Hovedoppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for ingeniørvitenskap
Institutt for maskinteknikk og produksjon

Jens Danbolt

The Capable-To-Promise Function In Production Planning & Control

Hovedoppgave i Produktutvikling og Produksjon
Veileder: Fabio Sgarbossa
Juni 2022

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Kunnskap for en bedre verden

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1 Abstract And Acknowledgements

Abstract
This thesis report focuses on Capable-To-Promise (CTP) concept within the Operations Management field of research. CTP is an extension of the more commonly used Available-To-Promise, and has potential for being more actively used for Production Planning and Control (PPC). A literature study is conducted that finds strong support for its use in making Order Promising and Order Acceptance decisions. A case company that produces IVD reagents for the medical industry is studied, and additional useful applications for CTP are explored. Some support is found for the use of CTP as a visual or mathematical aid in Production Planning and Control, and in Sales and Operations Planning for estimating the cost of capability to satisfy different 'quantity - due date' combinations. The case company produces a narrow range of products to stock, through a production process that is slow, but not complex. Results may not be applicable to other environments than the studied Make-To-Stock environment.

Acknowledgements
This report is the result of a master thesis in Operations Management at NTNU, and is delivered at the end of a 5-year study program in Mechanical Engineering. The grading counts for 30 standard study points. I want to thank the Case Company for their support throughout the process, and my supervisor, Fabio Sgarbossa, for providing the necessary support and answering all my requests.

Contents

2 Introduction

2.1 Background

The thesis project is conducted in cooperation with CGE, an independent developer and manufacturer of IVDR products. Despite a relatively low product mix, the company faces some challenges with its PPC process. Production requires several biological process steps that take long and varying amounts of time, but still it is the non-biological and supposedly simpler filling and packing process that experiences the greatest challenges with Production Planning and Control.

2.2 Topic Motivation

Inventories and Production Planning at CGE is managed through an MRP system combined with forecasts received from the Marketing department. Planning is usually done with internal lead times assumed to be somewhere between the average and the worst case duration, over time making that duration the default.

In practice, production planning and control is manual: Making the MRP, scheduling production and adjusting to changes take up a large proportion of the entire Production Department's work hours. Minimizing inventory costs is not prioritized in this process. Attention is given to producing enough on time to meet forecasted demand, although consideration is given to avoid producing more than is likely to be sold before expiry.

The pre-study indicated that there is lack of clear connection between high level planning (forecasts and MRP) and low level control (reception of new Purchase Orders and adjusting of production plans). The high level plans are used to inform and guide the low level, but there is no official methodology for how that should be done. Employees solve this puzzle through discussion and intuition, which gives usually acceptable results, but is work-intensive. As product portfolio expands, one expects the difficulty of production planning and control (PPC) to grow. Additionally, without documented methodology it is impossible to accurately determine root cause of failures when they happen, therefore conflicting with the company's Quality Management System principles.

2.3 Research Topic and Questions

In production control activities at CGE, one of the most used and most frequently updated variables is the Available-To-Promise (ATP) quantity. It is the cumulative net quantity of planned production minus planned sales, which makes it useful for determining whether the current plan will or will not satisfy demand. It is updated every time a new sales order (SO) or planned production (PP) is registered, a significant advantage over the periodic MRP.

However, it is not quite powerful enough to by itself determine time and quantity of production. First, it only includes known POs and therefore underestimates actual demand by an unknown quantity. The forecast quantity can be added to the demand, but this comes with some challenges that will be discussed in Section 5 - Cast Study. Second, it lacks information about what additional production can be added if and when new purchase orders do arrive.

Thus the topic of this research project: To study how these three factors (ATP, unknown demand and unknown supply) can be combined in a standardized method for PPC - deciding when and how much to produce.

Some authors of Production Management extend ATP with production capacity, reflecting that more can be produced than what is at the time scheduled. This quantity is called Capable-To-Promise (CTP), and it aligns with part of the project goal. However, initial study indicates that it is used for order promising to customers, not for the internal PPC process. A literature study is therefore conducted to study CTP potential as a variable for PPC.

RQ1: How is the Capable-To-Promise concept defined and used for decision-making in Sales and Operations Planning?

RQ2: Does the Capable-To-Promise concept have additional utility for Production Planning and Control in a Make-To-Stock production environment?

The hypothesis is that modeling CTP as function of time is potentially beneficial, and not sufficiently studied in the PPC field. The reason it may be beneficial is the following: CTP viewed as a function of time graph will show what quantities can be delivered at different times through the projection period, given the production plan inputs: What is on hand (time=0), already planned finished goods receipts minus outgoing orders (traditional Available to Promise) and what can be added at what time if more orders are received. A CTP graph can display this information in a single element, and may be compared against estimated demand to help decision-makers with the challenges of production re-planning.

2.4 Structure and Limitations

Section 1 contains background information on the project and topic of research. It motivates the choice of topic and presents the research questions that are to be answered in the following sections.

Section 2 describes the methods used to collect information from literature and case company for the research. And how they fit into the overall methodology.

Section 3 contains the result from two literature studies: A methodical study for a specific answer to Research Question 1, and a broader but less methodical search for related theory.

Section 4 contains a Case Study of the production system at a manufacturer in the medical industry.

Section 5 summarizes findings from the previous two sections and discusses how they may contribute to answer the research questions.

Section 6 concludes on the research project, looking back at the research questions to evaluate whether they have been answered. The validity and limitations of the findings are evaluated, and further research suggested.

Most figures are collected at the end of the document. It is recommended to use printouts or a second display to view them in context with the text where they are mentioned.

Limitations and Scope

Solutions may only be analyzed on a theoretical basis. Real world tests will not be conducted, as they are not possible within the limited project duration and access to conduct real world testing at a case company. A case study is included that studies current practice, but it is not able to test and compare any proposed solutions.

ERP system was introduced from third quarter 2021. The ERP system contains an MRP module, but the monthly MRP is made in Excel spreadsheet and the ERP planning feature is used together with other spreadsheets for planning and recording the production in detail. Studying the ERP system was decided against, as many of its features outside of the Production Planning module are considered out of scope of Operations Management research, and the module is more interesting from a product review perspective than from a scientific one. It also limits potential improvements to those that its tool set facilitates. The ERP system and its functionality, and ERP systems in general, are therefore excluded from scope.

Advanced Planning Systems (APS), an extension of MRP2 that uses data analysis to generate optimized production plans. Literature in Production Management has developed and tested a large number of APS models. In a case study it is possible to either attempt to find an existing model with potential fit and study its performance in the case, or to use the case to develop a new APS model. Some experimentation with the former approach was conducted in the pre-study, but the candidate models were found to require data inputs that at the case company were unavailable or did not fit the model. The second option was evaluated to be outside the researcher's range of competence.

3 Methodology

Use present tense: "A literature study IS conducted".

3.1 Methodology

A research project is conducted to discover and attempt to answer knowledge gaps in the field of research - in this case Operations Management. There are three stakeholders of the research project: The Operations Management field of study itself, the company where case study is conducted, and the researcher self. When prioritizing between pursuing questions of academic versus business interests of the case company, the academic will be chosen since that is the purpose of the study. The case company receives access to read and use the research findings freely, but intellectual property rights remain with the author.

3.2 Literature search

Scientific articles, theory books and previous master theses are used as sources of information on relevant theory and for discussion. Only peer-reviewed scientific articles are used as supporting evidence for new claims. Theory books are useful indicators for what terminology and practice is commonly known or suggested among professionals in the field, because many use these books in their education or training. They are not interpreted as proofs to questions about the current state of the art or actual best practice. That is what peer-reviewed scientific papers are for.

