Simulation of production flow

– A study of what effects a different product mix has on capacity, bottlenecks and inventory levels at Sandvik Materials Technology

Simulering av ett flöde

– En studie om vilka effekter produktmixvariationer har på kapacitet, flaskhalsar och lagernivåer på Sandvik Material Technology

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Abstract

This master thesis has been carried out in AB Sandvik Materials Technology within product area Tube. The study is intended to analyze the hot flow within Tube. The production flow is divided into two different parts according to dimension of the tubes: large and small flow. Both flows consist of three steps: billet preparation, extrusion and finishing. The flow is complicated and it is difficult to understand what kind of effects the changes have on the flow.

This study aims to build a virtual factory of the flow in order to test different scenarios and see how changes influence the flow. The purpose is to define and verify the current capacity and how variations in product range affects this capacity. This study intends to define the bottlenecks of the flow and see what kind of effect the variations in the product mix have on bottlenecks. The object is also to study if the bottlenecks can be avoided and what are the inventory levels in the flow.

The study was initiated by mapping the current state according to the tool Value Stream Mapping, which gave a good picture of the flow and how it is working. Then, a simulation model was build with the program called Extend. Extend was chosen, because Sandvik Materials Technology already had a license for this program and because the supervisor at Royal Institute of Technology has a deep knowledge of it.

Three different product mixes were chosen; the first one had 25 % of the material duplex, the second 50 %, and the third 70%. The same simulation model was tested with all these product mixes. The bottlenecks found were cutting in the billet preparation of the small flow, pickling in the finishing, and deep-boring in the billet preparation of the large flow. The last mentioned was the bottleneck only when high percentage of the material was duplex. The duplex material means longer process times in the billet preparation.

To avoid the bottleneck in the pickling process, the simulation model was modified so that some extra capacity from previous operation was moved to pickling. This new model was tested with the two first product mixes and the result was that the overall output was increased noticeably from 4390 tons to 6030 tons (with product mix of 25 % duplex).

The inventory levels in the small flow stayed under the decided limitations with all the product mixes. Problems occur in the large flow in the inventory before extrusion, because of the uneven flow into this buffer. The production cells in the billet preparations are specialized to produce certain dimension, which means that there are several different dimension coming to the buffer at the same time. On the contrary, the flow out from the buffer happens according to an extrusion sequence. This sequence has a critical effect on the inventory level in the buffer.

Sammanfattning

Detta examensarbete har utförts hos Sandvik Materials Technology AB inom produktområdet Tube. Arbetets mening är att analysera varma flödet inom produktionen på Tube. Produktionsflödet är delat i två delar enligt dimensionerna på rör: grova och klena flödet. Båda flöden har tre delar: ämnesberedning, extrusion och färdigställning. Flödet i helhet är komplicerad och det är svårt att förstå hur ändringar påverkar flödet.

Syftet med denna studie är att bygga en virtuell fabrik om flödet för att kunna testa olika scenarier och se hur förändringar påverkar flödet. Meningen är också att definiera och verifiera kapacitet och titta på hur variationer i produktmixen påverkar kapacitet. Tanken är att definiera flaskhalsar i flödet och se om de påverkas av produktmixen. Att studera om flaskhalsar kan undvikas och vilka är lagernivåer i flödet ingår också i arbetet.

Arbetet började genom att kartlägga flödet enligt verktyget Value Stream Mapping, vilket gav en bra bild av flödet och hur den fungerar. Sedan byggdes flödet till en simuleringsmodell med hjälp av programmet Extend. Extend valdes för att Sandvik Materials Technology hade redan en licens för programmet samt att handledaren på Kungliga Tekniska Högskolan hade djupt kunskap om det.

Tre olika produktmixer valdes: den första hade 25 % av materialet duplex, den andra 50 % och den tredje 70 %. Samma simuleringsmodel användes när dessa produktmixer testades. Flaskhalsar som hittades var sågning i ämnesberedningen i det klena flödet, långhålsborrning i ämnesberedningen i det grova flödet och betning i färdigställningen i båda flöden. Långhålsborrningen blev en tydligare flaskhals när andelen duplext material var stor. Duplext material har längre processtider i ämnesberedningen medan cykeltiderna annars är ungefär samma som austenitiskt material.

För att undvika betningen som flaskhals, ändrades simuleringsmodellen så att kapacitet från föregående operation flyttades till betningen. Denna nya modell testades med de två första produktmixer och resultatet blev att den totala kapaciteten ökade avsevärd från 4390 ton till 6030 ton (detta med 25 % duplext material).

