implementation of case-specific solutions.

8.2 Summary of contributions and achievement of objectives

In chapter 7, the study's findings were outlined and discussed, and in Table 8-1 the main contributions to knowledge from each of the study's research questions are summarised, with reference to where in the thesis more detailed descriptions can be found.

Table 8-1: Linking research questions and contributions to knowledge

Research question	Theoretical contribution		Reference
RQ1: What are the characteristics of food supply chains?	T1.1	More comprehensive understanding of food supply chain characteristics and how these impact on PPC of food producers	Table 4-2, Table 6-2, section 4.3
	T1.2	Framework for characterisation of supply chains	Sub-section 3.1.3 and Table 3-1
	T1.3	Methodology for linking supply chain characteristics with requirements for PPC	Sub-section 4.3.4 and Table 4-3
RQ2: How can PPC be differentiated according to food supply chain characteristics?	T2.1	Concept and framework for differentiated PPC	Sub-section 5.1.4, Figure 5-3 and Figure 5-4
	T2.2	Demonstration of how the differentiation concept and framework can be operationalised	Section 6.3.2
	T2.3	Decision tree for determining demand predictability of a food product	Figure 6-21
	T2.4	Methodology for how to design a differentiated PPC system	Table 7-1
	T2.5	Design proposition and proposition of causal links between PPC structures, practices and performance/capabilities	Sub-section 7.5.3, Table 7-3 and Figure 7-7
RQ3: What are potential benefits of differentiated PPC?	T3.1	Identification and structuring of potential benefits of differentiated PPC	Table 7-2
	T3.2	Illustration of typical effects of differentiated PPC for a food producer	Table 6-13
RQ4: What are the tactical and operational challenges of differentiated PPC?	T4.1	Increased understanding of key tactical and operational implications of hybrid MTO-MTS production environments	Section 7.4

The study's scientific goal was to contribute to increased understanding of how differentiated PPC can enable food producers to meet external product and market requirements in an effective and efficient manner – with particular focus on responsiveness as an OM phenomenon. The study's contributions towards the knowledge on responsiveness and differentiation were outlined and discussed in section 7.5.

Four objectives for the research were formulated in section 1.3, and the degree to which each objective has been achieved is briefly outlined below with references to where in the thesis more details can be found.

Objective 1: Identify challenges of current PPC in the food sector
This objective was met through RQ1 which used literature to develop a framework for characterising supply chains (sub-section 3.3). The framework was subsequently used to collect and structure empirical data from literature, resulting in an overview of the key product, market and production system characteristics of food supply chains (section 4.2). The characteristics' impacts on PPC were then logically derived (section 4.3) and the findings confirmed and illustrated through the TINE case study (sub-section 6.1.1).

The findings and conclusions were also presented and discussed with TINE representatives and other industry representatives, as well as other national and international academics, thus strengthening the trustworthiness of the study's conclusions. It is therefore reasonable to say that objective 1 was achieved.

Objective 2: Develop a concept and framework for differentiated PPC in the food sector
This objective was achieved through RQ2. A literature study resulted in the development of a concept (section 5.1), which was further expanded into a framework (section 5.2) and an initial and revised design proposition for how PPC can be differentiated in the food sector (sub-sections 2.2.2 and 7.5.3.1 respectively).

Again, the framework and insights from the case study were presented and discussed with TINE and other industry representatives, as well as other national and international academics, thus strengthening the trustworthiness of the study's conclusions. It is therefore reasonable to say that objective 2 was achieved.

Objective 3: Conduct a case study to identify current PPC challenges, develop new solutions and investigate the potential benefits of differentiated PPC
The third objective was achieved through RQ3. The case study of TINE and the TINE Heimdal facility (chapter 6) assisted in:

- Framing the practical industrial problem
- Illustrating the application of the developed frameworks, the concept and the design proposition
- Developing new solutions
- Evaluating the potential benefits of the proposed solutions
- Revising the initial design proposition

The close collaboration with industry was critical in achieving objective 3. TINE representatives were involved in all stages of the case study, thus strengthening the trustworthiness of the conclusions and ensuring the practical relevance of the practical problem under investiga-

tion, the solutions developed and the expected benefits. It is therefore reasonable to say that objective 3 was achieved.

