CHALMERS
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Developing a Supply and Demand Planning Optimization

Case study from the Precast Industry

Master's thesis in Construction Management

Lars E.O Jacobson & William Lindh

Department of Architecture and Civil Engineering
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Supervisor: Abderisak Adam, Construction Management
Examiner: Göran Lindahl, Construction Management

Master's Thesis 2019:NN
Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

The precast industry is reliant on experienced employees throughout its ETO process, in which unique elements are distributed from centralized facilities to customers' construction sites.

Thus, in terms of supply and demand, where the construction sites have a demand for precast elements, and Company Alpha as the case study company supplies precast elements, Company Alpha wants to optimize the manner of which they decide which demand leads to follow. This means that the thesis' purpose was to conduct a supply and demand planning optimization, and thus examine how Company Alpha best are to decide which offers to undertake, in regard to profitability and capacity.

By the use of documentation and interviews, Company Alpha's sales-to-delivery process was mapped, in which information required by the supply and demand planning optimization was identified. The sales-to-delivery process constraints the planning practices in the precast industry, since details affecting the required capacity use prior to a project first becomes available after the structural engineering is completed, which happens after the decision of which offers to undertake is made. The main details which during the production planning are uncertain, were concluded to be factors which affect the complexity of the elements, and was defined as holes, cast-in materials, angles and height. Additional information required by the optimization was concluded to be production capacity, order status, profitability and product groups.

To cope with the lack of information in early stages, three strategies were examined, Industry Foundation Classes, Historical Averages and Traceable Qualitative Input. In the optimization, Traceable Qualitative Input became the strategy of choice. It includes complexity in the production planning, whereas input in terms of complexity estimations and productivity becomes comparable and distinguishable.

Keywords: Supply and Demand Planning, Operations Management, Business Intelligence, Production Planning, Production Scheduling, Precast Industry, Optimization

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Lars E.O Jacobson & William Lindh, Gothenburg, June 2019

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1
Introduction

With the title being Developing a Supply and Demand Planning Optimization, the following introduction aims to introduce the master thesis' background, purpose, research questions, delimitations and scope.

1.1 Background

The laws of supply and demand are central within the area of operations management, and not least within the specific industry of precast concrete. The precast industry has a long history and has recently expanded, much because of the increased need for just-in-time deliveries and limited space at construction sites. Precasting large elements have a clear advantage in the logistics of a construction site, but also in the specialization of the product. Additionally, the precast industry can also make better use of the key characteristics of the concrete, which in turn support the sustainability of the building process according to Holton et al (2010).

Hence, the precast industry is referred to as the business in which precast elements are manufactured using molds in a centralized facility, and then transported and assembled at the specific construction site. The life cycle of precast elements depends thus on processes concerning design, manufacturing, construction and customer service. Each precast element is therefore unique, which implies that the Sales-to-Delivery process is different for each element. Moreover, the quality of the finished product needs to fit the construction drawings for the construction project in order to avoid structural errors. Koskisto and Ellingwood (1997) argue that the structural reliable performance of precast elements are complex, which implies that structural details may be missed in production. Koskisto and Ellingwood (1997) also claim that the risk of failure during production is high, and can generate massive costs to the precast company which decreases the already pressed margin. Since each element is unique, and the customers require high quality, reliability and flexibility, the precast manufacturing process involves challenges on multiple levels. One challenge specifically, is that the precast industry and its planning practices are greatly dependant on experience, which implies inefficient resource utilization, over-inventory and ultimately delayed deliveries according to Chan and Hu (2002).

Thus, this master thesis will perform a case study of Company Alpha combined with a literature review, and thereby further examine the precast industry, and in particular its reliance on experience within operations management.

Company Alpha produces and distributes ready-mixed concrete and precast concrete products to commercial and private customers with a network of ready-mixed concrete production plants in northern Europe and in the United States. The precast concrete business area is exclusively located in Sweden, with four production plants and a trading department (subcontractors).

As of now, Company Alpha have formulated several ”To-Be Building Blocks” as part of their short-term business development strategy, one of which being ”Demand and Supply Planning and Optimization”. Thus, in terms of supply and demand, the construction sites have a demand for precast elements, and Company Alpha supplies precast elements. The need for such an investigation and action plan originates from their unwanted current position with occurrences of plant over/under capacity, last minute adjustments and little optimization. The Sales-to-Delivery process steps in which these problems take place could be summarized in three major blocks;

1. Production Data Preparation
2. Design and Production Process Capacity
3. Production Planning

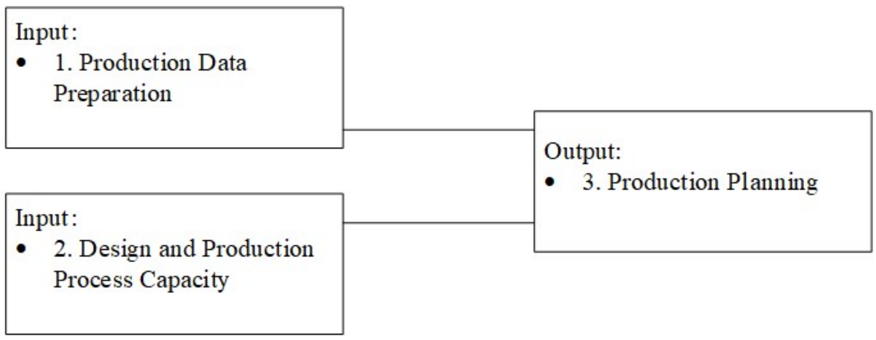

Figure 1.1: Company Alpha’s Three Major Sales-to-Delivery Blocks.

The Production Data Preparation block concerns the gathering and validation of production and product data, combined with a demand estimation of opportunities and leads. The Design and Production Process Capacity block involves deciding the theoretical maximum capacity on each process that considers capacity as a constraint. These two blocks are then input to a high level Production Planning, that will be used to forecast and schedule production.

1.2 Purpose

The thesis’ purpose is to conduct a supply and demand planning optimization in regard to profitability and capacity constraints.

1.3 Scope

Prior to each block, improvement measures must be investigated and deployed. When preparing the production in the third block, Company Alpha have an interest to understand if there is an opportunity, and if so, how to improve and standardize the manner of planning for estimated demand. The main aim is thus to standardize and optimize such a supply and demand planning, which means investigating how to best decide which projects (demand opportunities) Company Alpha are to undertake. This optimization part of the supply and demand planning allows maximization of overall in-house capacity and the use of outsourcing to satisfy excess demand, due to its consideration of capacity and profitability.

If demand opportunities are thought of as offers, the decision of which projects to undertake during the production planning, can be conceptually illustrated in Figure 1.2.

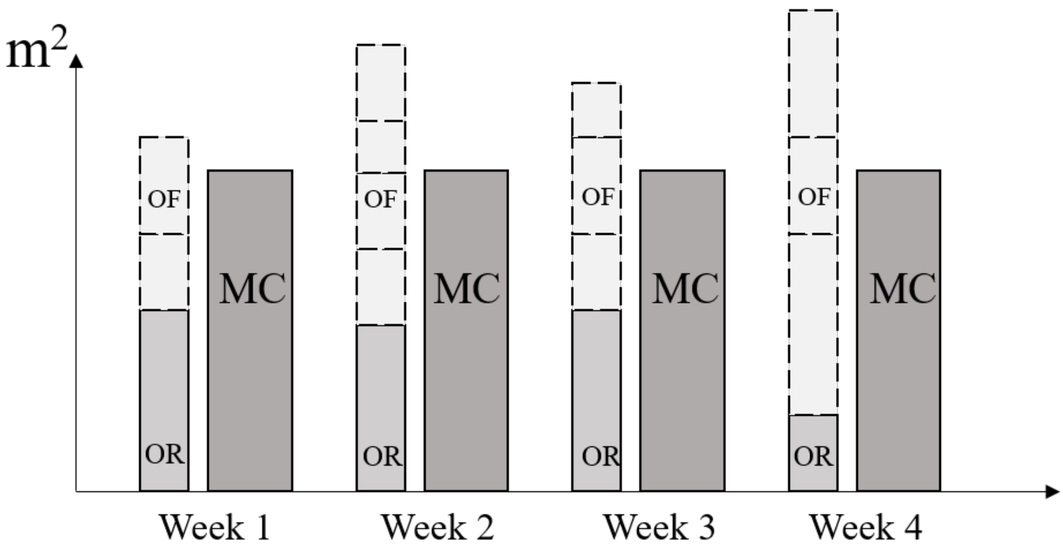

Figure 1.2: Planning for Production.

Figure 1.2 displays the maximum capacity(MC), order book(OR) and offers(OF), illustrating the main aim in terms of examine how to best decide and optimize which offers(OF) Company Alpha are to undertake.

The supply and demand planning optimization requires however a wider scope than just production planning, and therefore there are further aims prior to the blocks listed above. Firstly, the production data must be identified, collected and compiled. Such data preparation enables the second aim in regard to the blocks, which is to determine design- and production capacity by characterizing product-/production specific details throughout the complete Sales-to-Delivery process.

1.4 Research Questions

The three major blocks could thus be supplemented by the following research questions.

- Where are the relevant product and production variables in the Sales-to-Delivery process to be found?