Literature search for scientific articles is conducted in online databases. Primary database is BIBSYS, a web portal that gathers articles from other databases, including ProQuest, Elsevier, ScienceDirect and Taylor&Francis. This enables a coherent search of multiple databases with a consistent combination of keywords and filters. Important limitations are that some databases, such as Diva and DAIM, are not searched by BIBSYS, and that it may not employ the full search functionality that are available in each of the individual databases. The search results should therefore not be treated as exhaustive - there may exist relevant articles for the search that are not found. After a search in BIBSYS, an evaluation is made on whether a wider (other databases) or deeper (new keyword combinations in included databases) search is likely to yield substantially different answers to the research question.

Some search queries may yield a number of results larger than what is feasible to study. This requires filtering or narrowing of the search query to reduce the number of results down to a feasible quantity while minimizing the risk of filtering out the most relevant ones. This can be done ad-hoc, selecting new filters or keyword combinations until the result number becomes feasible. For the purpose of research repeatability, a method is defined and adhered to:

First, choose a primary keyword from the research question that best captures the topic. A 'keyword' may be more than one word.
The number of results N is considered excessive if it is greater than 100. Apply filter or keyword changes in the following order until N¡100.
1) Filter to only papers in peer-reviewed journals and date is after 2010.
2) Search only for papers that contain the keyword in the title or abstract section.
3) Filter to only papers with date newer than 2017 (5 years ago).
4) Choose secondary keywords, search for papers containing both the primary keyword and, consecutively, each secondary keyword.
If one of the steps restrict the search results to 10 or less, it may be too strict. Consider skipping it or going to another filter or keyword combination. Record the choice.

3.3 Case Study

In theory, motivation for research should start with a goal to contribute to a knowledge gap in the field, and direction of the research project branch out from there to eventually land at a conclusion that contributes to filling that gap. That means identifying the gap first, and then choosing literature and case subject(s).

In practice, I do not have the luxury of choosing any case to study, I have access to one case; the CGE company, thanks to contacts and proximity. This limited research questions to those that can be meaningfully studied with this case, or alternatively conduct a study without a case study.

Sales numbers were exported directly from the ERP system and analyzed with Excel and Python, but most information come from a set of interviews with Operations Manager, Logistics Employees (who handle incoming purchase orders), Product Manager in Marketing Department and Production Employees. The educational background of most employees of the company, including the majority of interview subjects, are in either biology or in business finance, accounting or sales. The educational and training background may inform and answer to interview questions. There is no employee with formal education in Operations Management, which may have given different answers from the same operational facts.

4 Theory

Terminology and definitions are introduced. Relevant theory for the topic is collected. A comprehensive literature search is conducted to study the use of Capable-To-Promise in Production Planning and Control.

4.1 Terminology

The Operations Management field of research is home to many abbreviations and terms that may have different meanings to different practitioners and researchers.

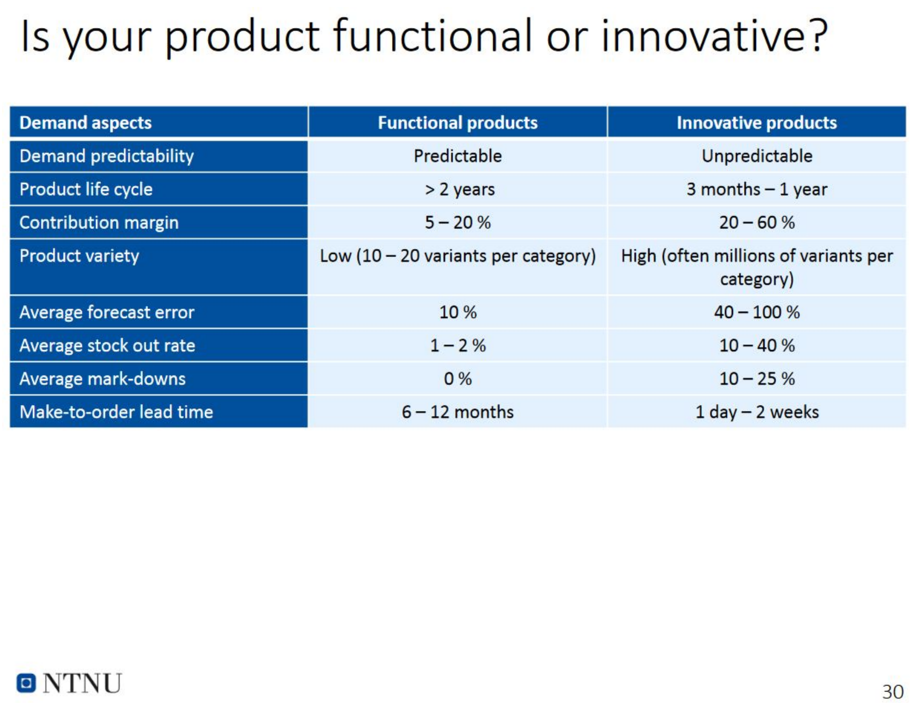
4.2 Broad Theory Search

PPC vs. MPC vs. S & OP
In [17], Sales and Operations Planning (S&OP) is defined as "the process through which enterprises develop tactical plans for aligning supply and demand management activities, usually with the objective of maximizing profitability." Romsdal [19] cites Slack et al., 2010 to define Production Planning and Control (PPC) as "the required principles and decisions to guarantee the availability of resources needed to satisfy customer demand". The meaning and use of the two terms in literature overlap to a large degree, with S&OP placing higher emphasis on planning and forecasting while PPC places higher emphasis on principles and re-planning. In this article, the two are used separately with the following definitions as follows: PPC is the process of deciding what to produce, in what quantity and at what time. It encompasses both planning near future production, and control, which is the process of changing the production execution as new information arrives inside the planning period.
S&OP in this article is defined to include production planning, but not control. It includes management of customer orders, which this article's definition of PPC does not cover. It includes longer term, strategic level capacity planning that the above definition of PPC does not cover.

Functional and innovative products

Fisher [1] categorized products as either Innovative or Functional, and the category should influence the choice of supply chain parameters to optimize for. This is because supply chains serve not only a product creation function, but also a market mediation function, with two associated cost sets:

The former function is the act of transforming and transporting raw materials into finished product to the user. Associated costs are production, overhead and transport.



Is your product functional or innovative?

Demand aspects	Functional products	Innovative products
Demand predictability	Predictable	Unpredictable
Product life cycle	> 2 years	3 months – 1 year
Contribution margin	5 – 20 %	20 – 60 %
Product variety	Low (10 – 20 variants per category)	High (often millions of variants per category)
Average forecast error	10 %	40 – 100 %
Average stock out rate	1 – 2 %	10 – 40 %
Average mark-downs	0 %	10 – 25 %
Make-to-order lead time	6 – 12 months	1 day – 2 weeks

Figure 1: Functional vs. Innovative classification, by Fisher 1997

The market mediation function is the act of matching variety and availability of products to actual customer demand. Associated costs are undersupply, oversupply and communication.

Supply Chains (SC) for Innovative products should focus on responsiveness to minimize market mediation costs, SCs for functional products should focus on physical efficiency to minimize product product creation costs.

It is important to note that the category is determined per product, not per company! It is possible that the company makes products that belong in different categories, and optimal differentiation can yield significant performance increases compared to using the same supply chain for all products [3], [15].

This theory is important because it has implications for the use of historical demand data for future demand estimation, which is of concern for RQ3. In the case study, a functional product will be selected for the analysis. Results may not apply to innovative products. It is noted that the category need not be inherent to the product itself,

Customer Order Decoupling Point

The Customer Order Decoupling Point (CODP), sometimes also called Order Penetration Point (OPP), "defines the stage in the manufacturing value chain, where a particular product is linked to a specific customer order" [2]. Different products made in the same facility may have different CODP placements. The CODP also defines the process status at which inventory is kept while waiting for customer orders, though this may not be the case when the throughput is supply-side limited. The status of waiting inventory gives name to the common categories of CODP: Make to Stock (MTS) is kept as finished stock, Assemble to Order (ATO) is kept as standardized parts awaiting assembly to order specified combination. Make to Order (MTO) products may have raw material on hand or a pre-determined supply source, but awaits a customer order before starting the most expensive or varying production processes. Engineer to Order (ETO) products delay significant engineering and design work, and also often sourcing of production inputs, until customer orders are received.