Objective 4: Provide guidance to industry on a relevant and current problem
The forth objective was related to the study as a whole and how this should contribute to closing the gap between theory and practice in OM research. The design science research strategy was a key to achieving this objective. Firstly, the research was sparked by the observation of a practical problem facing food supply chain actors, in particular food producers. This problem was firstly confirmed through empirical data collected both from literature and the case study, and then investigated from an academic perspective using existing theoretical frameworks and concepts.

Abductive logic was used to develop new theoretical insights and propose new solutions to the practical problem by alternating between theory and the empirical world. This ensured that the research was relevant to practice and that the developed frameworks, concept and insights could in fact provide guidance to industry. Detailed descriptions of the practical problems, the proposed solutions and the development process are included in the thesis in order to facilitate the transferability of the outcomes to other food production companies and other industrial contexts facing similar problems.

And again, the close involvement of practitioners, as well as the presentation of the research at national and international industrial and academic conferences, seminars and workshops, strengthened the trustworthiness of the conclusions. In sum, it is reasonable to say that objective 4 was achieved.

8.3 Implications for practice

This section outlines the implications for practice of the study's findings and results, first with regards to TINE and then for other industrial actors and sectors.

8.3.1 Implications for TINE

As the host of the main case study in this research, TINE was the first company to get access to the ideas, solutions and insights while they were being generated. Although the research had to limit the scope of the study and could not address all the PPC complexities facing all of TINE's different facilities, products or markets, there is reason to believe that the research provided valuable insights which will have some implications for planning and control in TINE in the future.

Firstly, the study revealed a number of weaknesses in the current PPC processes of TINE at both the central and local level. Based on these findings, it is reasonable to say that TINE could benefit from re-designing, formalising and standardising its PPC processes, irrespective of whether or not this is accompanied by the proposed differentiated approach to PPC.

Secondly, a realisation of the proposed solutions (methodology for PPC system re-design, the decision tree and the differentiation framework) will require a number of issues to be addressed before implementation. The process of designing a full-scale differentiated PPC solution will for instance require involvement of a number of resources from different functions, facilities and management levels. Further, as outlined in section 7.4, a number of tactical and operational issues remain to be solved before a differentiated PPC solution can be implement-

ed in practice. The use of the decision tree will further require a formalised process for obtaining the data needed to perform both the quantitative and qualitative evaluations. The re-designed PPC system should also include an evaluation at regular intervals to re-assess the classification of products, and determination of appropriate performance indicators for monitoring the performance of the new PPC solution.

Thirdly, using the decision tree to determine a product's demand predictability will involve assessment of both qualitative and quantitative factors. This does not mean that the process cannot be automated and formalised into an ICT-supported decision support tool. The quantitative evaluations will require large amounts of data and complex calculations which can be automated based on defined criteria and reviewed as needed. In addition, the qualitative evaluations can be performed by humans and entered into the ICT systems which then carry out the calculations, classifications and groupings of products for PPC purposes.

Fourthly, a current barrier to the realisation of the differentiation concept in TINE Heimdal is the long packing lead time due to the required cooling down time which makes an MTO approach infeasible for many of the products. This issue could however easily be solved by investing in readily available cooling technology, for instance a cooling tunnel between the packing lines and the finished goods warehouse, thus reducing cooling down time to a few minutes instead of several days. Such an investment would increase the applicability of the concept considerably.

Finally, as mentioned, a differentiation approach to PPC would be only one part of a broader process for improving PPC in the TINE Group. Thus, realisation of the solutions proposed in this thesis would have to be part of a larger implementation process which should involve ensuring organisational readiness, employee involvement and testing through pilot studies.

8.3.2 Implications for other industrial actors

As mentioned, the relevance of knowledge cannot be generalised beyond the specific context. However, there are certain contributions and insights from the study which may be suitable for adaptation to other contexts.