Combining the prepared data and the known production characteristics, a production plan in regard to profitability could be performed.

- Which variables shall a supply and demand planning optimization consider?
- What is a possible concept of a supply and demand planning optimization model?

1.5 Deliminations

The analysis will be limited to four of Company Alpha's precast plants located in Sweden. Naturally, there will along with these specific plants come a focus on their corresponding market and capacity, i.e. Swedish customers and their specific product and production details.

From Company Alpha's perspective it is important that the optimization is comprehensible, and thus not too complex in order to be shareable within the organization. Simplicity and comprehension may therefore be prioritized over complex optimization loops and content. Hence, the thesis' focus is to form a feasible guide in decision making, instead of automating the decision making process without influence from organization users.

2
Theoretical Framework

The theoretical framework first covers operations management, and then how business intelligence can be used within. Lastly the specific operation of production planning is described, and especially how it is coped with in the precast concrete industry.

2.1 Operations Management and Strategy

Greasley (2007) describes operations management as managing the set of activities included in the process of delivering a service or a product. Doing so, i.e managing operations, in the long run is thereby by the author defined as the operations strategy. Slack and Lewis (2008) elaborate upon operations strategy as the long-term planning of operations, and argue its inclusion of items such as setting broad objectives, path planning to reach these goals and dealing with the bigger picture rather than day-to-day activities. Thus, operations strategy concerns the total transformation process of the business rather than individual processes, and therefore corresponds to the changing competitive environment of which operations are affected.

What operations have to develop in order to meet challenges set by the competitive environment and the market, Slack and Lewis (2008) describe in terms of performance objectives. The performance objectives are thereby the aspects of the operations' performance which aim to pursue the market requirements, and could be characteristics such as quality, flexibility and cost etc. Naturally, how companies handle or prioritize these objectives prior to operations decide their market positioning. However, each performance objective does not only interact with the market requirements, but with several decision areas as well.

Slack and Lewis (2008) use decision areas such as capacity, supply network, process technology and development and organization. According to the authors these can differ between different literature regarding groupings or names, but their purpose should still be coherent. A decision area involves thereby the decisions needed to manage operations' resources prior to that area, i.e understand and configure operations regarding for instance capacity. Preferably, these decisions should also be in correspondence to the performance objectives.

Operations strategy could thus be defined by the interaction between a company's performance objectives and their decision areas. Slack and Lewis illustrate this by the operations strategy matrix, and their manner of modeling this matrix is shown in Figure 2.1.

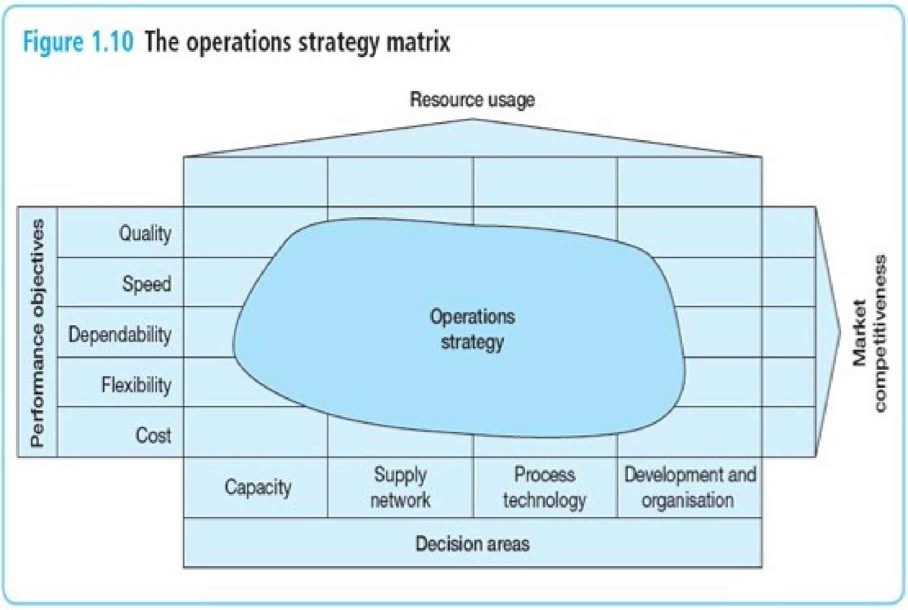

Figure 2.1: The Operations Strategy Matrix by Slack and Lewis (2008, p30).

The matrix emphasises thus on the interactions between the performance objectives and each decision area. For instance, the capacity strategy should in each interaction be able to explain how it will affect the performance objectives, and when done prior to each decision area, the operations strategy should become comprehensive.

2.2 Business Intelligence

Prior to the decision areas and performance objectives in the operations strategy 2.1, there has to be available business information and data in order to best base decisions on facts.

According to Loshin (2012), there has over the last decades been a significant transition within creation, collection and utilization of data. As of today, data management and its aim to extract business value from mountains of bytes and bits, is much more about storing, sharing and distribute data across different file formats and structures, rather than only store it in structured data systems. However, even though data management has improved, challenges in terms of filtering out and delivering the right data to the right person at the right time remains. Being able to accomplish this, Loshin (2012) lists several possible business advantages, due to common key characteristics in terms of proper data analysis and action plans. Thus, successful use of business intelligence, i.e the strategies used to handle business information, allows for the following selection of business advantages from Loshin's (2012, p2) list:

- Continuous product profitability reviews.
- Best customer identifications.
- Supplier comparison.
- Supply and demand forecasts.

There is therefore much value in proper use of business intelligence and the exploration of hidden value in collective sets of information. As mentioned, historically the use of data has been precise and short-term in terms of functioning as the raw-material in operational activities and transaction systems. However, today the use of data sets are much more agile, with the intent of achieving different business objectives. For instance, business intelligence includes data sets to be re-purposed after usage, and simultaneously have them feed both operational and analytical processes. Thus, limiting the data sets to adhere to their original purpose is an outdated manner of handling business information according to Loshin (2012). The aim should on the contrary be to expand data utility to support tactical and strategic decisions, as well as operational activities.

As the operations strategy matrix in Figure 2.1 implies, there are also according to Loshin (2012) few decisions within a business that is without the use of any gathered data from relevant business processes/operations. However, even though there is available data, the challenge of providing it to the right person at the right time remains. Therefore decision makers can still be limited in the sense of not being given the information they need. Such a scenario could for instance be what is later in Section 2.3 described as production planning under uncertainty. Loshin (2012) claims however that providing more information may not address the situation. By referring to ”analysis paralysis”, the author argues that a decision maker given too much information may delay one's decision while waiting for even more. Information which from the decision maker's point of view could simplify that impending decision.

Once again, ”analysis paralysis” is a challenge in terms of providing the right data at the right time. Doing so successfully allows according to Loshin (2012) for optimization in day-to-day activities. Therefore the risk of ”analysis paralysis” is best coped with in terms of filtering out the required intelligence prior to a specific decision. Business intelligence is thus about to utilize and identify actionable information, in order to facilitate transitions from what has happened in the past, to enable making the best possible decisions in the future.

2.3 Production Planning and Scheduling

Preferably by the use of business intelligence, the operations management within the decision areas of supply network and capacity needs to plan for supply and demand, which is the operation this thesis aims to optimize.

The terminology within supply and demand planning require however some clarification, and especially the difference between production planning and production scheduling. Herrmann (2006) refers to production planning as the input to a production scheduling process, meaning that during the production scheduling there are no more orders generated. The production planning is thereby the process that decides which orders the production company are to undertake, and the production scheduling is the process that aims to form a feasible production plan at the specific plant. Production scheduling thereby consider capacity limitations such as time constraints and material flow. The basic difference between the two processes is thus that the production planning determines which orders to produce in the long run, and the scheduling process determines how to do so short term. Both therefore consider time, but does so on different levels in terms of accuracy.

The production scheduling process is further described by Herrmann (2006) as a dynamic network, in which personnel share information and collaborate in order to decide which of the planned jobs to do and when to do them. The shared information could thereby include items such as job status, manufacturing resources and inventory etc. In the specific business of precast concrete production, there is an extensive amount of performed research on the application of production scheduling methods. According to Wang et al (2018), the many researchers have applied and proposed various computational techniques which aim to manage scheduling issues such as demand variability or lack of available resources. The production scheduling scope is thus to optimize the planned production in regard to the production capacity.

The production capacity is also highly involved in the production planning process. Prior to the production planning and the production capacity, the decision of which orders to undertake and thus schedule could be based on profitability. A possible strategy of doing so is the commonly used technique of calculating contribution margin prior to a specific product, service or project. Such a calculation subtracts the variable cost from the revenue, and results in what the concerned item contributes to total costs and profit. Each project or order has thus a contribution margin, which could be put in context and be used in comparison purposes.

The orders undertaken during a production planning process in specific regard to precast concrete companies, can according to Chen et al (2017) be divided into four areas in terms of structural design, production scheduling, handling operations and component manufacturing. Since the undertaken projects can vary in both difficulty and size, the production scheduling process at each plant must take the project characteristics into account. Such characteristics and required production scheduling preparations are by the authors given in terms of design drawings, component classifications, manufacturing resources and plant specific resources. Thus, the precast concrete production scheduling consists in general of quite short work cycles, which puts pressure on the decision makers to produce a production schedule as soon as possible, while there is at the same time a need of having the schedule weekly adjusted due to the actual production or erection changes at the delivery site. The projects' level of difficulty however must not only be considered during the production scheduling process, but during the production planning process as well. More complex precast components for instance may require more capacity, which is one of the main constraints/uncertainties from which the production planning is done.