Make-To-Order (MTO) manufacturing is widely adopted by companies servicing customers that require customized products. Stevenson et al. [4] reviewed a set of approaches to Production Planning and Control (PPC): Kanban, MRP II, Theory of Constraints, Workload Control (WCL), Constant Work In Progress (CONWIP), Paired cell Overlapping Loops of Cards with Authorization (POLCA) and web- or e-based Supply Chain Management (SCM).

P/D ratio is ratio between accumulated production lead time and required delivery lead time [Buer 2018's citation nr. 6]. If P/D is greater than 1 and P only contains processes downstream of CODP, then most orders will be tardy. Orders may still be tardy if P/D less than 1, because there is always some variance in individual lead times.

Fit of planning environment with company characteristics
Buer et al. [12] and Olhager [2] sort characteristics into Product, Market and Production Process categories, and this categorization will be used here. Looking at the Market and Production Process characteristics, they seem to call for a Lean approach; cutting the excess lead times and variance with the application of Kaizen and Total Quality Management while cutting the significant WIP inventories by adopting a Pull based operations strategy. However, the biological processes and medical IVDR regulations introduce sources of lead time and lead time variance that cannot be addressed within the scope of production management. This means significant finished goods and work-in-process (WIP) inventories need to be kept.

4.3 Capable to Promise

In pursuit of RQ1: "How is the Capable-To-Promise quantity defined and used for decision-making in Operations Management?, an in-depth literature study is conducted. "

First, two popular theory books on Operations/Materials Management were searched for usage of the terms Available-to-Promise, ATP, Capable-to-Promise and CTP. These inform the sub-question "what is the common or established understanding and use of ATP and CTP?"

Chapman [10] on ATP
Chapman treats ATP under the section about Master Production Schedule (MPS). The MPS is the basis for the MRP, it determines forecasted demand in the planning period, after which the MRP is made to plan production sequence to fulfill that demand. "In MTS environment, customer orders are satisfied from inventory. In MTO and ATO environments, demand is satisfied from production capacity. In either case, sales and distribution needs to know what is available to satisfy customer demand." "As orders are received, they consume the available inventory or capacity. Any part of the plan that is not consumed by actual customer orders is available to promise to customers. In this way, the MPS provides a realistic basis for making delivery promises. "

Comment: ATP under this definition is exclusively forecast-driven, or push. A monthly MPS makes the MRP fulfill the demand forecasted on 1st of March until 31st of March, even if by 15th of March fewer than half of forecasted orders have been received. The system operates with a time fence, after which changes to the production plan are not accepted due to costs caused by schedule disruption. While lean is not the central topic to this thesis, it is fair to say that this is a practice that in Lean philosophy should be avoided if possible.

Slack [8] on ATP
Slack also does not list Capable-To-Promise in the index of terms used, and therefore is assumed to not use this term. ATP is treated, as in Chapman, in the section about MPS. "Master production schedules are time-phased records of each end product, which contain a statement of demand and currently available stock of each finished item. Using this information, the available inventory is projected ahead of time. When there is sufficient inventory to satisfy forward demand, order quantities are entered on the master schedule line."" The known sales orders and any forecast are combined to form 'Demand'." "The third row is the MPS; this shows how many finished items need to be completed and available in each week to satisfy demand." "The MPS provides the information to the sales function on what can be promised to customers and when delivery can be promised. The sales function can load known sales orders against the MPS and keep track of what is available to promise (ATP)."

The same comment can be made as for Chapman. The ATP system reacts to new demand information by showing the projected result on the ATP quantity. If and how the production should respond is kept out of the ATP scope.

To supplement the "popular" understanding, an online business dictionary result is included:
"Capable to promise (CTP) systems enable enterprises to commit to customer orders based on production/resource capacity (available or planned) and inventory (available or planned). CTP solutions consider resource (equipment, people and materials) availability, capacities, constraints, work in progress or planned work, multiple steps in the production process, multiple nodes in a sup-

ply chain network (including, in some sophisticated use cases, supplier networks) and various rules to calculate accurate promises. Newer systems also consider non-production-related constraints, such as transportation, which enable delivery factors (such as shipping mode options) to be factored into promise dates." Source: https://www.gartner.com/en/information-technology/glossary/capable-to-promise-ctp-systems

To answer the sub-question "what is the state-of-the-art literature on use of CTP?", a scientific literature search is conducted according to methodology described in Section 3. Reminder that the Research Question is "How is the Capable-To-Promise quantity defined and used for decision-making in Operations Management?". Primary keyword is selected: 'Capable-To-Promise'.

Search in BIBSYS database resulted in 413 documents. This is considered too many to individually inspect, so the filter 1 is applied: Only results from peer-reviewed papers after 2010.

37 papers were found in this search. The number is considered appropriate for study, no more filter or keyword changes are needed before individual study. Each paper is studied with the research question in mind: How does it describe the **use** of Capable-To-Promise. Papers are discarded if they do not use it or their topic is unrelated to Operations Management. The following table provides an overview of how CTP is used in Operations Management literature. EDIT: Due to an unresolved rendering error, the table is positioned with the figures at the end of the document, which was not intended. It is located between the bibliography and the list of figures.

20 papers were discarded, 17 were selected. Among selected papers, 6 contain usage of the CTP quantity for making Order Acceptance decisions, that is determining whether to accept or reject incoming customer orders. It is found surprising that so much attention is given to whether or not to accept customers, but further research on the topic is out of scope. 12 papers contain usage of the CTP quantity for making Order Promising decisions, that is to provide customers a time and/or quantity of delivery for fulfillment of a received order. 3 papers mentioned other uses for the CTP quantity. These were: Managing Uncertainty, Order Capture, and Downstream Supply Chain Optimization.

The latter was not in a scientific paper, but in a report from a seminar. While the topic is interesting: That frequently calculating Capable-To-Promise and giving customers access to this information may improve supply chain optimization, it is not studied further in this project. The former, Managing Uncertainty, ...

Jose M. Framinan and Rainer Leisten [6] created a framework that integrates a number of managerial decisions that relate to Available-To-Promise. They encompass Order Acceptance, due date setting (Order Promising) and the interrelated decisions under the umbrella term Order Capture. Already in 2010, the publishing year of the paper, almost all ATP calculations are done in computer systems that may may vary significantly in functionality. In the scope of Operations Management research, the underlying model is studied, not the technical implementation.

According to the literature study results, the following definitions for ATP and CTP will be used for the remainder of this thesis:

Available-To-Promise (ATP) is defined as the mathematical quantity of a finished good projected to be available in the near future, based on a predetermined schedule of sales and productions. At each point in time T1 in the forecasted period, ATP equals the smallest projected inventory between that time until the end of the projection period. Commonly, it is an output of calculating the Master Production Schedule in a push production system, or it is an output from a digital MRP system. Most ERP systems contain an MRP system. The ATP number is primarily used to help logistics and sales functions answer incoming customer orders: Will the currently planned inventory and production be able to satisfy the demand, and at what time?

An example table and plot, with starting inventory of 80 and a number of planned sales and production for the next 14 business days is provided in the list of figures. Figure 2 and 3 show the same data, in table and plot form. Note that while there is 170 items in inventory on day 4, that inventory is already committed to known future sales and therefore not ATP.