Firstly, the framework for characterising supply chains and the methodology for linking characteristics with requirements for PPC may be of use to both practitioners and researchers who wish to increase the understanding of a particular supply chain setting. Further, the concept of differentiated PPC might provide inspiration for how PPC can be differentiated in other contexts based on product and market characteristics. The study will hopefully contribute to increasing the food industry's awareness of the need to differentiate how products with different characteristics are planned and controlled – and this insight is not only applicable to the food sector or to the production stage of a supply chain, but to all companies that operate in supply chains with differing product and market characteristics.

The idea of focusing PPC efforts on the products that have the lowest demand predictability is also likely to be of value in other industrial settings where MTS is the dominant PPC approach, although the principles, tools and techniques to support PPC in practice should be adapted to the particular internal and external contexts.

Given that the six configurations in the Kittipanya-ngam (2010) framework capture the most important characteristics of food supply chains, the concept of linking supply chain configura-

tions with different strategies and approaches may also be useful for other purposes, for instance inventory management, distribution, forecasting, and supply chain information sharing and collaboration models. Further, the concept of differentiating PPC based on product perishability may also be of value in other sectors that deal with assets that lose value over time, e.g. pharmaceuticals, computers, mobile phones, and high fashion apparel.

The study's findings might further raise industry's awareness of the increasing need for flexibility to meet external requirements – insights which should also be taken into consideration when investing in production technology. Technological developments towards quicker and less resource-demanding changeovers are enablers of more differentiation and higher degrees of flexibility in the physical production processes.

The differentiation strategy might also have some implications for the way supply chain partners cooperate and collaborate with each other. A differentiation strategy may therefore also include associating different product-market combinations with different types of information sharing models like vendor managed inventory (VMI), efficient consumer response (ECR) and collaborative planning, forecasting and replenishment (CPFR) – which will contribute to making both companies' internal planning and control and the overall supply chain planning and control more effective and efficient.

Finally, the research can be perceived to have contributed to society in a broader perspective. Considering that food producers are major contributors to the waste of food and other resources in the supply chain, the study may also have a contribution towards supply chain sustainability. In an embedded emissions perspective, reducing waste upstream in the supply chain avoids wasting resources on transporting, storing and managing products downstream (Nereng et al., 2009). The study is therefore a step towards helping food products fulfil their function, i.e. being consumed before their shelf life expires. Although perhaps motivated primarily by financial reasons, the differentiation approach may thus also have some impact on the environmental and social performance of the food supply chain when considering that more effective and efficient PPC can result in a reduction of global food waste.

8.4 Suggestions for further research

There are a number of opportunities for further research that follow naturally from this study. Some of these are related to the methodological weaknesses and limitations of the study, while others are more directed towards further research on the key theoretical concepts of the study and further development and application of these in other industrial contexts.

This study has addressed differentiation, responsiveness and PPC on a conceptual level. Building on the discussions related to RQ4 there is therefore a need for further investigation of how the concept can be operationalised on the tactical and operational level. A combined MTS-WLC approach was suggested as one alternative which could be further explored. Also, the question of which PPC techniques that are appropriate for different degrees of perishability, demand predictability and customer order lead time allowances remains open. Other relevant aspects to investigate include the impact of differences in maturation and production lead times, the point of variant explosion for different product families, and interdependencies between different products for instance in terms of set-up times and costs.

Once the above issues have been sufficiently investigated, there is a need to define parameters that can be used to measure the benefits of the concept. Related to this, the study revealed a

need for a framework or tool for evaluating the effectiveness and efficiency of PPC. Although there are a number of typical performance objectives for the operations function, these may not be the best to identify weaknesses related to PPC system design and performance.

A redesign of PPC processes along the lines suggested in this study will have important implications for the social system of an organisation. Thus, investigation related to change management, employee involvement, motivation, using ICT to support human decision making, etc. are highly interesting topics for further research.

Investigating the transferability of the differentiation concept to other industrial sectors would be highly interesting, as well as the usefulness of the idea of differentiating planning and control in other supply chain stages. Again, the starting point in all such efforts should be to 'design not copy' and 'adapt not adopt' (Godsell et al., 2011). Also, further investigation of how differentiated PPC can contribute to handling the supply uncertainty facing food producers is highly relevant, for instance looking at how differences in raw material perishability could be exploited to reduce exposure to supply variability.