The production planning process can be done by the use of a Advanced Planning System (APS), which is a system model that plans and optimizes production in regard to a vast amount of data, production related constraints and production complexities. Jonsson et al (2007) divide the usage and problems of APS into planning complexity, planning model and design, planning data and planning organization. The greater the planning complexity is, the greater is the need of an APS. The complexity planning concerns complexities in the physical supply chain such as number of links and capacity processes, as well as complexities in the decision making. For instance a complexity in decision making could be internal customer priority, and therefore possible trade-offs between customer relationships and profitability have to be taken into consideration. Having however identified the different complexities, the planning model and design needs to choose the appropriate number of constraints, the aggregation level (high or low) and optimization functions. Therefore the authors argue that a successful APS implementation must be customized using supply chain planning software, since the optimization problems to a high degree differs between organizations. One organization might optimize in regard to profitability with finite capacity, meanwhile another optimizes in regard to infinite capacity depending on their corresponding level of complexity.

Planning data in terms of APS refers to the data that forms the base of the production planning. Therefore the APS must be closely linked to the organization's IT structure, and thus its Enterprise Resource Planning system and business intelligence. The performance of the APS is thereby highly dependent on the data quality and its validation, and just as the model and design planning part, the planning data must have an aggregation level. If high, the planning objects become fewer, but so does the details. In the same way, with low level of aggregation comes more objects, but possibly along with more planning data uncertainty. In summary, Jonsson et al (2007) state that APS in production planning depends on the planning complexity and the planning data. The APS could thereafter use a planning model based on optimization in regard to appropriate constraints such as profitability and capacity.

Uncertainty during production planning is further examined by Mula et al (2005). By referring to Ho (1989), the authors categorize uncertainty into two subgroups in terms of system uncertainty and environmental uncertainty. Environmental uncertainty is described as constraints beyond the production process, such as uncertainties regarding supply and demand. System uncertainty however includes uncertainties within the production process, such as lead times, product structures and quality. To clarify further, Mula et al (2005) use Gailbraith's (1973) definition of uncertainty in general, as "the difference between information required to perform a task, and the amount of information already possessed." (Mula et al, 2005, p.1).

Models of handling system uncertainty within production planning are by Mula et al (2005) classified into 4 general types of models, concerning 7 areas within production planning. For example, one model within the production planning area Material Requirement Planning (MRP) is the conceptual model of "yield factor". In order to embrace system uncertainties, such a composed factor relates the quantities of required input to the losses of output. The yield factor could thereby be a percentage of capacity or item loss after production. This factor is then used to modify the bill of material, and subsequently influence the material or capacity planning.

3
Methodology

This section contains the thesis' method for achieving the aim of the project and covers the thesis' data gathering processes and research design.

3.1 General Approach

The thesis' general research approach is divided into seven decision points and is motivated in the section paragraphs.

1. Purpose = Descriptive
Yin (1994) argues that there are several research methodologies that can be used to investigate and explain report writing. An explorative study is used when there is little knowledge in the studied area and the purpose of the study is to get basic understanding of the topic. An explanative study is used when deeper knowledge of the studied area is the goal and when the goal is to explain the studied area. A descriptive study is used when there is basic knowledge in the studied area and the goal is to explain what the studies are, but not explain relationships according to Björklund and Paulsson (2003).

A descriptive approach was preferred as purpose in this thesis since the problem is well structured and aims to perform studies where the answer of the research question are unknown with a clear goal of what is to be answered, which is by Eriksson Wiederheim-Paul (1997) confirmed to be a valid choice of approach.

2. Run-up = Qualitative
Qualitative research design is suitable for projects with in-depth character of one or more objects. This thesis examines the research questions with reference to the theoretical framework, a method in which a qualitative approach is suitable according to Lundahl and Skärvad (1999). Qualitative research methods are also according to Bell et al (2018) preferred when the purpose of the study is to get a deeper understanding for the research questions, and not generalize upon the results. The run-up of the thesis is based on the research questions and the data needed to answer the research questions, meanwhile it also used a qualitative approach since the goal was to achieve better understanding within a specific area. There are however some parts of the thesis that used a segmented quantitative approach for specific generalizations. These areas mainly concerned the data preparation and the usage of Company Alpha's ERP system.

3. Strategy = Case Study

This thesis´s research questions are formed as "what"-, "which"- and "where"-questions, which affected the choice of research strategy and guided the decision towards a case study approach, since the purpose was to generalize from case study to theory. Theory development facilitates the data collection phase, and is meant to appropriately match the case study according to Yin (1994).

4. Method of Data Gathering = Documentation and Qualitative Research Interviews

This thesis used documentation as the main data gathering method, since the source of information was stable, precise and valid during a significant period of time, in accordance with Yin (1994). This type of documentation covered the foundation of current theories in the area, and described current research and specific theories whereupon information from the case study added a deeper level of insight.

5. Selection = Selective

The selection process in this thesis was selective and the criteria for selection of sources of information was concluded at an early stage. All data selected could also be validated to support the research scope of the thesis.

6. Data analysis = Abductive

The research design of this thesis was highly in line with the data analysis method, which in this case was an abductive approach and was based on the gathered information from the case study and theoretical framework. Abductive reasoning was necessary in order to propose a prediction that may be true based on the given information and due to lack of qualitative data. This thesis therefore needed to predict the answers in order to answer the research questions.

7. Analytical strategy = Based on Theoretical Framework

The theoretical framework of this study was constantly updated during the entire project in accordance with Alvesson and Sköldberg (1994), and the analytical strategy therefore used the theoretical framework in the analysis in order to answer the research questions.

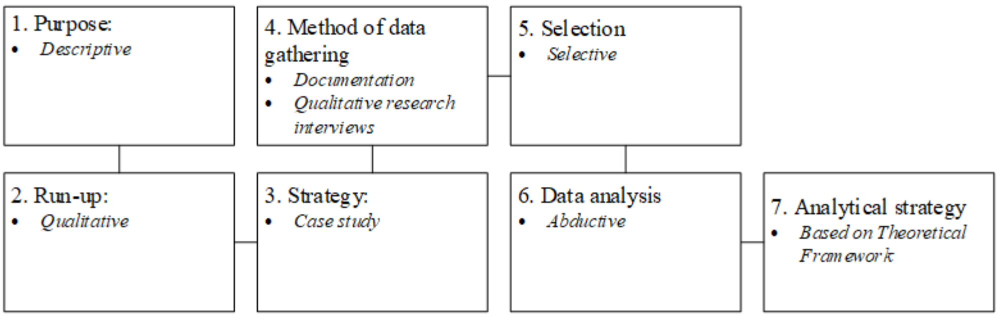

Figure 3.1: Schematic Figure of the Reports General Research Approach.

3.2 Research Design

Figure 3.2 shows the conducted qualitative research interviews and field studies of the thesis. A total of eight interviews and two field studies were conducted, with two of the interviews being with external interviewees outside of Company Alpha. Thus, the research design was highly dependent on getting proper input from stakeholders at Company Alpha. In the start-up phase of the thesis, the main process areas related to the scope was identified. These needed to be validated and described by interviews, document analysis and data analysis. The field studies were used as an additional validation, in which the information from the interviews, document analysis and data analysis was challenged and confirmed or unconfirmed. Data gathered from several steps was combined and formed the description of processes and the case concept of a demand planning optimization.

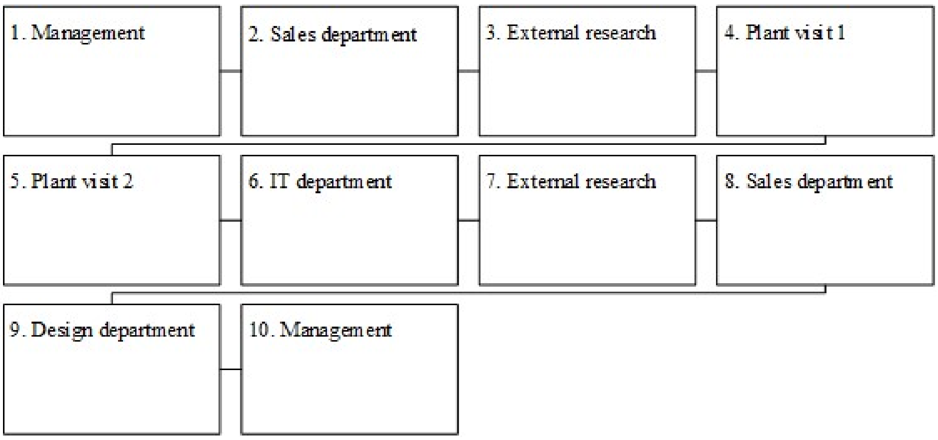

Figure 3.2: Conducted Qualitative Research Interviews.