Capable-To-Promise (CTP) is an extension from ATP [7] and attempts to include information about what can be produced in addition to what is planned. It therefore assumes unused capacity exists, either internally or externally. Mathematical implementations vary much more widely than those for ATP, so a mathematical definition can not be given. The information input and resulting calculation may be customized down to an individual product, and give fixed numbers or estimate probability for a given quantity-time combination. Example of the former, with the same data as before is shown in Figure 4. CTP equals ATP until lead time is reached, at which time it grows according to capacity, in this example 40 per day after a lead time of 4 days.

5 Case Study

The Case Company is introduced in detail. After headline information, the company characteristics are described. Characteristics are sectioned according to the framework by Buer et al. [12]: Product characteristics, Market characteristics and Production process characteristics. The summaries of characteristic properties of each category is adapted from this framework, but modified.

Access and control of business information
The company is publicly traded and subject to regulations on Insider Information. There is also an internal Information Security policy for competitive and GDPR compliance purposes, and the researcher is bound by a Non-Disclosure Agreement from previous work contract with the company. The company, its employees, customers and suppliers is therefore anonymized, and identifying information is given pseudonyms. This enables the case study to give a detailed account of the company's operational characteristics without risk of violating any of the regulatory restrictions. Case Company identification is limited to the researcher, his Supervisor and his Institution (NTNU-IPK). Researchers who wish to verify information in the case study may contact one of these for forwarding the request.

Entity - Pseudonym list:
Case Company - CGE
Raw Material Supplier - NBS
External Processer - GTA
Name of Product 1 - GC11

The company is in a growth phase, running a deficit while aiming to introduce new products every year and maintain the trend of 30-50% yearly growth. To reach profitability, the growth must be achieved without a matching growth in expenses and inventories, so process simplification, automation and optimization is pursued. Improved PPC can contribute to simplification, optimization and inventory reduction.

A mapping of the flow from raw material to finished goods is provided in Figure 7. This map should be inspected thoroughly before reading the rest of this section.

5.1 Product Characteristics

Product Characteristics Overview
CODP placement: MTS.
Degree of customization: None.
Product variety and number of stock-keeping units: Low
BOM complexity: Low, one level.
Product data accuracy: Medium

Level of process planning: Partial
Product life and perishability: Effective 1.3 years
Transportation and handling: Refrigerated
Hygiene requirements: High

The research is conducted in collaboration with "CGE", a developer and manufacturer of In Vitro Diagnostic (IVD) reagents. Definition from United States Food and Drug Administration [18]: "In vitro diagnostic products are those reagents, instruments, and systems intended for use in diagnosis of disease or other conditions, including a determination of the state of health, in order to cure, mitigate, treat, or prevent disease or its sequelae. Such products are intended for use in the collection, preparation, and examination of specimens taken from the human body."

CGE manufactures reagents, not instruments or systems. The reagents are mixed with a target specimen, for example a blood sample from a patient, and will react to the presence and concentration of certain compounds in the sample. The reaction of the IVD reagent is measured in an IVD instrument, and the measurement result is used by a doctor to support or rule out a medical diagnosis. For example, the presence of an inflammation may be detected by measuring the concentration of creatinin or cystatin c in a blood sample, and a number of products may exist in the market that measure each compound in a different way.

CGE uses biological materials to produce its reagents, by vaccinating a donor animal against a target compound so that antibodies are produced. Creating and measuring the reaction of antibodies is an established method of developing IVD products for a compound of interest. The bio-technical manufacturing challenge is to produce a reliable and consistent product from highly variable biological raw materials. The process steps to achieve this make up the majority of the supply chain, encompassing all nodes between reception of raw materials and CQ release of bulk finished goods. The process technologies are secret and out of scope for this research project; only the production quantities, prices and times are in scope. In the first process stage, production of "juice" from raw material, the extracted quantity per raw material input varies with a standard deviation around 10%. In the later process the variance can be mostly neglected. This means WIP inventory can accurately predict the finished goods quantities that may be produced within the timespan of one lead time, while quantities derived from raw material inventory or purchases are somewhat less predictable. Because accuracy is achieved so early in the overall makespan, it is considered unproblematic.

The company offers 5 different reagents, and for each reagent a set of supplementary materials: Calibrator material and Control material. The supply chain in Figure is the one for the oldest product, GC11. The others follow a similar but slightly different route. Only GC11 production is studied in this project, the others are not considered except that they introduce competition for schedule in the shared bottleneck which is the kitting workstation.

GC11 has an expiry date rated for 2 years (104 weeks) after production starts, and must be stored at refrigerated temperature. Standard policy is that the product must have six months (26 weeks) remaining shelf life to be sold, although some customers have a different shelf life specified in the supply agreement. This means actual shelf life at CGE is approximately 104 weeks life - 26 weeks - 10 weeks = 68 weeks, or one year and four months. Expiries have not been significant a significant challenge for this product in the last two years, but it has been for some of the company's other products that share the same shelf life. The product manager attributes this to the more unpredictable demand for the products, as they are newer. Margins for those products are far larger than for GC11, and it is worth noting that this combination of higher margin, higher uncertainty of demand aligns with Fisher's [1] framework for distinguishing between Innovative and Functional products. This indicates that classification in that framework need not be constant through the product's life cycle, and that more functional behaviour should be expected over time if a product stays in the market.

5.2 Market Characteristics

Market and Customer Characteristics Overview
P/D ratio: varies
Demand type: Combination of forecast, safety stock and customer orders
No. of customers: Large (50+)
Type of customer: Business-to-Business
Type of contract: Supply agreements, varying terms.
Market requirements: Strict on quality. Medium on price and availability.
Market location: Global. EU dominates revenue, China dominates quantity.
Demand variability: Medium
Demand uncertainty: Low
Order sizes: Mixed very large and very small. Few in between

Headquarter and factory facility is co-located in the southeast of Norway. All products are produced here, and almost all sales are exports to customers in the EU, USA and East Asia. Reagents are produced in batch sizes between 1 and 30 liters, which may be sold either directly in bulk or as many packaged flask kits (0.5-10 mL). Customer orders can thus be sorted into three categories: bulk reagent orders (1+ liter containers), large kit orders (100+ kits), and small kit orders. The company does not sell freely; a supply agreement must be made with each customer, which specifies the mutual regulatory obligations and determines customer-specific pricing, ordering and delivery terms. Total customer database has 100 entries, though not all are active. A customer usually buys only one of the product sets, and for about half of the customers that is CGY. Volume is dominated by a small number of customers who place large orders with long due time. Smaller customers pay a higher price per kit, but place orders for small quantities with short delivery time.

One customer of note is the only one in China and the only one that buys CG11 in bulk. The stated reason for this is that bulk is much cheaper to transport than the same quantity in kits, so it is worth doing separate kitting process there. In practice, this customer functions as a distributor to the Chinese market. CGE has a sales representative in China, who works to secure more CG11 contracts for this customer. Since this customer covers the whole Chinese market, this customer will be given pseudonym 'China' in this text. This customer consumes a majority of the total CG11 reagent quantity, but since kit products are priced higher, it is not a majority of revenue.

Historical kit sales over a six-month period was collected from the ERP system and analysed. Their distribution may be used to predict future demand patterns and compare against the capability of the company to satisfy it. If larger orders comes with less strict delivery time requirements than smaller orders, this may be exploited to reduce need for safety stock compared to a situation where all orders must be fulfilled quickly. For this purpose, the distribution of size and delivery time of historical sales was plotted. See figures 5 and 6. One customer in particular buys very large kit orders. In the first plot, sales to this customer is excluded so that the distribution of the others is better visible.

5.3 Production System Characteristics

Manufacturing Process Characteristics Overview
Manufacturing mix: Homogeneous
Shop floor layout: Functional
Type of production: Serial production
Throughput time: 11 weeks
Number of major operations: 5
Batch size: 30 liters until finished bulk, 400 kits (4 liters) from bulk to kit.
Frequency of production order repetition: 4 per year for bulk. 12 per year kits.
Fluctuation of capacity requirements: Low
Set-up times: Medium
Part flow: Bulk and lot-wise
Material flow complexity: Low
Load flexibility: Low

Production Capacity and Lead Times
Figure shows the processes and inventories that raw material (left side) passes through until finished goods. On the bottom row, estimated lead time for each section of the process is provided, and CODPs are marked.