8.5 Concluding remarks

The core mission of any design science initiative is to develop general knowledge that professionals can draw upon to design solutions to their specific challenges and problems (van Aken, 2004). Given the calls for more practical relevance of OM research and the need for OM to lead rather than follow practice, our research should also include explorative elements which synthesise the existing body of knowledge and develop forward-looking principles (Holmström and Romme, 2012). This study's research questions were driven by field problems and the study sought to address these by synthesising existing knowledge and then applying new solutions in a case study to investigate their ability to solve the problems in the field.

The initial ideas for the research were sparked by observing actors in the food supply chain discussing how they could benefit from advanced collaboration models like VMI and CPFR. The underlying notion was that each actor could take advantage of access to more up-to-date demand information to make their processes more responsive and demand-driven. However, both in practice and literature it was clear that food producers lacked the maturity and knowledge to fully exploit this type of information in their internal processes. Thus, there appeared to be a need for investigating how demand information could in fact be used to improve the planning and control of production and inventory in food supply chains, and this study was a timely contribution in that respect.

The increasing product variety and demand variability is likely to continue to increase the complexity of companies' PPC tasks in the foreseeable future. On the other hand, advances in ICT are now also providing access to unprecedented amounts of data which can be exploited for planning and control purposes. Advances in production technology are also continuously reducing the time and cost of equipment changeovers, thus enabling production of a wider range of variants in smaller batch sizes. These developments show that this study has been both relevant and timely since this is the time to prepare the ground by investigating how PPC can support these changes, and thereby contribute to providing food producers with the capabilities they need to meet future market and product requirements in an efficient and effective manner.

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APPENDICES

Appendix 1 Related research projects in TINE

Over the years, the PhD candidate has collaborated with different parts of the TINE Group through a number of research projects. In some cases the researcher was involved through her employment as a research scientist at SINTEF Technology and Society, other times on a voluntary basis as part of the PhD project since the projects provided an opportunity to establish personal contacts and get to know TINE better. Typical data collection activities in the related projects included workshops with TINE, other companies and researchers, formal and informal meetings and interviews, review of company documents, informal telephone conferences between researchers and company representatives, and site visits.

Project title:	Smart vareflyt (Smart flow of goods)
Project type:	User-driven research project, financed by participating companies and the Research Council of Norway
Thematic focus:	Smart, efficient and safe flow of goods enabled by intelligent packaging and eTracking. The project focused on how to enable more efficient logistics processes and collaboration models in the food supply chain through the use of information from RFID tags on packaging. TINE was one of the participating companies.
Researcher's role:	Proposal writing, defining and carrying out research activities
Period of involvement:	Sept – Oct 2006 (proposal), Jan 2009 – Jan 2010 (project)

Project title:	TIPS; TINE's integrated Production Control System
Project type:	Proposal for user-driven research project submitted to the Research Council of Norway
Thematic focus:	PPC in TINE. Project objective: develop and implement an integrated control arena for increased sustainability, productivity and service levels in complex production facilities and networks.
Researcher's role:	Project definition, proposal writing
Period of involvement:	Dec 2011 – Feb 2012

Project title:	SFI NORMAN; Norwegian Manufacturing Future
Project type:	Centre for research-based innovation, financed by participating research institutions, companies and the Research Council of Norway
Thematic focus:	The centre's vision is to develop new and multi-disciplinary research on next-generation manufacturing, and create theories, methods, models, and management tools that enable Norwegian manufacturers to thrive in global competition. TINE is one of the case companies, focusing on development of the future's solutions for efficient and effective food production.
Researcher's role:	Proposal writing (2005), defining and carrying out research activities
Period of involvement:	Jan 2007 – on-going