3.3 Data Collection

The required optimization variables was first hypothesized to be produced quantity, required quantity for new project, order status, product type, total quantity, sales price, cost of sold goods, delivery time and production plant. This hypothesis was concluded after start up meetings with stakeholders at Company Alpha and was in later steps validated. More data was needed and is presented in Section 4.2 Identified Optimization Variables.

The data gathering process started with qualitative research in terms of the interviews with stakeholders with respect to their respective process area, in order to get a first validation of the hypothesized variables. This was done iteratively combined with a literature review of the optimization variables. The next step in the data gathering process was field studies, after which all processes were mapped and documented to further conclude how to get proper proxies for the optimization variables, since the optimization variables also are validated and present in Company Alpha's databases.

4
Results

This section will present the results from the plant visits and the qualitative research interviews.

4.1 Process Mapping

In order to answer the research question where the optimization variables are to be found, a process mapping section was formed based on the qualitative research.

The process areas affecting a supply and demand planning optimization were concluded to be Sales/Order, Structural Engineering/Detailing and Production/Delivery. The Sales/Order process area combines capacity constraints, order book and leads and aims to create sales orders. Structural Engineering/Detailing and Production/Delivery are the constrained processes when it comes to capacity. This high level process is illustrated in Figure 4.1.

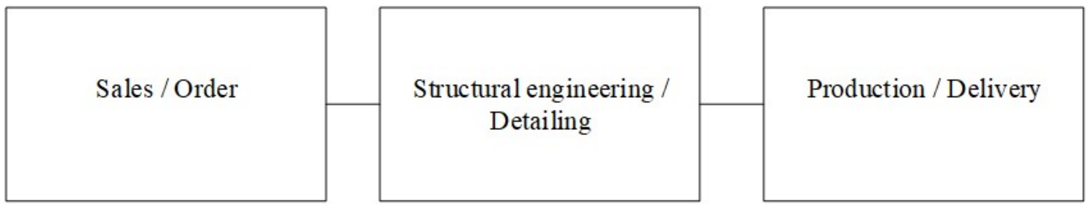

Figure 4.1: Main Process Areas.

Sales/Order is the process area where the decision of which projects to undertake has to be made, and the process can be broken down with a higher level of detail compared to Figure 4.1, as shown in Figure 4.2. The Sales/Order process starts with establishing the production data, consisting of Capacity Constraints from design and production, demand estimations in terms of Leads and Opportunities and the Order Book. The production data is then used in the Analysis/Calculation block, where each new offer is given a sales price to a specific customer. The offers are manually compared to the Capacity Constraints and the Order Book. If the sales price is profitable enough, the offer is sent to customer for confirmation and can either be confirmed or rejected. An offer is converted into a Sales Order when the offer is confirmed from the customer. An offer does not necessarily have to be followed through after it is sent, but it is industry praxis not to refuse an order due to customer relationship reasons.

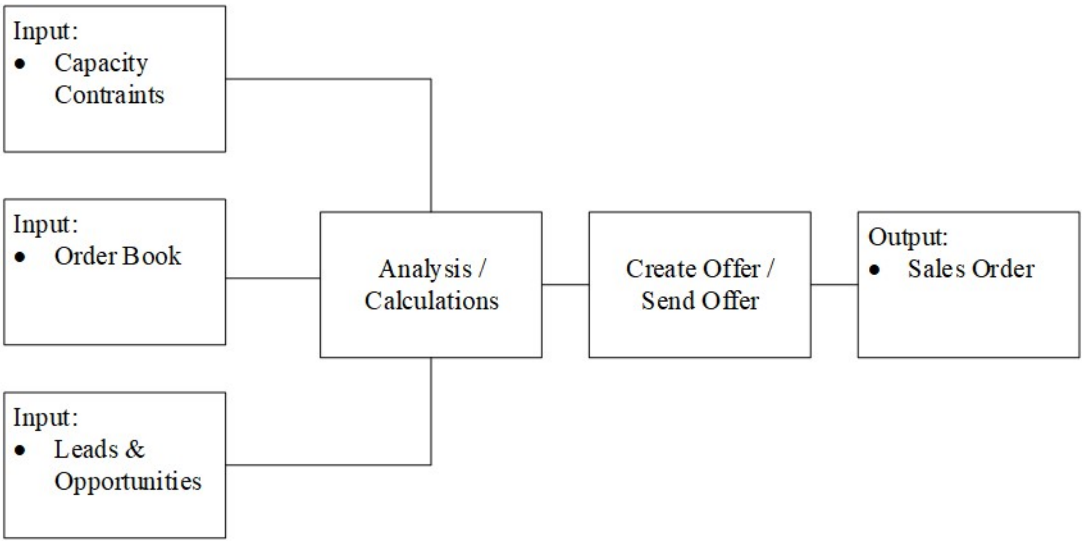

Figure 4.2: Sales/Order Process Area.

Structural Engineering/Detailing is the process area (see Figure 4.3) where the project management starts. The project management team coordinates Structural Engineering and Detailing but also a high level Production Planning in terms of time constraints based on the information given in the Sales Order. Structural Engineering and Detailing are both processes that hold capacity constraints, and need therefore to be concluded before Shop Drawings can be produced.

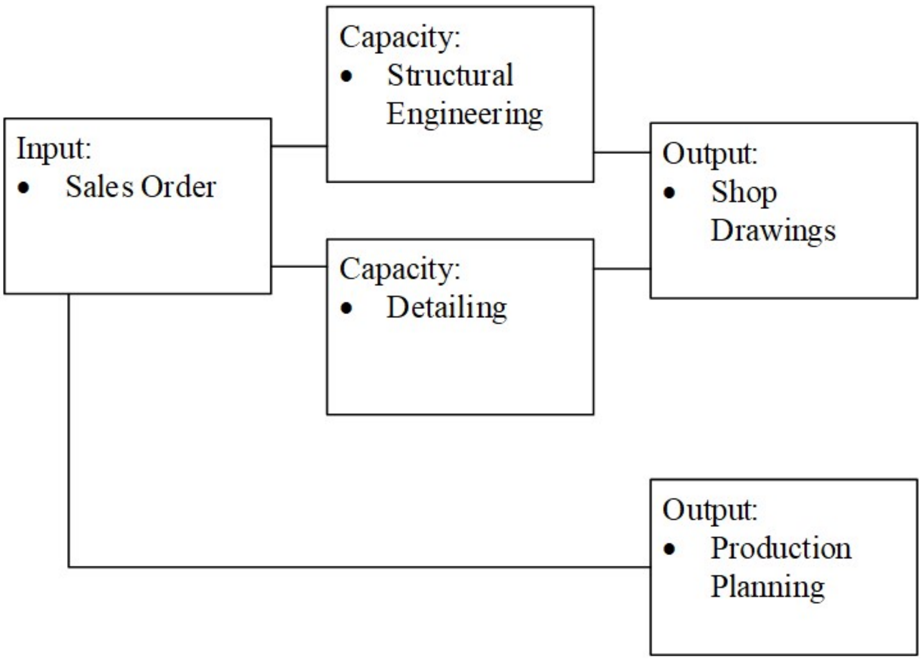

Figure 4.3: Structural Engineering/Detailing Process Area.

Production/Delivery is the process area in which the finished goods are produced. For the production to start, Shop Drawings and a high level production plan is required as input. The next process step combines these into a more detailed plan in the Production Scheduling block. Company Alpha performs the Production Scheduling and corrects for over-capacity if needed by outsourcing excess capacity.

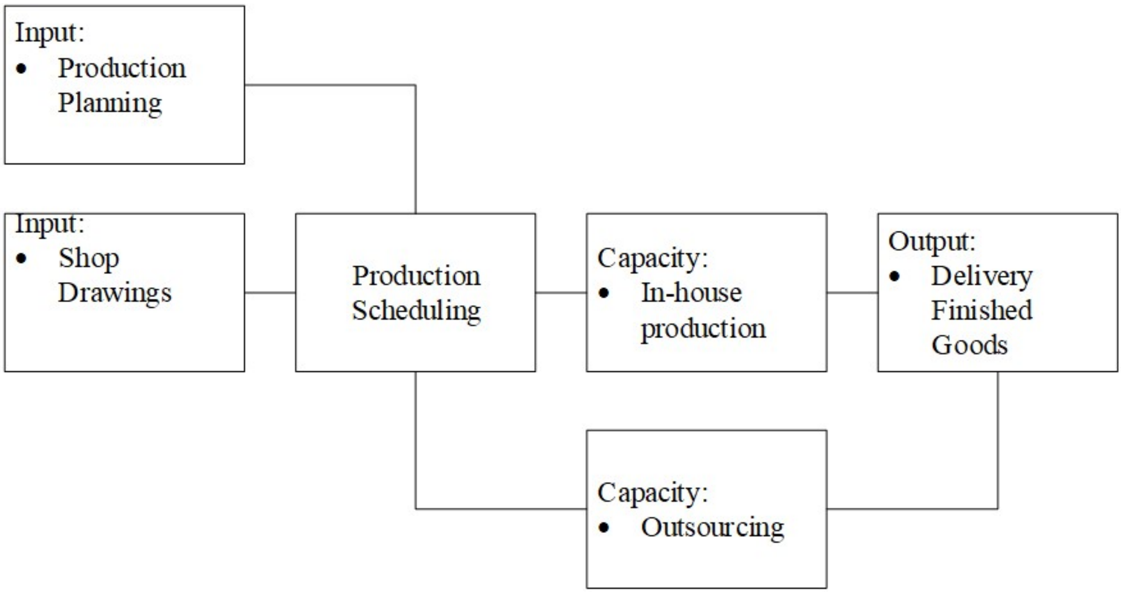

Figure 4.4: Production/Delivery Process Area.