Filling and Packing is identified as the bottleneck for kits. This station is also the one that does product scheduling, as all products run in parallel chains until they all pass through the FP station. CODP's are on either side of this station; bulk CODP is right before FP, kit CODP is right after FP. Scheduling at the FP station is challenging, as all products go through them and there is no standardized measure of priority. However, production order scheduling is not the topic of this project, so current throughput and lead time numbers will be taken as given. The queuing at FP station means average throughput time is longer than lead time, as the average production batch waits a number of days for its turn. Quoted lead time for a filling can be achieved when it is prioritized.

There is currently not a defined scheduling policy. Time and size of jobs are determined by the employee responsible for that process, usually after verbal communication with employees at upstream or downstream processes and/or with manager. A stated target is to maintain finished goods inventory equal to three months' demand, but in practice it is determined by experience and discussion on a case by case basis.

Use of ATP and CTP at the Case Company

Forecasts are provided by Marketing department for 1-month, 3-month and 6-month periods, and they are all updated once per month. For the filling & packing (FP) function, which operates on smaller and more frequent quantities than the upstream functions, it can be hard to say exactly what time during the forecast interval that the forecasted quantity needs to be finished. The forecast includes both known/semi-known purchase orders and history-based probable demand. The former come with a due date some time during the forecast period, the latter is stochastic distributed through the period. Thus the forecast answers the question "how much is needed in the period", but not "when is it needed" except that it's before the end of the period.

As new information is received within the monthly MRP period, there is a choice between re-calculating the MRP, adjusting unofficial/lower level production schedules without changing the MRP, or continue as planned and accept the cost of supply-demand mismatch. Unless reliable automation tools are available, options A and B require a significant amount of employee time. Option B is default practice at CGE, except when the new information points to the supply-demand mismatch being overproduction, which is ignored (option C).

Production is planned in shared Excel spreadsheets, and are entered into the ERP system either before or when the production is performed. The ERP system therefore maintains a record of inventories and production history, but incomplete information for an accurate ATP projection. Incoming orders are entered into the ERP system by logistics personnel, and ATP is automatically recalculated. If the result is negative or below Safety Stock level the logistics employee may press the "Plan Production" button, which makes the system suggest a production at a time and quantity that would fulfill the projected deficit. This is usually done to make the product virtually available, so that received sales orders can be processed, but is not used for determining the actual time and quantity of productions. The production personnel usually overrule the system suggestion, as they know more than the ERP system does about a range of other considerations.

As defined in the theory section, the ATP calculation accounts for all sales. This creates a minor issue when very large orders are placed far in the future: If a sales order is confirmed today for 1000 kits to be delivered in six months, it applies -1000 to the ATP, starting from today. To current solution to this is to plan a false production which adds to ATP, while the actual planning is done by placing this quantity and deadline in the Excel spreadsheet so that production knows to complete the amount before then. There are technical issues with this: The order automatically consumes current lots from the digital inventory instead of waiting to let earlier sales take them, and the false production plan affects all items in Bill Of Materials, such as bottle caps and tubes. However, these are worked around so that sales are not affected and not very interesting for the goals of this thesis.

Concluding from this, there is three sets of information available to inform PPC: Forecast and Master Production Schedule, provided by Marketing and Operations management on a monthly basis, Shop Floor production and demand estimates in spreadsheets, updated continuously, and confirmed orders and MRP calculations within the ERP system.

5.4 Inventory Policy

The company faces a classical PPC dilemma: There is a cost to over-stock finished and semi-finished goods, but long lead times makes it hard to reduce inventory without frequent stock-outs. Current practice is a mix of MRP and make to stock pull, and significant management time and guesswork is spent on planning and monitoring demand and supply. A postponement strategy is needed, and reducing the PPC workload is as important as improving the actual PPC performance.

For the studied product set, holding costs increase significantly when transformed from bulk to kit form, for two reasons: The first is that physical volume is increased by 30 times, demanding more refrigerated storage space. The second is that it commits the product to a subset of potential customers, with higher demand variance than the aggregate.

Inventory holding costs are the following:
Storage space, capital cost, product expiry, quantity held.

Storage space: 40 000 NOK per year per refrigerated room. A room can hold about 20 000 kits, so yearly space cost per kit is 2 NOK. Bulk takes 1/35th the size of kits, so space cost is 0.17 NOK per year per cL, or 17 NOK per liter.

Capital cost was said to no more than 8%, as interest rates are currently low. This number was provided by an employee in marketing, it is possible that finance would have given a different number if they were asked directly. The value of a kit cannot be pinned down to a single number, as prices vary from 2000 to 5000 NOK depending on order size and contract with the customer. Because the large customers with lower prices dominate volume, the average sale price is in the low end, 2500 NOK, so this value is assigned to inventory. Bulk price is lower, 50000 NOK per liter which is 500 NOK per kit volume of one centiliter. Thus we have a yearly capital cost of 42 NOK per centiliter (kit size) for bulk, and 168 NOK per kit.

Expiry is equal between the two. It is 500 * P(kit expires), which is a probability function of kits demand¡production in an expiry period.

Planned PPC
A significant amount of work is required per batch through the filling and packing station, therefore kits are produced in 200 to 600 kit batches. The production employees themselves spend two hours on setup, paperwork and ERP registry for a batch. The bigger cost is Quality Control (QC) and Quality Assurance (QA), which must approve each batch. QC takes a number of random sample tests of each batch equal to the square root of the batch size plus one, so larger batches require fewer tests for the same number of kits. QA must check and sign off on the QC process methodology and its documentation before the finished product is released. The QC and QA processes of a batch do not by themselves take a lot of time, roughly one hour each, but there is significant communication and waiting time in this process. QC and QA employees are based in the upstairs office area, where they do their other work, instead of being co-located with production. For a batch to go from filled to filled and released, QC must be called on, find free time from their other tasks and dress into lab clothes, and after that the same for QA. An improvement to this process would be valuable, as in lean theory it is classified as waste work, but some of this is imposed by IVD safety regulations and it is not central to the research questions of this thesis.

A new inventory strategy is scheduled for adoption. Batch sizes will be increased to 1000 kits, and ready bulk will be made into kits immediately as received, instead of keeping some inventory in bulk form.

Pricing the general CTP curve
When there are no pending sales orders, ATP equals the current inventory, and the CTP function becomes the sum of two simple component functions: inventory, which is a flat line, and production capacity, which adds some curve on top of the inventory. A "General CTP function" can be plotted that shows the average supply capacity: average inventory (safety stock + 1/2 batch size) plus the capacity function. A company that knows the price of different choices of components, can therefore calculate the cost of creating the resulting CTP curve. This may be compared against the estimated change to service level, similar to how optimal safety stock is calculated in a Reorder Point inventory system under stochastic demand [9].

Examples for illustration:
Increasing finished goods inventory by 100 adds a flat +100 to CTP curve. The cost is the holding cost of 100 finished goods, the resulting change in CTP curve is visible, and the cost may be compared against the expected increase in service level.
Increasing production capacity by 20/day increases the slope of the CTP curve by 20/day after lead time LT. It adds 100 to the CTP curve at day LT+5, 200 at day LT+10, and so on.

Using the same example data as before and removing pending sales and planned productions, the General CTP Function is produced for a company with average inventory of 120 kits, lead time of 4 days, capacity of 40/day until running out of raw material inventory (200) is illustrated in Figure 8.

6 Discussion

Results from theory and case are summarized. This section discusses how they, individually or combined, may answer the research questions. Practical uses are suggested.