Lagernivåerna i det klena flödet stannade under bestämda nivåer med alla testade produktmixer. Problemet bestod i det grova flödet i ett lager innan extrusion på grund av ojämn inflöde till lagret. Produktionscellerna i ämnesberedningen producerar olika dimensioner, vilket betyder att flera olika dimensioner kommer till lagret samtidigt. Däremot utflödet från lagret sker enligt en extrusionsekvens, vilket innebär långa sekvenser om en viss dimension. Extrusionsekvensen har en stor betydelse för lagernivån i detta lager.

Acknowledgement

I would like to express my gratitude to all those who gave me possibility to do this thesis at Sandvik Materials Technology. It has been a great opportunity. I would like to thank all of you who work at GP for your interest, advice and support. Especially, I would like to thank my supervisors at Sandvik AB, Magnus Andersson and Niklas Abrahamsson for your help, support, interest and valuable hints.

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Sandviken, 20th of December 2007

Heini Paavola

Table of Contents

1. Introduction

An introduction to the topic is viewed in this chapter. A background to the study, problem statement and the purpose of this study, and delimitations are introduced. In the end, there are some advice and introductions for the reader.

1.1 Background

Sandvik Materials Technology (SMT) is a world-leading manufacturer of stainless and high-alloy steels, special metals and process systems. Tube is an area within SMT that makes seamless stainless steel tubes for different industries. Hot flow within Tube in Sandviken is organized to two different flows according to dimensions of the tubes. Both flows include three operation steps; billet preparation, extrusion and finishing. The flow is complex and it's difficult to build an idea how different changes in the flow effect on each other. The idea of this master thesis is to simplify these difficult problems by building a virtual factory where different scenarios can be easily tested.

1.2 Problem statement and the purpose of the study

The purpose of this thesis is to study the hot flow within the product area Tube from the beginning to the finishing, and be able to define and verify the capacity of the production in different situations. A part of the task is to find out how variations in product range effect the flow and the capacity. Changes in product range means variations in product characteristics (steel sort, dimension etc.). To find out where the bottlenecks are, how they effect on the flow and the capacity, and eventually if they can be avoided, are also important parts of the study.

SMT has also an on-going process to implement lean production to all of its production facilities. One of the objectives of this lean process is to reduce inventory levels. By building a virtual factory, the inventory levels can be easily monitored. It is also easy to see what kind of effect the different product range has on the inventory levels. The ambition of this study is to find out the ideal and necessary level of inventory.

1.3 Limitations

The flow considered in this study is delimited to billet preparation, extrusion and the pickling part of the finishing. Operations after the pickling are, in other words, not included to this study. The standpoint is meant to be technical, and this means that things like work environment and organization are excluded from this study. A Value Stream Mapping –tool is only used to create a current state map. A future state map is not included in this study.

1.4 The body of the report – advice and instructions for readers

In this chapter, some advice and instructions are given for the readers with the intention of helping the reader to find out the relevant parts of the report according to their interest and background.

Chapter 1 and 2 are recommended for everybody, because they go through the background and the purpose of the study. The method explains how this study is accomplished.

In the chapter 3, the Sandvik AB is presented. This is a relevant for readers outside of the Sandvik, because all the different parts of the company are put into its context. SMT Business system is presented in the end of this chapter.

Chapter 4 includes the theory and the literature review, which is good to familiarize with, because it is reflected in the results and conclusions. Chapter 5 aims to map the current state of the production flow. All the process steps are described, and a current stare map according to VSM is drawn. This chapter is good to read if the reader is not familiar with the production flow at Tube in Sandviken.

Chapter 6 concentrates on modeling and the different models made for this study, which is relevant for everybody. Chapter 7 presents the results of this study.

Chapter 8 consists of the discussion and the conclusions. These are obviously relevant for everybody.

2. Method

This chapter goes through the method used in this master thesis. Literature is presented and the method of doing a simulation project. To get valid and right data is often the most difficult part of the simulation; this is explained in this chapter as well as critical view of the chosen method.

2.1 Approach

The method of this study is do production simulations with the program called Extend. The flow is complicated, and it is difficult to analyze the situations in some other simpler way, that's why simulation is used. Simulation program is chosen to be Extend, because that's the program used at Sandvik AB and because they have valid license to use the software. Program is also used at KTH, which makes it easier to get supervising. For these reasons no other simulation programs have been considered.