4.2 Identified Optimization Variables

In order to be able to optimize the supply and demand planning, the following variables were identified as key characteristics and constraints. Each variable was identified during the process mapping with respect to the hypotheses stated in the Methodology Section 3.3.

4.2.1 Design and Production Capacity

What the optimization will be based on is whether or not the plants and structural engineering have capacity to produce and deliver upon an offer.

Design

The Structural Engineering/Detailing process area is part of the project management, and the output from this process is the Shop Drawings that are later delivered to production. This means that Structural Engineering/Detailing needs to be concluded before production can start. The main takeaways from the design process area is the maximum capacity for Structural Engineering and Detailing, which is shown in Figure 4.3. Structural Engineering and Detailing are two process steps within the process area, that are not dependent on each other, but both need to be completed in full before production can start.

Structural Engineering includes the design process of each precast element. Each element is drawn in CAD software and put through FEM calculations. Therefore, the Structural Engineering has, just as production, a max capacity in terms of how many orders or projects that can be designed within a specific time frame. Company Alpha uses consultants for flexibility in capacity for Structural Engineering and Detailing which allows for spikes in capacity. However, due to customer changes in late stages or other unforeseen factors, these process steps can be very urgent to revise and production can be affected. Thus, in this thesis these capacity constraints will not be seen as constraints, since what is planned can be delivered from Structural Engineering/Detailing.

Production and Product characteristics

The last process area, Production/Delivery, displayed in Figure 4.4, is set to produce and deliver the content of the Shop Drawings produced by the previous process area. There are several decision points in this process area that will be scheduled in production, e.g. if the specific Shop Drawing, input to the process area, should be produced in-house or if production should be outsourced. If production is in-house, the maximum capacity is highly dependant on the production process where internal processes and supply chains directly constrain the maximum capacity. Thus, productivity varies due to inefficiencies and impact both the theoretical maximum capacity and the actual capacity, both of which being identified as optimization variables.

The production process works differently for different products. The precast industry works exclusively with unique products, i.e. Company Alpha designs and produces each product. Because of this, products are grouped into product groups on the criteria that it is possible to produce a specific product group at a specific production plant, i.e. the production plant's capability (see Figure 4.5). Four product groups are defined for Company Alpha by that criteria in terms of slabs(S), pre-stressed slabs(P), double walls(D) and balconies(B). Company Alpha have some restriction when it comes to its production plants, since as mentioned not all plants can produce all product groups. The process area of production must consider which production plants have free capacity and the correct equipment for the specific element that is going to be produced. Thus, the product groups become optimization variables.

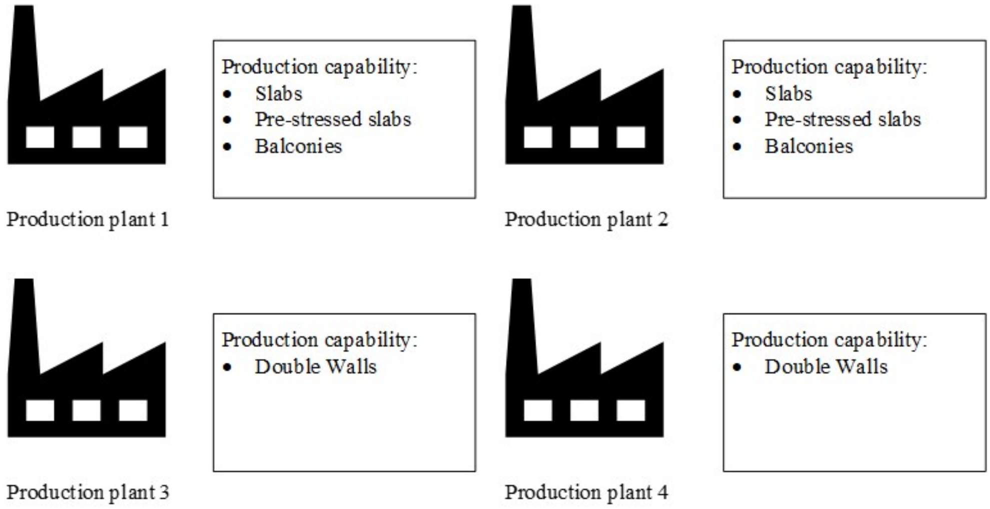

Figure 4.5: Production Plant Capabilities.

Company Alpha produces its own reinforcement (girders and mesh) for the product groups slabs, pre-stressed slabs and balconies. This is however not a bottle neck since there are close relations to suppliers that produce equivalent products designed for Company Alpha's production needs. This will therefore not affect the overall production capacity for finished products, since these suppliers have a high capacity and can cover the production needs and more. Outsourcing covers the excess demand needed in the reinforcement case, but for the outsourcing mentioned in Figure 4.4 that is not the case, since the suppliers that Company Alpha use for finished products have a limited capacity.

As defined in the Theoretical Framework (see Subsection 2.3), production planning deals with which orders to undertake and high level time management, meanwhile production scheduling deals with how to produce the orders at their corresponding plant. Both processes consider the plants' max production capacity. There are however two types of max capacities, one theoretical and one actual. The theoretical capacity is based on calculations and goals, meanwhile the actual capacity is what the plant actually manages to produce. Company Alpha currently use an average actual capacity, stating that the production quantity will be lower than the theoretical capacity due to complexities in products and productivity constraints, which is further described in Section 5.1.1.

4.2.2 Order Status

Each order have both in Company Alpha's ERP system and in the process mapping a specific order status. It varies between:

- Offer (Based on Opportunities and leads)
- Order
- Delivered

An offer is an unconfirmed order which contains limited data about the project. This is preliminary volume, preliminary delivery date and sales price based on pre-calculations. When the offer is sent to customer and confirmed, it turns into an order which is then used as reference throughout the design and production processes until it is delivered. During this time, the order will be iteratively updated with information which establishes more and more details of the order in the high level production planning. Just before production starts, the order is scheduled in the production scheduling.

Prior to the supply and demand planning optimization, the order status Offer is the status which the optimization will have to use for comparison purposes. To utilize the free capacity at each plant, the supply and demand planning optimization needs to screen projects by their status and sort out those who match the order status Offer. These offers will thereby be the ones compared to one another while answering which of the projects Company Alpha are to undertake.

4.2.3 Profitability

If there is available capacity and the orders have been sorted out, the next step would be to determine the projects' profitability. Profitability at Company Alpha is calculated and measured in terms of contribution margin (described in Subsection 2.3) for the specific product types slabs, pre-stressed slabs, double walls and balconies. These are however not fixed. The contribution margin is calculated by the products' specific Cost of Goods Sold (COGS) subtracted from the sales price.

Transport

Transportation is the process of moving finished goods from stock to the construction site of the customer, and is highly dependent on the progress of the specific construction project. The construction project needs the precast elements in order of assembly, and if the project is not ready for assembly, the storage capacity on the site is often very limited. This order of delivery needs to be defined as a joint effort from the precast firm and the construction firm and is called stack planning, where each stack is given a number which is then decided as the order of delivery. Transport which is very much used since each precast element is delivered to construction site is in Company Alpha's case not a specific optimization variable. Its cost are included in the COGS and trucks used for transportation are in principal always available.

4.2.4 Stock

Stock is just as transportation not a specific optimization variable due to the assumption that it almost never is used to its max capacity. This is due to that the production scheduling allows for a buffer in warehousing and the overall short delivery cycles, meaning produced precast elements are not stored for very long at each plant before customer delivery.

4.2.5 Complexity

During the process mapping, the lack of details was identified as a constraint in the Sales/Order process area (Section 4.1). This means that when deciding which orders Company Alpha are to undertake, a lot of information is missing since this happens before Structural Engineering/Detailing. This missing information in terms of design characteristics is used during the production scheduling and the actual production, and a basic rule is that the more there are of these characteristics, the more complex is the element to produce. Therefore these characteristics can be called complexity characteristics, and are in the precast element identified as the following:

- Angles
- Cast-in materials
- Height
- Holes

Angles refers to whether or not the element is squared. Cast-in materials are installed details such as sprinklers. Height complexity becomes relevant if the element does not fit the pallet accordingly, and holes could be represented as e.g. doors or windows.

Section 4.2.1 introduces the product groups balconies (B), slabs (S), pre-stressed slabs (P) and double Walls (D). The complexity characteristic Height is only prior to double walls, meanwhile the rest of the characteristics apply to all product groups.

An element designed with high level of complexity requires more capacity than one with low level. Therefore, along with the introduction of complexity characteristics, there is a consequence in terms of "Effort m^2 [em^2]" . Effort m^2 is what the thesis call the required and estimated capacity prior to the complexity characteristics. Two elements or projects with the same size or amount of m^2, but with different level of complexity, will ultimately have different effort m^2:s. How much larger the effort m^2 compared to the regular/actual m^2 is thereby determined by the magnitude of the weight from the complexity characteristics.