6.1 Summary From Theory and Case Study

Traditionally, service level is calculated from the safety stock and lead times [9], [10]. To calculate service level for a CTP curve, the probability of stock-out occurring in a given time frame is as P(stockout)=P(D¿CTP), where D and CTP are the cumulative estimate of estimated demand (D) and capacity to fulfill that demand (CTP). When some demand is unknown, that part must be estimated. This can be as a given forecast number, or it can be a probability distribution of time and quantity.

6.2 Utility of the Capable-To-Promise concept at CGE

The first three components are already managed with traditional MRP and widely used ERP systems, such as SAP which CGE uses, through the ATP calculation. It is the last component that is interesting for research. When a new order is received to an MRP system, it checks for ATP and answers yes/no to whether it can be fulfilled. If the answer is no, the MRP must be changed, usually by adding to the production plan, so that there is planned ATP and the order can be accepted. Properly working MRP2 will check that capacity is available to actually deliver the added production before approving the MRP change.

Modeling 'Capable to promise' and 'probable demand' as functions of time, the PPC goal should be to keep the CTP curve over the PD curve at all times, but as low as possible. More advanced version: As probability functions of two variables: time and quantity.

Pricing the general CTP curve
When there are no pending sales orders, ATP equals the current inventory, and the CTP function becomes the sum of two simple component functions: inventory, which is a flat line, and production capacity, which adds some curve on top of the inventory. A "General CTP function" can be plotted that shows the average supply capacity: average inventory (safety stock + 1/2 batch size) plus the capacity function. A company that knows the price of different choices of components, can therefore calculate the cost of creating the resulting CTP curve. This may be compared against the estimated change to service level, similar to how optimal safety stock is calculated in a Reorder Point inventory system under stochastic demand [9].

Examples for illustration:
Increasing finished goods inventory by 100 adds a flat +100 to CTP curve. The cost is the holding cost of 100 finished goods, the resulting change in CTP curve is visible, and the cost may be compared against the expected increase in service level.
Increasing production capacity by 20/day increases the slope of the CTP curve by 20/day after lead time LT. It adds 100 to the CTP curve at day LT+5, 200 at day LT+10, and so on.

Using the same example data as before and removing pending sales and planned productions, the General CTP Function is produced for a company with average inventory of 120 kits, lead time of 4 days, capacity of 40/day until running out of raw material inventory (200) is illustrated in figure 9.

6.3 Optimization-Complexity Trade-Off

Scheduling how much to produce at what time (PPC) is extensively studied. Whether push or pull, companies start out using the intuition of their employees and social decision-making processes as PPC system. As they grow, more formal systems are sought, for the purpose of enabling optimization, scalability and automation. In some cases, human involvement in the PPC can be largely eliminated (such as serving web content), but most manufacturing companies never fully eliminate human intervention. Either the PPC is formal for only parts of the Supply Chain, or humans edit the output from the formal system in order to account for various factors that could not be included in the formula. The goal is not to eliminate or even diminish human involvement.

7 Conclusion

Conclusion to the Research Questions
Research Question 1, "How is the Capable-To-Promise concept defined and used for decision-making in Sales and Operations Planning?", was answered in the literature study. It is defined as an extension of ATP with the addition of non-committed supply capacity. It is used almost exclusively for managing customer orders; either to respond with a Due Date and Quantity confirmation (Order Promising decision), or for deciding whether an order must be rejected (Order Acceptance decision).

A significant amount of evidence for this conclusion was found, see figure with table of literature. However, it is possible that other definitions and uses may be found if search was extended to alternative databases or with a different search strategy. Further research may do this to verify or falsify the conclusion that is summarized in the previous paragraph.

Possible answers to Research Question 2, "Does the Capable-To-Promise concept have additional utility for Production Planning and Control in a Make-To-Stock production environment?", was explored in the Case Study and Discussion. Two potential uses were identified. The first is the use of a live updated CTP curve as a visual aid or a mathematical input to aid production planning and control. Some methods for this was presented, but they lack testing and therefore should be considered speculative at this time. Further research should attempt to go in further detail with practical case studies or simulation before the utility of this proposed use of the CTP concept can be scientifically supported. The second is the use of a general supply curve for profit optimization, by pricing the cost of maintaining a hypothetical curve against what additional order quantities can be captured. Only the first half of that equation, ie. the pricing, was discussed. The second half was not, and must be researched before this use case of the CTP concept can be verified.

Other Conclusions
The use of spreadsheets for PPC, despite the recent implementation of a market-leading ERP system, is not entirely surprising. De Man & Strandhagen [13] offers an important reminder of the resiliency of the spreadsheet despite the emergence of newer and more advanced digital planning systems over several decades. One of the stated goals of the ERP implementation was to simplify production planning and eliminate the use of spreadsheets. While management does not evaluate the overall ERP implementation to be a complete failure, this objective was not achieved. ERP implementation is difficult, as evidenced by the large number of studies on the topic [16], [5], [11].

An attempt was made to simulate a CTP system for a combination of both known and unknown stochastic demand, giving a probability density function of the two variables time and quantity. One distribution for probable demand, and one for probable CTP to satisfy the demand. Expected probability of deficits could then be calculated by integrating over the two functions. Available time and programming competence of the author proved insufficient to achieve this. Further research is suggested to complete such a simulation, as it would provide a much faster and robust service level calculation. The code for the incomplete simulation system, written in Python with the Numpy, Pandas, Scipy and Matplotlib libraries, is available on GitHub: `https://github.com/jensdanb/Capable-To-Promise_Simulation`

The code implementation itself is not discussed here, as this is not a thesis in computer science, but the model logic is of interest. The probability density function for demand is made through two layers: A Poisson distribution for the probability of receiving different number of purchase orders before each date, which is then passed through a Normal distribution for the size of each order to arrive a probability for each possible cumulative demand within the given date. If there are pending orders, the distribution is shifted up the quantity axis by that amount. Inputs for the distributions (frequencies, average sizes and standard deviations) are taken from historical demand data.
The CTP function may be known (certain quantity for each day in the projection period) or itself a probability distribution. Starting inventory is then taken as Random Uniform distribution between safety stock (SS) and SS + Batch Size, and the lead time to first receipt of newly produced material is Normal distributed within a range of dates obtained by asking the employees of that production process.
As stated, no simulation with this model was completed in this research. Future research in this direction should also evaluate the choice of assumptions and consider if a different model is more suitable.

The simulation was intended to be used to analyse the cost and benefit of different options for bulk vs. kit inventory policies. In retrospect, this attempt was not successful and was abandoned too late to properly conduct an alternative approach to analysing the case company situation, thus weakening the answer to the second research question.

8 Workspace

8.1 To-Do List

Urgency: A max, B, C low
Importance: 1 max, 2, 3 low

8.2 Abbreviations

OM - Operations Management. The overall field of study.
PPC - ...

8.3 Jo Wessel Strandhagen, 2015 specialization project

This project report is the result of the specialization project that is a part of the master's degree program Mechanical Engineering at the Norwegian University of Science and Technology (NTNU). It was conducted as a case study by scientific research, with Kongsberg Maritime Subsea (KMS) as the case company. KMS develops and produces advanced underwater acoustic sensor systems used for underwater navigation, underwater mapping and fishing. This project work is related to the SoundChain research project where efficient production at KMS is one of the goals, with the aim of reducing throughput times and levels of work-in-process. To address that, this specialization project has examined the approach to production planning and control. The project aim was to perform an analysis and outline advices related to production planning and control, including the placement of the customer order decoupling point, at KMS. Based on this the following research goal and research questions were developed:

How can existing frameworks for mapping characteristics features of manufacturing companies be applied and adapted in order to analyse and redesign production planning and control in complex job-shop and MTS environment?

1: Which frameworks exits and are relevant for mapping when designing a system for production planning and control, and how are they related?

2: What types of characteristics are of importance for designing a system for production planning and control, and how can the frameworks be adapted and applied?