Project title:	**MatID (FoodID)**
Project type:	User-driven research project, financed by participating companies and the Regional Research Fund Mid Norway
Thematic focus:	The project investigated how information and ICT can be used as enablers of more efficient logistics in food supply chains. The project consisted of a number of pilots and TINE was one of the participating companies.
Researcher's role:	Proposal writing (2010), defining and carrying out research activities
Period of involvement:	April 2011 – Dec 2012
Project title:	**Planning and control in fresh food production**
Project type:	Master project, Terje Bye, TINE/NTNU
Thematic focus:	Master project focusing on the operationalisation of differentiated PPC in food production using TINE as a case. The PhD candidate was the master student's supervisor and the master student became the PhD candidate's key informant.
Researcher's role:	Supervisor
Period of involvement:	Aug 2011 – Mar 2013
Project title:	**LogiMat; Logistics for food specialities**
Project type:	Knowledge-building project for industry, financed by participating research institutions, companies and the Regional Research Fund Mid-Norway
Thematic focus:	Pre-project and project focusing on developing and demonstrating knowledge, methodologies and solutions, and building a competence network on logistics for food specialities. The aim is to make Mid Norway the leading Norwegian region in food specialities through superior logistics solutions.
Researcher's role:	Proposal writing, defining and carrying out research activities
Period of involvement:	Oct 2011 – on-going
Project title:	**Continued education course in Lean Production**
Project type:	Semester papers by TINE employees
Thematic focus:	Numerous TINE students have followed the NTNU master course Lean Production (PK6023). As part of the course students wrote a semester paper mapping and analysing the operations of TINE.
Researcher's role:	Supervisor
Period of involvement:	Spring 2010, spring 2011

Project title:	**Sustainability measurement in the fresh food sector**
Project type:	Master project, Yong Zhou, NTNU
Thematic focus:	Master project focusing on sustainability measurement in the fresh food sector. TINE was used as a case to illustrate a developed framework.
Researcher's role:	Supervisor and liaison with TINE
Period of involvement:	Spring 2012
Project title:	**Evaluation of food producers' responsiveness**
Project type:	Master student 5th year project, Marine A. V. Gran and Susanne A. Kvame, NTNU
Thematic focus:	Student project that developed a framework for evaluation of food producers' degree of responsiveness. Data from TINE was used to illustrate the developed framework.
Researcher's role:	Supervisor and liaison with TINE
Period of involvement:	Fall 2012
Project title:	**Food production and supply chain planning and control**
Project type:	Master project, Marine A. V. Gran and Susanne A. Kvame, NTNU
Thematic focus:	Master project focusing on operationalisation and control of differentiated solutions for food production and food supply chains. Specific solutions were developed for TINE.
Researcher's role:	Supervisor and liaison with TINE
Period of involvement:	Spring 2013

Appendix 2 Quantitative data analyses

The TINE Group has a large number of ICT systems which capture and store enormous amounts of transactional data. For illustration, in 2011 a total of 2,3 million customer orders were registered, containing 38,8 million order lines. A key challenge for the study's quantitative analyses was therefore not mainly a lack of data or data access but rather identifying which data to extract and how to clean and structure it for the purposes of the different analyses.

In the beginning of 2012, an overview of the desired analyses and their purposes was developed. Based on this, the questions to be answered through the data were specified and the associated data requirements identified.

Ideally the quantitative data extraction and calculations would have been carried out by TINE's ICT department. However, due to internal operational and ICT challenges and other on-going internal projects, the ICT department did not have available resources to assist in the study. Therefore, the data extraction and structuring was done by the key informant – who already had in-depth knowledge of TINE's ICT systems after having worked in the ICT department for several years (see also Appendix 1). Thus, the key informant designed and built the required data infrastructure in an iterative process in consultation with the PhD candidate, operational resources, planners and the people responsible for the relevant subsystems.

An SQL database was created where different data elements were represented in a number of tables. The database was integrated with the following systems:

- TINE's ERP system M3 (Lawson)
- Notes database containing data on market activities and campaigns
- JDA forecasting solution
- QlikView data warehouse

The data for the database was extracted from the different systems and Excel was used to analyse and present the result of the analyses. A simplified overview of the architecture for the quantitative data analyses is illustrated in Figure A - 1.