The concept of effort m^2 could be illustrated in equation 4.1, in which the coefficient $C_{complexity}$ is the arbitrary complexity factor. Q_e and Q are thereby the effort quantity and actual quantity respectively.

$$Q_e[em^2] = C_{complexity} * Q[m^2] \tag{4.1}$$

The magnitude of the added complexity is determined by measuring the extra effort needed for square meters with a specific complexity characteristic. This calculation is best grasped in terms of productivity and time. The productivity at each plant could be measured/calculated by m^2/t, meaning that during a constant period of time, the complexity factor is equal to the ratio between the productivity prior to two elements or projects. In this calculation the constant time can be shortened, which is shown in Equation 4.2 where the complexity factor for angles is calculated.

$$C_{Angles} = \frac{Q1[m^2]/t}{Q2[m^2]/t} \tag{4.2}$$

Q2 should therefore involve elements with complexity, meanwhile Q1 should not. As mentioned, effort m^2 is thereby used when the quantity is estimated by using the complexity factors as in Equation 4.1, not while describing actual quantity which is the case when a specific complexity factor is calculated, as in Equation 4.2. This also enables tuning of the calculated/measured complexity factor, since it can be adjusted continuously by comparing quantities with different complexity traits produced during a specific amount of time.

4.2.6 Summary

Table 4.1 displays a summary of the identified optimization variables throughout the process mapping in Section 4.1.

Table 4.1: Summary of Optimization Variables.

Optimization Variable	Process Area	Relevance
Design Capacity	Structural Engineering/Detailing	Not Included
Production Capacity	Production/Delivery	Included
Product Groups	Production/Delivery	Included
Reinforcement	Production/Delivery	Not Included
Order Status	Sales/Order	Included
Profitability	Sales/Order	Included
Transport	Production/Delivery	Not Included
Stock	Production/Delivery	Not Included
Complexity	Production/Delivery	Included

5

Analysis

This section presents the analysis of this thesis results together with the theoretical framework. The analysis covers industry specific constraints and possible strategies to cope with these constraints together with a recommended approach.

5.1 Industry Specific Constraints

One of the main takeaways from the field studies and interviews, was the conclusion that the information flow from the customer to the salesforce constraints the thesis' aim to optimize planning for supply and demand. In order to optimize supply and demand in terms of comparing projects' profitability and capacity requirements with existing capacity, the optimization variables in section 4.2 needs to be known. However, since it was in the process mapping 4.1 concluded that this comparison and control happens in the Analysis/Calculations process, before an offer is sent to customer and before Structural Engineering/Detailing, details such as the complexity factors in Subsection 4.2.5 are missing. Therefore the optimization has to be done in the Analysis/Calculations process, but not with data gathered from Structural Engineering/Detailing.

5.1.1 Current Strategy: Max Capacity Adjustment

The lack of information and the uncertainty while deciding which offers to undertake can however be coped with. As of today, Company Alpha in the Analysis/Calculation process use a theoretical max capacity lower than the actual capacity. This means that personnel in the salesforce add qualitative input based on experience while controlling for free capacity. The theoretical max capacity is decreased due to variances in productivity as concluded in Section 4.2.1, and is estimated by historical and forecast productivity measures such as sick leaves and internal processes. Complexity will inevitably be a part of the adjustment, but its effect is not distinguishable from the productivity. Therefore, the attempt of using effort m^2 for the theoretical max capacity is somewhat limited and not accurate, as seen in Figure 5.1.

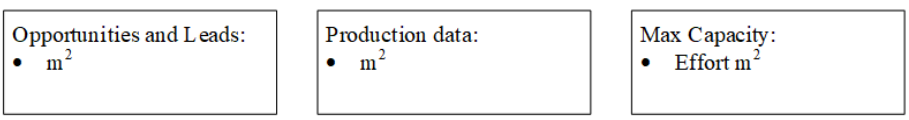

Figure 5.1: Max Capacity Adjustment.

By doing this, i.e. reduce the theoretical max capacity under production planning uncertainty (see Section 2.3), the salesforce may not utilize the full available capacity, but at the same time rarely risk overcapacity. This manner of planning for demand is also not very transparent, in the sense of the knowledge possessed by the salesforce not being visible throughout the organization. The causes of the lack of transparency and the risk of not utilizing the available capacity can be tracked in the current manner of demand planning, which is illustrated fully in Figure A.1 in the appendix. The current solution does also not provide any optimization on new offers in regard to profitability, since the capacity control is manual and there are no comparison between offers.

Thus, there are four main disadvantages with Company Alpha's current manner of coping with uncertainty under production planning:

- Complexity and productivity not being distinguishable from one another when estimating the theoretical max capacity
- Risk of not fully utilizing the plants' max capacity
- Lack of transparency of the knowledge possessed by the salesforce
- Little optimization

Due to the drawbacks with the current manner of working, alternative strategies or concepts of planning for production under uncertainty was examined with the following result.

5.1.2 Strategy A: Industry Foundation Classes

The challenge of missing information and data conversion between architectural models and structural models is not bound to Company Alpha, it is on the contrary, a precast industry specific constraint. Hu et al (2016) describe the problem in terms of inadequate interoperability while managing information or Building Information Models(BIMs), and therefore propose a solution involving the industry initiative, Industry Foundation Classes (IFC). IFC is by McPartland (2019) defined as an open and platform neutral file format, which is not controlled by a single actor. The object based file format was developed in order to facilitate interoperability in the AEC (Architecture Engineering and Construction) industry, and therefore aims to nurture collaboration in BIM based projects. Hu's et el approach aims thereby to use IFC in a manner which increases the interoperability between different software applications, and between architectural and structural BIMs.

However, the usage of IFC requires standardization, meaning the stakeholders in charge of the architectural BIM need to use the file format as well as the stakeholders in charge of the structural BIM. In Company Alpha's case as well as in the current market, that is not the case. Drawings from architects varies between formats such as PDF and AutoCAD, and IFC as an industry initiative is not yet fully established. IFC posses the opportunity of increasing the amount of information received from customer during Structural Engineering/Detailing, but at the same time require customers to change their current way of working. Therefore the alternative of using IFC to cope with missing information, will in this thesis not be further examined, since preliminary organizational and strategy changes may not fit within the thesis delimitations.

5.1.3 Strategy B: Historical Average

The use of historical average would tackle the missing information while planning for demand by categorization and statistics. An order or offer containing little information could by the salesforce's experience be categorized, and with respect to such a categorization historical production data could be gathered from Company Alpha's ERP system. Thus, an offer would be labelled as a project with certain traits, and the salesforce during Analysis/Calculations would subsequently have a data bank available with information prior to projects with similar characteristics or optimization variables. There are difficulties characterizing the unique projects in the precast industry, and according to this thesis conclusions, the characterization should be rough since detailed grouping is not applicable.

5.1.4 Strategy C: Traceable Qualitative Input

A third manner of compensating missing information could be standardizing the qualitative input made by the salesforce. Such a strategy would involve having the complexity characteristics prior to a project estimated until data is available. This approach would be similar to the current way of working, but instead of decreasing the theoretical max capacity, the specific project's theoretical capacity would be adjusted based on qualitative input. This implies that the input data is in effort m^2, defined in Equation 4.1, and the max capacity is in actual m^2 as presented in Figure 5.2. Having the required capacity prior to a specific project adjusted, instead of decreasing the total max capacity, could enhance Company Alpha's transparency, since the causes of the adjusted capacity would be visualized by the complexity factors. Thus, complexity becomes traceable and precautions can be made.

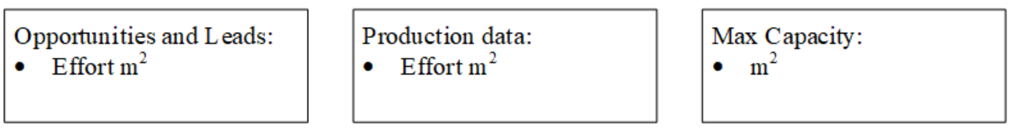

Figure 5.2: Traceable Qualitative Input.

5.1.5 Choice of Strategy

The choice of the final strategy incorporated in the case concept was the strategy of traceable quality input. The optimal strategy would be Strategy A: Industry Foundation Classes, but the industry is not yet there and would thereby not include all projects or even a majority of the projects. Therefore, Strategy C: Traceable Qualitative Input, is preferred before using Strategy B: Historical Averages, because of difficulties characterizing projects and the planning data's aggregation levels. Strategy C also offers benefits in an industry reliant on experienced employees since this knowledge will be quantified and made accessible to the entire organization.

The planning data's aggregation level is described in the Theoretical Framework see 2.3 as "*...the planning data must have an aggregation level. If high, the planning objects become fewer, but so does the details. In the same way, with low level of aggregation comes more objects, but possibly along with more planning data uncertainty.*". Strategy A: Industry Foundation Classes would therefore have low level of aggregation, but arguably still with low planning data uncertainty since the data used would originate directly from structural models. IFC would in this sense once again be the preferable strategy. Strategy C: Traceble Qualitative Input would also have a low level of aggregation in terms of several planning objects, such as the complexity factors. Compared to strategy A however, strategy C would include more planning data uncertainty, since the data used would come from the salesforce's estimations, and not from structural models.