3: What are the characteristics features related to the planning environment of Kongsberg Maritime Subsea and which implications do they have for PPC and CODP in KMS?

4: Which planning and control concepts are available, specially related to creating shorter throughput times and lower WIP levels, which can support to implications identified for KMS?

8.4 PPC - Buer et. al., 2018

In "Strategic Fit of Planning Environments: Towards an Integrated Framework" [12], Buer et. al. "aims at developing a comprehensive framework for mapping a company's planning environment. This mapping can be used as a starting point for selecting appropriate PPC methods, comparing companies, and identifying possible improvement areas."

Mapping Variables:
They use the 21 variables selected by Jonnson and Mattson [their citation nr. 6] as basis, and extend it, as justified by Jonnson and Mattson pointing out that a larger number of variables "are of great value".
This correlates to the APS discussion I'm working on, where more variables (inputs) are required for generating better plans.

They reference Lödding [their citation nr.11] as containing fewer variables than Schönsleben and Jonnson and Mattson, but the included variables are more related to the shop floor, where the larger frameworks are lacking - making Lödding a good complement for the new, broader framework.

They then describe the 30 variables of their new framework, and categorize them into product, market and manufacturing process categories.

P/D ratio is described in section 4.2 - Market Related Variables, but I don't understand why it is here, instead of a description of what characterizes Market-Related variables.

The 'Volume/Frequency' variable, which "refers to the annual manufacturing volume and the frequency of which products are manufactured. The variable ranges from a few high-value customer orders per year, to a large number of customer orders per year", is placed in the Market-related category. Should this be re-described to "refer to the frequency of customer orders" or moved to Manufacturing Process category?

"Type of production" is in the Manufacturing Process category, and "refers to the average size of the production run and how frequently these runs are repeated." Four generic types are identified: single unit production, small series, serial production, and mass production. Does this overlap with the Volume/frequency variable in Market category?

Usage:
From Buer [12] section 6.3.

Suggested as common reference framework for future PPC case studies, like the one I'm doing. Increasing ability to cross-examine case studies.

Tool for case studies. Read subsection "Case Study Tool" carefully again. Note for example that "While the standard values for each variable simplifies the cross case studies, it might be argued that the framework therefore is better for cross case analysis than for single case studies. However, the framework can easily be adapted to an in-depth single case study through making the values more exact, for instance by giving the exact number of product variants".

Company profiling, and identification of missing fit.
The framework was used in a 2019 case study [14] (conference paper), and the following revision was suggested: "'production monitoring accuracy' be added as an environmental variable. Production monitoring accuracy refers to the accuracy of data that is used to monitor actual production with respect to planned production. The availability and reliability of this data was found to play a vital role in the success of the delivery date setting".

Future Research:
The following future research is suggested [12] in section 7.
1: Examine whether it is beneficial to make the variables and their respective values more precise.
2: Investigate "how to use a mapping of a company's planning environment to determine appropriate PPC methods".
3: Verify/falsify the causality hypotheses. They were "based mainly on logical assumptions and can be seen as an initial hypothesis regarding how the variables interact." However, this requires "large-scale empirical studies", which I don't have time and access to perform.

The following research is suggested by me.
A: What other variables should be included in the framework? For example specific storage cost (high: fresh food — medium: packaging — low: wrist watches), quality/regulatory requirements, degree of automation.
B: Is a different variable categorization than source (product, market, process) and control scope (internal, external) more useful?
C: Can the demand variables be integrated into a single "demand function"? For example as probability distribution of Dirac-Delta pulses over a planning period? Suggested planning period can be total production lead time (P) or typical delivery due time.
D: How to use this framework in combination with the Control Model methodology by Alfnes and Strandhagen?

9 Appendix

9.1 Figures

List of Figures

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Number, Year	Title	DOI Link	Use of CTP
1, 2020	An advanced order acceptance model for hybrid production strategy	https://doi.org/10.1016/j.jmsy.2020.02.012	Order Acceptance
2, 2018	A decision support tool for the order promising process with product homogeneity requirements in hybrid Make-To-Stock and Make-To-Order environments. Application to a ceramic tile company	https://doi.org/10.1016/j.cie.2018.05.040	Order Promising
3, 2015	Robust order promising with anticipated customer response	https://doi.org/10.1016/j.ijpe.2015.05.026	Order Promising, Managing Uncertainty
4, 2015	Evaluating order acceptance policies for divergent production systems with co-production	https://doi.org/10.1080/00207543.2016.1193250	Order Acceptance,
5, 2019	Simulation and Evaluation of Coordination Mechanisms for a Decentralized Lumber Production System with Coproduction	https://doi.org/ 10.13073/FPJ-D-19-00002	Order Acceptance
6, 2013	Solving the order promising impasse using multi-criteria decision analysis and negotiation	https://doi.org/10.1007/s12159-012-0094-9	Order Promising
7, 2019	Trust-based resource sharing mechanism in distributed manufacturing	https://doi.org/10.1080/0951192X.2019.1699257	Order Promising
9, 2010	Business integration model with due-date re-negotiations	https://doi.org/10.1108/02635571011030051	Order Acceptance
10, 2017	A survey of semiconductor supply chain models part III: master planning, production planning, and demand fulfilment	https://doi.org/10.1080/00207543.2017.1401234	Order Promising
11, 2018	Transition to a JIT production system through ERP implementation: a case from the automotive industry	https://doi.org/10.1080/00207543.2018.1527048	Order Acceptance
13, 2011	Increasing accuracy and robustness of order promises	https://doi.org/10.1080/00207543.2016.1195024	Order Promising
19, 2012	Order Management in the Customization-Responsiveness Squeeze	https://doi.org/10.1111/j.1540-5915.2011.00342.x	Order Promising
20, 2010	Available-to-promise (ATP) systems: a classification and framework for analysis	https://doi.org/10.1080/00207540902810544	Order Acceptance, Order Promising, Order Capture
24, 2010	An Algorithm for Customer Order Fulfillment in a Make-to-Stock Manufacturing System	http://univagora.ro/jour/index.php/ijccc/article/view/2238	Order Promising
27, 2009	An available-to-promise model considering customer priority and variance of penalty costs	https://doi.org/10.1007/s00170-009-2389-9	Order Promising
35, 2011	Engineering education on supply-chain management for students and for employees in industry	https://doi.org/10.1002/cae.20293	Order Promising, Downstream SC optimization
37, 2010	Study on Models of Planning and Scheduling in IT Manufacturing Processes	https://doi.org/10.4028/www.scientific.net/AMM.20-23.28	Order Promising

	supply	demand	inventory	ATP
0	80	0	80	20
1	0	0	80	20
2	0	-60	20	20
3	0	0	20	20
4	150	0	170	20
5	0	0	170	20
6	0	-100	70	20
7	0	-50	20	20
8	0	0	20	20
9	150	0	170	70
10	0	0	170	70
11	0	0	170	70
12	0	-100	70	70
13	0	0	70	70
14	0	0	70	70