During the data extraction, cleansing, structuring and analysis phases, a number of weaknesses and deficiencies in both the master and transactional data were discovered. To ensure good data quality, corrections and adjustments were made in consultation with the owners of the relevant subsystems both in the centralised ICT department and at the local facility.
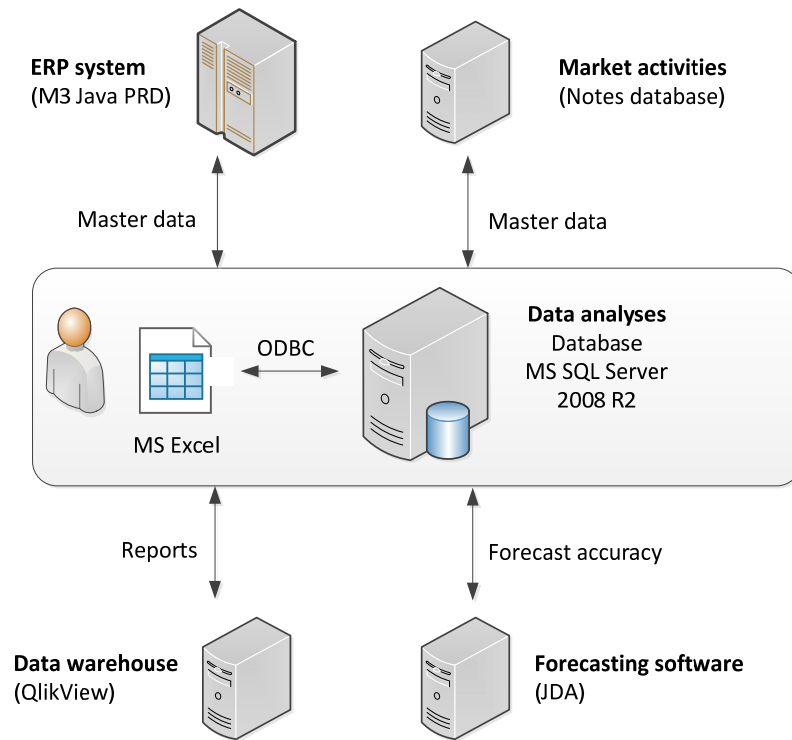
Figure A - 1: Architecture for quantitative data analyses (adapted from Bye, 2013, p. 53)

Appendix 3 Formal interviews, meetings and workshops

The main case data was collected in collaboration with the key informant in TINE. Terje Bye has worked in TINE in different positions since 2000, currently as head of TINE Supply Chain Management's group 'Method and development', and previously as technical lead for supply chain software in TINE, project manager for a technical upgrade of the ERP system M3, controller in TINE's IT department, and management trainee.

In addition to informal meetings and discussions with different TINE employees at the central and local planning levels, case data was collected through some formal interviews, see Table A - 1.

Table A - 1: Overview of formal interviews

Date	Name	Position/role in TINE
26 April 2012	Oddvar Alstveit	Configuration of M3, responsible for M3 production module
26 April 2012	Carl Fredrik Øiom	Responsible for M3 planning module
26 April 2012	Hugo Johnsen	Planner and production supervisor at TINE Heimdal
26 April 2012	Bjørn M. Nordkvelde	Replenishment planner, central production planner for packing facilities
26 April 2012	Tor M. Midtbrø	Product responsible, incl. sales forecasting

In addition to the interviews, the PhD candidate and the key informant organised some formal meetings and workshops to verify data, discuss results, develop and discuss solutions, and evaluate findings in broader forums. The details of these are listed in Table A - 2.

Table A - 2: Overview of formal meetings and workshops

Date	Purpose	Participants
8 Feb 2010	Discussion of collaboration opportunities, including the use of TINE as a case company in the PhD project	TINE: Egil Sørset NTNU: Anita Romsdal, Jan Ola Strandhagen, Heidi C. Dreyer
5 Nov 2012	Presentation and discussion of concept, discussion of challenges and requirements for implementation, discussion on potential effects	TINE: Bjørn M. Nordkvelde, Arild Borren, Terje Bye NTNU: Anita Romsdal
31 Jan 2013	Presentation and discussion of concept, findings, results and solutions from case study	TINE; Egil Sørset, Terje Bye NTNU: Anita Romsdal