The work was started by planning the project and making a Gantt chart over the remaining time. Milestones were planned to make it easier to manage the work and be able to see easily if the project is left behind on the schedule. After the time frame was done, it was time to start studying literature and mapping the current state.

2.2 Literature study

Literature, which was studied in this project, includes books about simulation and modeling, and lean production. Sandvik Materials Technology has an on-going program to implement lean production to its production. It's important that all the changes, investments and possible recommendations are done in the spirit of lean production. Thus, deep understanding for lean principles and tools is crucial. Literature includes also material about the company and production processes used at Tube in order to get a better understanding of the processes and flow.

2.3 Empirical study

In order to be able to build the model, an analysis of the current state has been made. A current state map is drawn by using a tool called Value Stream Mapping (VSM). This map shows the overall material and information flow in production. The idea of this current state map is to serve as some kind of bridge between the layout in reality and the simulation model. The method to do this map is to collect the information about the production flow and draw a simple map according to VSM (Rother, Shook 2003). Value stream mapping is described in chapter 4.1. Information about the flow is collected through interviews and discussions with the people working at Tube (GP).

Like in every other project, it's always an advantage to have a strategy how to complete the task. To build a simulation model is not an exception. It's important to try to get a work structure and timeframe to work with. I have tried to follow the strategy recommended by a book called Business Modeling and Simulation (Oakshott 1997).

1. Define the problem and schedule the time frame

   It's very important to have defined the aim and the goal of the project before the beginning of work. Planning the time frame in the beginning helps to estimate the cost of the project.

2. Collect and analyze the data

   Step 2 and 3 is usually carried out parallel, because the model can be defined before the data collection is completed. Both steps require a deep understanding of the system, which have to be obtained first. Logical connections have to be identified and assumptions of the system in order to keep it simple have to be made. The collected data has to be analyzed, which often means that variables have to be adapted to the model.

3. Build a concept model

   A parallel with data collection, a concept model is build, which includes all the mathematical and logical connections as well as connections between the main parts of the system. This should make it easier later to continue building the model.

4. Validate the concept model

   It's very important to get all the logical connections right and verify them before moving forward. In this step the model is presented to some key persons who has the understanding to the system and who can adjust the incorrect connections and false assumptions that occur due to incomplete understanding of the system. The time, that is used here to find the errors, is often paid many times later.

5. Develop the model

   Build the rest of the model with all the details. Start with a simple model and add the grade of complexity little by little.

6. Troubleshoot the model

   There are always some faults in all the models when they are run first time. Faults can be visual or hidden, but it's equally important to find them.

7. Validate the model

   The model has to be controlled to produce the results that go along with the reality or the planned system. Easiest way is to do a visual validation but results should also be compared statistically with the reality. Some experts of the real system should also judge the accuracy of the model.

8. Design the experiment

An experiment has to be designed and some factors have to be defined in advance. These are: length of the simulation, length of the "warm up" –period, initial conditions etc. The relations that the simulation is aimed to look for and the variables that explain the observed effect need to be defined.

9. Run the model

   After the model is approved it's time to run the model the necessary amount of times. This takes a different time depending on the structure and contents of the model.

10. Analyze the results

    Analyzing the results can be, for example, comparing results between two different systems, or studying the effects of different changes in model causes.

11. Write a report and recommend the actions

    Results are analyzed to be able to give recommendations. The most important result is often that the system is understood better than before.

After the model is functioning correctly with correct data, the results are analyzed. Different kinds of experiments are designed with the purpose of testing the model in different circumstances and be able to notice what kind of effect the changes have on the flow and capacity.

2.4 Data collection

Collecting data is the most difficult part of the project. It's not easy to validate the data and quite a lot of it comes from the assumptions and guesses. All these assumptions and guesses are validated by the experts. This makes, of course, the margin of errors smaller but doesn't take it away.

A large part of the data is based on experts' calculations and data from the suppliers. Some suppliers have calculated the cycle times for their machines or tools depending on the different materials. In some cases, a random value is added for example to form batch sizes for crane lifting or to mark defect products that has to go through an extra operation.

2.5 Critical view of the chosen method

No method is perfect; there is always a risk that the results are not completely reliable. The problems with this method are discussed below.

2.5.1 Problems with the method

The biggest problem with this method is the data collection. It is important to know what data is needed and how the data is going to be used when you are collecting it. The flow is very complicated, and it takes time to understand how everything is connected. Thus in the beginning of the project, it was difficult to know which data is relevant and important. In contrast, the aim of the study has been clear from the beginning; and for that reason, it has been clear how the data is going to be used. The data is needed to define the capacity of the flow, it is also very important when comparing different kind of options and alternatives in the flow. It is difficult to estimate the margin of errors in the used data.