Figure 2: Table of Supply, Demand and resulting Inventory and ATP

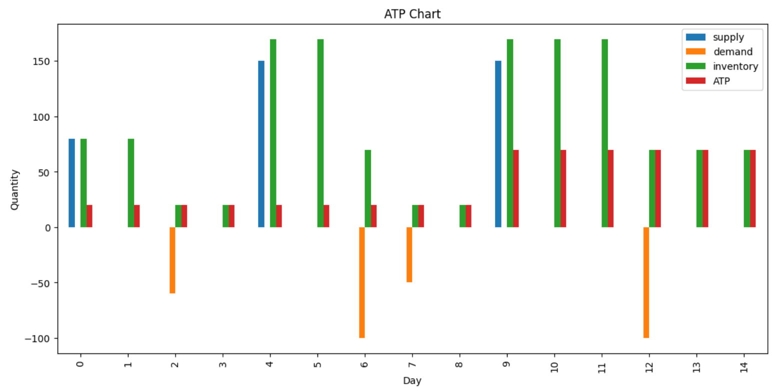

Figure 3: Plot of Supply, Demand and resulting Inventory and ATP

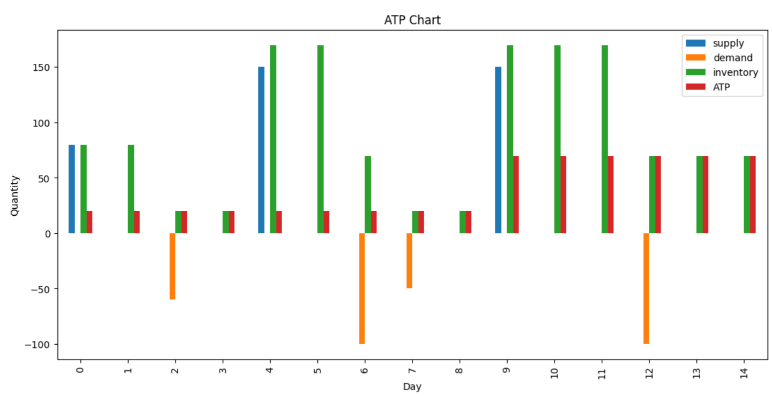

Figure 4: Table of Supply, Demand and resulting CTP and ATP

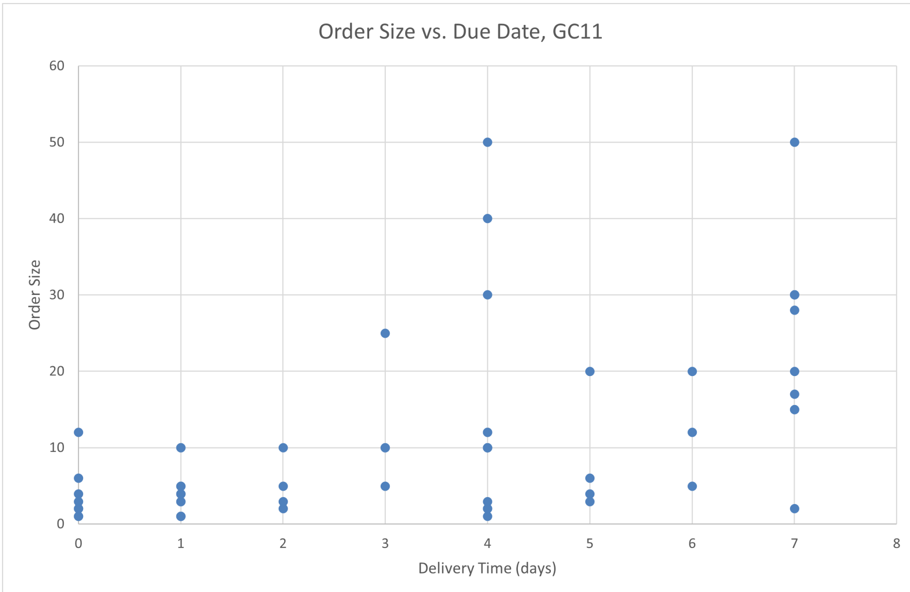

Figure 5: Order Size versus Delivery Time

Figure 6: Order Sizes, Dominant customer included

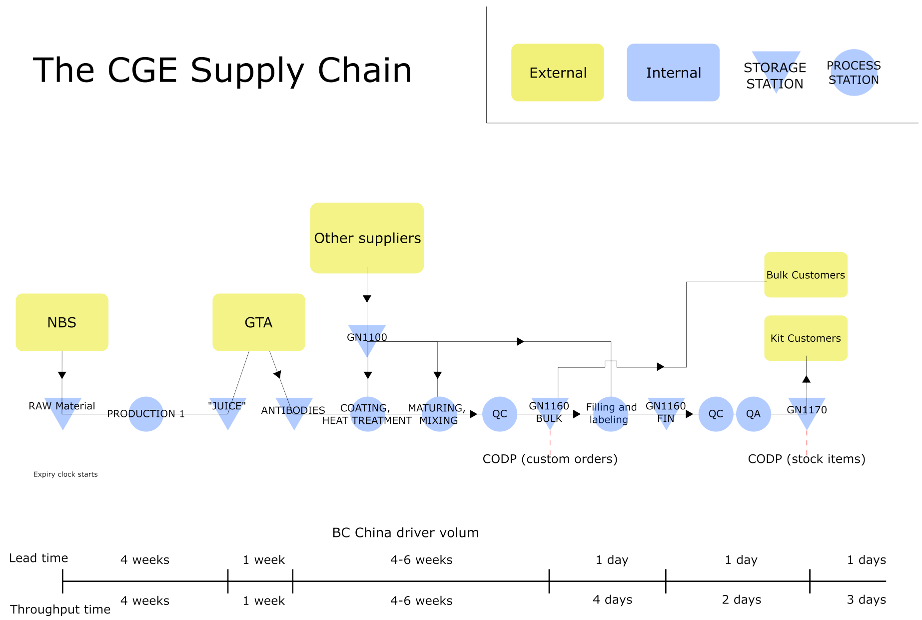

Figure 7: Value Stream Map, IVDR production at CGE

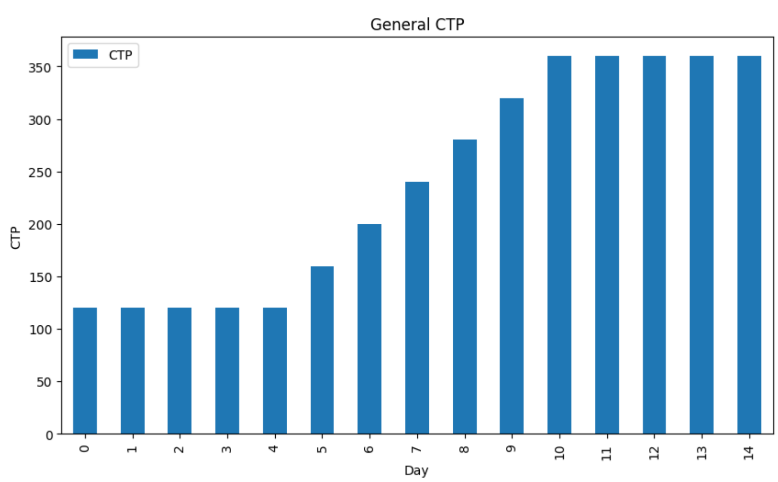

Figure 8: CTP plot with known demand

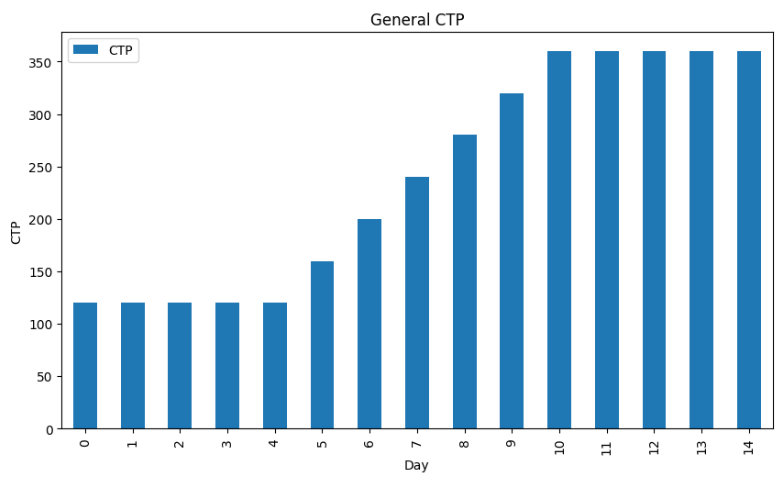

Figure 9: General CTP plot

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