Strategy B: Historical Averages' level of aggregation would arguably depend on the number of possible categorizations of projects/offers. If there are several categories, the planning objects becomes few, but in accordance with the definition, so does the known details. Categorizing projects was however by the salesforce thought to be difficult. Additionally, this strategy does not enable traceability of complexity characteristics, and therefore Strategy C: Traceable Qualitative Input would arguably be the best plausible strategy for Company Alpha.

6

Case Concept

What is in the Theoretical Framework described as an Advanced Planning System (see Section 2.3) will in this chapter be presented as a case concept of a supply and demand planning optimization model. This means that below a concept model will be formed, illustrating a potential manner of how a supply and demand planning optimization in Company Alpha's case could look and be used in their business intelligence (see Figure 6.1).

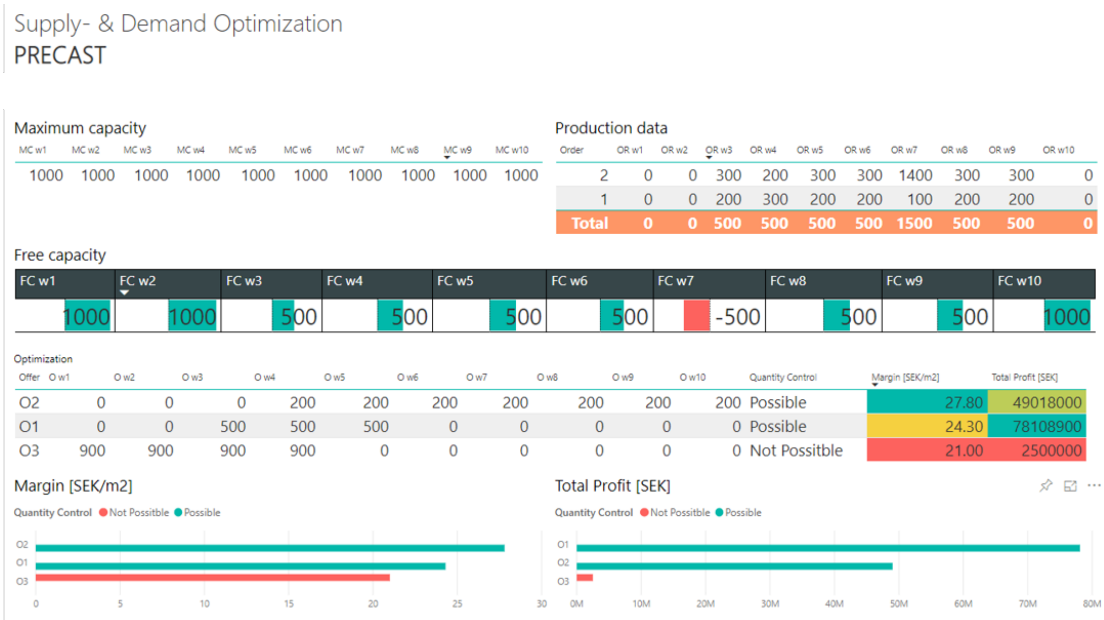

Figure 6.1: Practical Implementation of Strategy C: Traceable Qualitative Input.

Maximum capacity, Production data, Free capacity and incoming offers are used to perform an optimization based on quantity and profitability. This optimization report is meant to propose the optimal incoming offers for Company Alpha, and all offers are compared and evaluated on the same basis. This implies that the final decision also requires other qualitative measures that is not measurable, e.g. customer relations, and is not considered in the optimization report.

Thus, Figure 6.1 displays a potential tool/report to use in Strategy C: Traceable Qualitative Input, which is displayed in Figure 6.2.

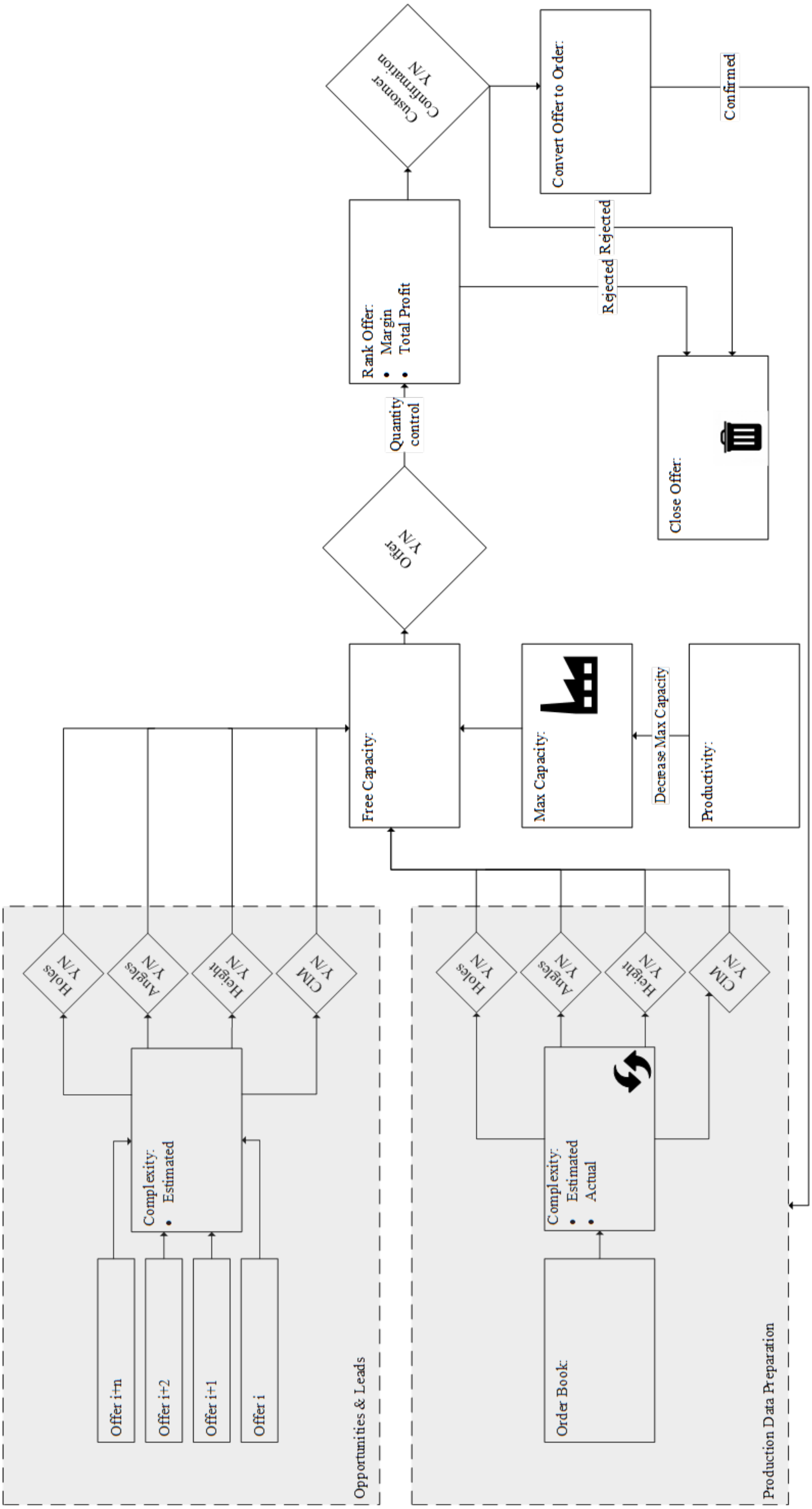

Figure 6.2: Case Concept of Strategy C: Traceable Qualitative Input.

Figure 6.2 displays two major blocks of input data, i.e. Opportunities & Leads and Production Data Preparation. Production Data Preparation consists of confirmed orders that are roughly or detailed planned in production. The Opportunities & Leads includes offers that are not yet sent to the customer. The complexity is then added as a factor per square meter to modify the data to effort m^2, as described in Equation 4.1.

The production data is evaluated with the max capacity in order to get the free capacity. The max capacity is 100% or more in order to take project specific changes into consideration. Customers might have delays which affect the delivery dates of the elements, hence the capacity is allowed to exceed 100%. Note that in Strategy C: Traceable Qualitative Input, the theoretical max capacity reduction is only based on productivity, and thus not bundled with complexity. Therefore the reduction is only prior to waste such as sick leaves.

At this stage, the optimization starts. The quantity to deliver upon of incoming offers are compared against the free capacity. Offers that are not possible to deliver upon because of capacity constraints are rejected and closed. Out of the offers where sufficient capacity are available, the offers that result in the highest joint value of margin and total profit are ranked as most profitable. From here, the decision to carry on with an offer has to be made before sending the offer to the customer and the remaining offers will be rejected. The customer can either confirm of reject the offer, whereas a rejected offer is closed and a confirmed order is then added in the production data as an order and will affect the free capacity. The effort m^2 is still estimated with the qualitative input from the offer, and will continuously be overwritten throughout the Structural Engineering/Detailing process area.