2.5.2 Validity

Validity refers to the degree to which a study accurately reflects or assesses the specific concept that it is attempted to measure. Validity is concerned with the study's success at measuring what it is set out to measure, which means the absence of systematic errors (Thurén, 1991). The model has been tested in small parts in order to check if it is working like it should be. Nevertheless, there are systematic errors in cycle times and in those assumptions that has been made; and these are very difficult to eliminate totally. In some parts, the model is simpler than the reality and this might cause some systematic errors in results.

2.5.3 Reliability

Reliability is the extent to which an experiment, test, or any measuring procedure yields the same result on repeated trials. Reliability is concerned with the accuracy of the actual measuring instrument of procedure, and this means the absence of haphazard errors (Thurén, 1991). The collected data is based mostly on mean values and experts' calculations of the mean value. This makes the risk for random errors smaller but the risk for systematic errors increases.

3. Presentation of the company

The presentation of the Sandvik Group and its business areas will be in this chapter. The business area Sandvik Materials Technology will be presented more closely as well as the product area Tube. SMT's business system is a way to work at SMT and a crucial ingredient in this study and therefore a part of this chapter.

3.1 Sandvik AB – history, growth and business areas

Sandvik is a global industrial group with high-technology products and world-leading position in selected niches. With representation in over 130 countries and an office in over 80 countries, the group reaches all over the world (figure 3.1). Sandvik has over 42 000 employees and sales of over 72 000 MSEK. The head office is located in Sandviken in Sweden.

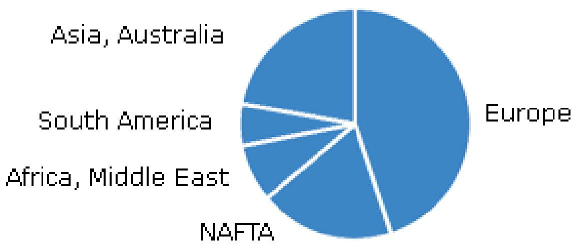

Figure 3.1 Invoicing by the market area.
(Sandvik's webpage)

The group was founded in 1862 by Göran Fredrik Göransson, who was the first in world to succeed in using the Bessemer method in steel production and this opened the doors to commercial production. Drill steel for rock-drilling was a part of product range from very early stage. Sandvik's listing on the Stockholm Stock Exchange took place in 1901. The production of stainless steel was started in 1921 and the production of hard metal in 1942. Sandvik became global very early. Already in 1860s, several agencies were established in Europe, and in 1909, first manufacturing site outside Sweden was opened. The group changed its name to Sandvik AB from Sandvikens Jernverks AB in 1972.

Since the foundation in 1862, the focus has been on high quality and added value, investments in research and development, close contact with customers, and exports. This strategy still remains unchanged. In addition to organic growth, Sandvik has expanded by acquiring several companies over the years. Some latest acquisitions include for example Tamrock (1997), the Finnish producer of rock-excavation equipment, Metso Powdermet (2006), the company within powder metallurgy, and Doncasters Medical Technologies (2007), the manufacturer of orthopaedic implants and instruments to medical industries.

Sandvik's success is a result of continuous investments in research, development and quality. Around 2.2 billion SEK is annually invested in these areas. This corresponds around 4% of the total sales. More than 2200 employees around the world work in these areas. Sandvik's goal is to actively contribute to improving the customers' productivity and profitability. The products and services offered by Sandvik shall provide maximum value to customers in terms of performance, quality, speed, safety, flexibility, and total economy. Activities shall in first hand concentrate to areas where Sandvik is, or has a possibility to be, world-leading (Sandvik's webpage).

The group's success is based on expertise in materials science. Operations are concentrated to three different business areas:

- Tooling business area focuses mainly on tools and tooling systems for metalworking applications. Major customers include companies in the automotive and aerospace industries.
- Mining and Construction specializes in rock-excavation equipment and tools used in mining and civil engineering worldwide.
- Materials Technology develops mainly products in stainless steel, special alloys and resistance heating materials as well as process systems. Customers are to be found in most industrial segments.

3.2 Sandvik Materials Technology – products areas and customer segments

Sandvik Materials Technology (SMT) is the oldest business area within Sandvik Group, the tradition and experience of producing high-duty steels started over a century ago. Therefore, the whole Group is often associated to SMT and its products. The name Sandvik Materials Technology was introduced on 1st January 2003. Before that the area was called Specialty Steels.

SMT is manufacturer of high-value added products in advanced stainless steels, special alloys, metallic and ceramic resistance materials, and process systems. Other specialties are alloys of nickel, titanium, and zirconium for advanced purposes such as tubes for nuclear power and aerospace industries. Many of the products and materials are developed in close cooperation with customers. Different customer segments and their sizes can be seen in the figure 3.2. Annual sales were 19.300 MSEK in 2006 and the number of employees is around 9000. SMT consists of six product areas: Tube, Strip, Wire, Kanthal, Process Systems, and Sandvik MedTech (Sandvik's webpage).

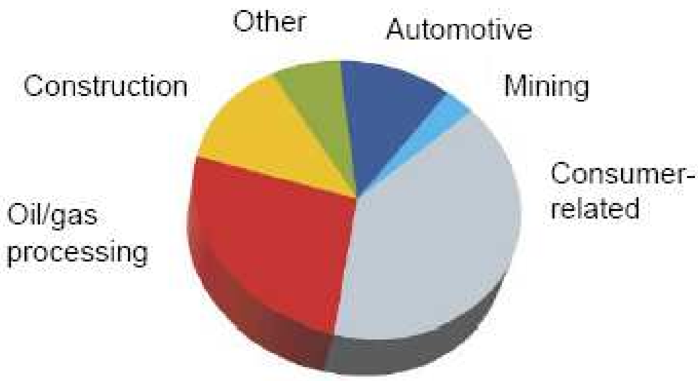

Figure 3.2: Customer segments in Sandvik Materials Technology.
(Sandvik's webpage)

3.3 Tube – market, products and customers

Tube is a product area within Sandvik Materials Technology. Tube's products include: seamless tube and pipe, welded tube and pipe, fittings and flanges, steels for machining, and sheet and plate. Customer segments are: chemical and petrochemical, oil and gas, power generation, aerospace, energy, and medical. The global stainless seamless tube market is concentrated to four main players, of which Sandvik is the biggest supplier with 18 % of market share. The whole process, from the melting steels to finished products, is done by Sandvik (SMT's internal webpage).

3.4 SMT Business System

A few years ago, SMT started a program with the aim of creating a common way of working in all parts of SMT around the world. The program is called SMT Business System. SMT Business System is based on lean production and Toyotas model called Toyota Production System. SMT has divided the system into five special areas to concentrate: manufacturing, marketing, purchasing, research & development, and competence development. The purpose of the model is to give the right tools and methods and basic conditions to succeed in developing a world class manufacturing.

The manufacturing part of the system is illustrated with the house (figure 3.3). The foundation of the house is all the principles. The walls are the structures and working methods, which cover the whole flow from raw material to final product. The roof is the goals and targets to achieve. Throughout the house there is a culture of continuous improvement and focus on creating value to customers.

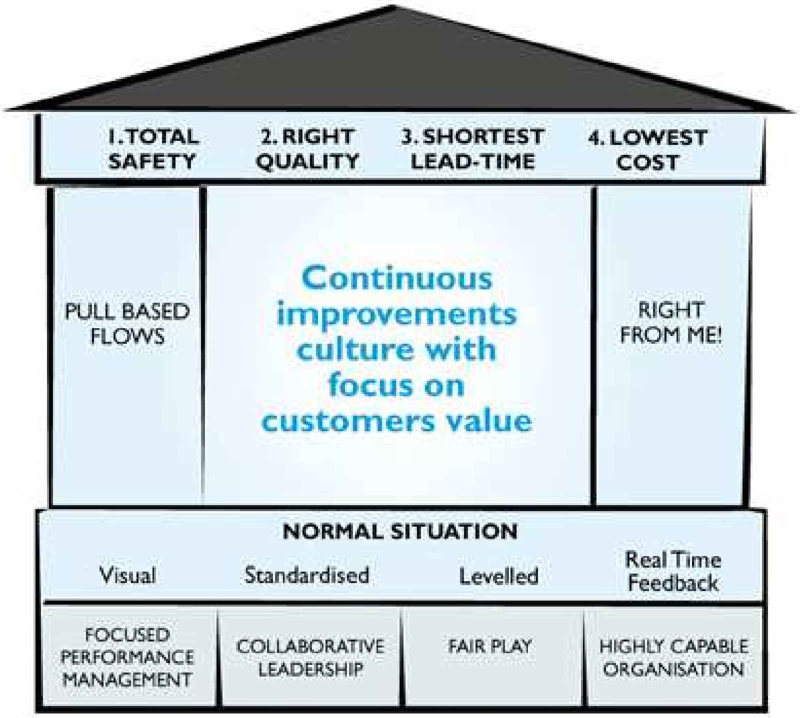

Figure 3.3: SMT Manufacturing System is illustrated by a house. (SMT's internal webpage)

SMT Business System uses the common lean tools and principles like continuous improvement, elimination of waste, heijunka, poke yoke, pull etc. The goal is to reduce lead times and costs, improve the quality and effectivity, and achieve the total safety. Creating value to the customer should always be in focus (SMT's internal webpage).