The use of complexity factors and effort m^2 in figure 6.2 can be further clarified by illustrating the qualitative input and the required calculations.

As described in Section 4.2.5, each identified complexity characteristic has a factor which is calculated by productivity differences. Therefore each complexity factor, four in total, contributes to a total of estimated effort m^2 for each product type within a specific project. Such a calculation for product type double walls(D) in project 'i' is shown in Equation 6.1, in which each complexity factor has been used to calculate its percentage of the affected quantity, in accordance with Equations 6.2 to 6.5.

$$Q_{eiD}[em^2] = Q_i[m^2] + Q_{Angles}[em^2] + Q_{Holes}[em^2] + Q_{CIM}[em^2] + Q_{Height}[m^2] \quad (6.1)$$

In Equation 6.1, $Q_{eiD}[em^2]$ is the estimated effort m^2 prior double walls(D) in project 'i', meanwhile $Q_i[m^2]$ is the actual quantity ordered by the customer in the same project. $Q_{Angles}[em^2]$, $Q_{Holes}[em^2]$, $Q_{CIM}[em^2]$ and $Q_{Height}[em^2]$ are the extra required square meters in terms of capacity, estimated by the use of the complexity factors.

Thus, the Equations 6.2 to 6.5 are the ones in which the eight [YES/NO] questions in Figure 6.2 are answered, by the use of the qualitative input.

$$Q_{Angles}[em^2] = Q_x[m^2] * C_{Angles} - Q_x[m^2] \tag{6.2}$$

In terms of qualitative input, $Q_x[m^2]$ is the estimated quantity of square meters in a project, which is thought to be affected by complexities concerning angles. By multiplying that estimated amount with the complexity factor for Angles, one get the estimated required capacity prior to that specific complexity characteristic. The same goes for Holes, CIM and Height.

$$Q_{Holes}[em^2] = Q_y[m^2] * C_{Holes} - Q_y[m^2] \tag{6.3}$$

$$Q_{CIM}[em^2] = Q_z[m^2] * C_{CIM} - Q_y[m^2] \tag{6.4}$$

$$Q_{Height}[em^2] = Q_w[m^2] * C_{Height} - Q_w[m^2] \tag{6.5}$$

To note here is however that double walls were chosen as the illustrative example since it is the only product group in which the complexity factor Height is relevant. Calculating the total effort m^2 prior to the three other product groups would therefore not involve $Q_{Height}[m^2]$ in Equation 6.1, and subsequently neither Equation 6.5.

Thus, with the effort m^2 prior to each product group calculated by four different versions of Equation 6.1, a project's total effort quantity, $Q_{ei}[em^2]$, can be estimated by summarizing each new quantity in accordance with Equation 6.6.

$$Q_{ei}[em^2] = Q_{eiD}[em^2] + Q_{eiB}[em^2] + Q_{eiP}[em^2] + Q_{eiS}[em^2] \tag{6.6}$$

Where $Q_{eiB}[em^2]$, $Q_{eiP}[em^2]$ and $Q_{eiS}[em^2]$ are the total effort m^2 prior to the product groups balconies(B), pre-stressed slabs(P) and slabs(S) respectively.

$Q_{ei}[em^2]$ as the total and estimated quantity prior to a specific project is however not used in the comparison with free capacity in Figure 6.2, since this calculation is done per product group.

7

Conclusion

In reference to the research questions in Section 1.4, it is evident that the entire Sales-to-Delivery process in the precast industry is relevant for a supply and demand planning optimization, where processes in early stages affect as well as processes in later stages of a project. Due to the flexibility of Transport (see Subsection 4.2.3), Stock (see Subsection 4.2.4), Reinforecement (see Subsection 4.2.1 and Design Capacity (4.2.1), the optimization variables can be found in the Sales/Order (see Figure 4.2) and Production/Delivery (see Figure 4.4) process area. Thus, a supply and demand planning optimization should consider the following variables:

1. Production and product characteristics (Subsection 4.2.1)
2. Order Status (Subsection 4.2.2)
3. Profitability (Subsection 4.2.3)
4. Complexity (Subsection 4.2.5)

The best way to develop a supply and demand planning optimization model was judged to be by following Strategy C: Traceable Qualitative Input (5.1.4), due to its benefits of traceability, transparency and optimization possibilities.

8

Further Research

This chapter will outline recommendations regarding further research.

8.1 Calculation of the Complexity Factors

The complexity factors Holes, CIM, Height and Angles all have a factor as described in Section 4.2.5. However, what the thesis did not manage to conclude were the actual arbitrary values of these factors. Therefore a time study needs to be conducted, in which productivity ratios prior to each factor are calculated. Such a measurement and calculation are to be done in the following manner, using Equation 4.2.

$$C_{Angles} = \frac{Q1[m^2]/t}{Q2[m^2]/t} \tag{4.2}$$

Prior to the calculation of the complexity factor for angles, quantities existing of elements with few angles (Q1) are to be compared with quantities existing of elements with several angles (Q2). Thus, during a constant period of time, the ratio between the different quantities will result in the factor of which angles affect capacity usage.

Such measurements are to be done prior to each complexity factor. However, a detailed plan are arguably to be generated in accordance with production and plant personnel and their knowledge, in order to form the best possible time and productivity study. Also, when having initially concluded the four values during such a study, their actual impact can be continuously monitored and measured over time, and therefore be allowed to be further tuned in order to become even more accurate.

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A

Appendix 1

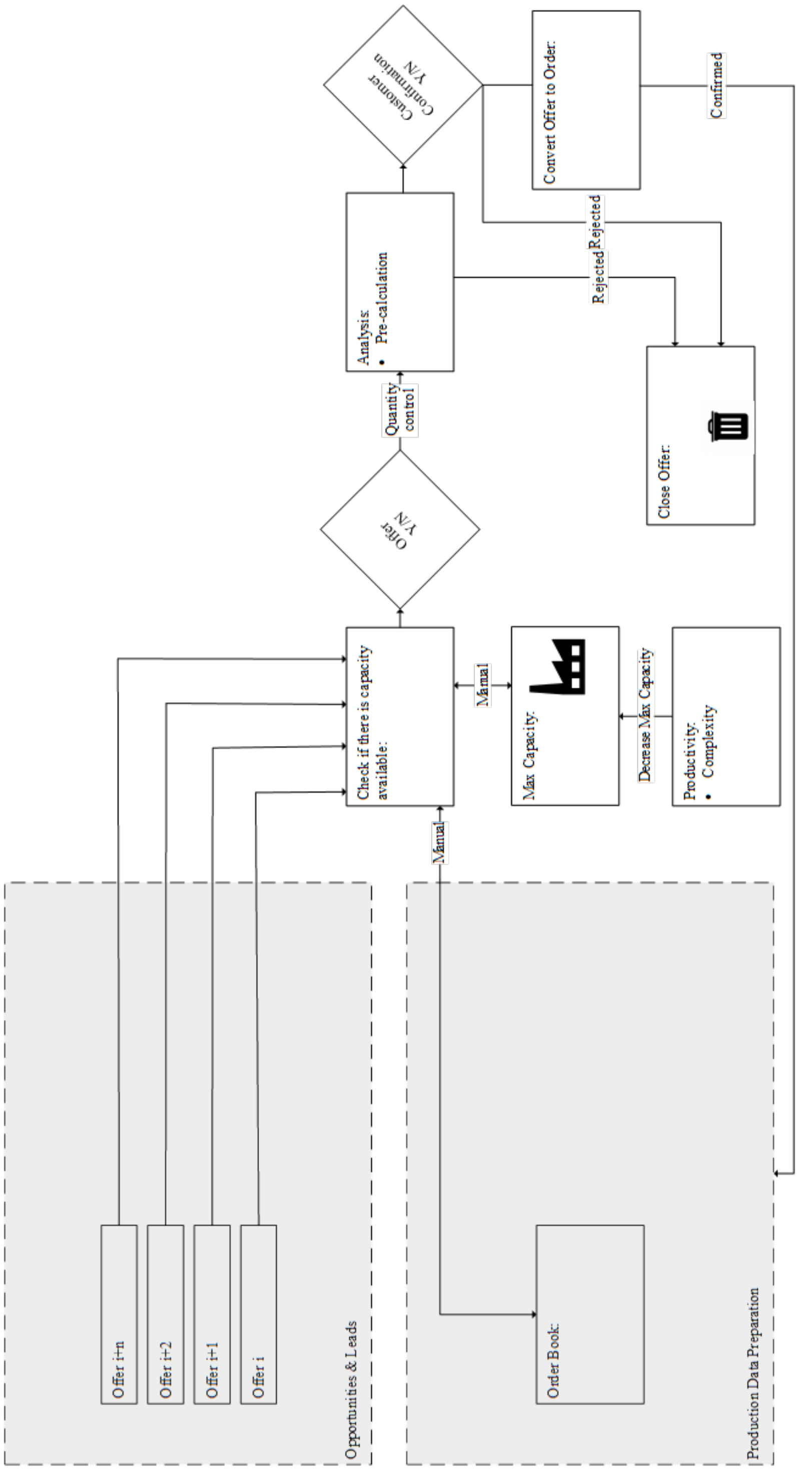

Figure A.1: Current Strategy: Max Capacity Adjustment.