4. Literature review

This chapter presents the literature studied for the master thesis. The literature contains the method for doing VSM and the guidelines to succeed with it. Some lean principles and tools have been studied to be able to make connections to SMT Business System. Literature about simulation and modeling is also an important part of this study and is presented at the end of this chapter.

4.1 Value Stream Mapping

Value stream means all the actions and operations currently needed to bring a product through the production flow from raw material to the customer. It can also mean the process to design a new product, from concept to launch. Value stream is both value added and non-value added actions. The method is presented in a book called Learning to See (Rother, Shook 2003).

Value stream mapping (VSM) is a tool for working on the big picture, improving the whole flow and not just optimizing individual processes. It is a simple tool that helps to see and understand the flow of material and information. The aim of the value stream mapping is simply to follow a product's way from customer to supplier, and draw a visual representation of every process in the material and information flow. Then with the help of this current-state map and a set of key questions, draw a future-state map of how the flow should look like.

VSM brings together lean concepts and techniques and makes it easier to use them. It concentrates the whole flow and forms the common basis of an implementation plan. VSM has three steps. The first on is to draw a current-state map, which is done by gathering the information on the shop floor. The second step is to draw a future-state map. These steps overlap each other because ideas for the future state arise when current-state map is made. The final step is to prepare and begin actively working with implementation. When the future state is achieved is time to draw a new future-state map.

In this study the concentration is on the current-state map. Current-state map will serve as a clarification between the real layout and the simulation model.

4.1.1 Current-state map – how to do it!

Mapping begins at the level of the door-to-door flow in a plant. Processes are drawn in categories like "assembly", instead of drawing each processing step. Guideline is to draw an assembly process with several connected workstations as one process box, even if there is some WIP (work in process) inventory between stations. But if there is accumulating, stagnating inventory between the stations or if products are moved in batches between the stations, then two process boxes should be used. Batching processes and inventories are important, because items often spend considerable amount of time in these activities. After the material flow, the information flow is added to map. If it looks messy on the paper after this, that's probably indicating, that it is messy in the reality as well.

4.1.2 Lean value stream

A value stream is lean if one process is making only what the next process needs exactly when it needs it. The lean value stream is linking all processes, from the final consumer back to raw material, in a smooth flow without detours that generates the shortest lead time, highest quality, and lowest cost. Below is presented some guidelines to leaner production (Rother, Shook 2003).

Guideline #1: Produce to your tact time.

"Tact time" synchronizes pace of production to match pace of sales. Definition is available working time per day divided by customer demand rate per day. Producing to tact requires fast response to problems, eliminating causes of unplanned downtime, and eliminating changeover time in downstream.

Guideline #2: Develop continuous flow wherever possible.

Continuous flow means producing one piece at a time, passing the item directly from one process to the next without inventory in between. Continuous flow requires process reliability and elimination of changeover times, which is not that easy. Sometimes it can be easier to begin with combination of continuous flow and FIFO ("first in, first out") –inventory.

Guideline #3: Use supermarkets to control production where continuous flow does not extend upstream.

In some part of the value stream, continuous flow is not possible and batching is necessary. Instead of using scheduling, a supermarket-based pull system can be used. The purpose of placing a pull system between two processes is to have a means of giving accurate production instruction to the upstream process, without trying to predict downstream demand and scheduling the upstream process.

Supermarket pull system

Supermarket is an inventory which contains a certain amount of every item. When downstream process needs an item, it takes it from the supermarket and production-kanban (signal) is sent to upstream process to replace that item and fill up the supermarket (figure 4.1).

Since the number of kanban on the factory floor determines the amount of inventory being held as buffers, it is important that they be properly sized. If the number of kanban is too low, there will not be enough inventories to supply the needs of downstream processes. If the number of kanban is too high, the factory is holding more inventory than it needs; even more importantly, products will flow through the factory more slowly than they otherwise could, leading to higher lead times.

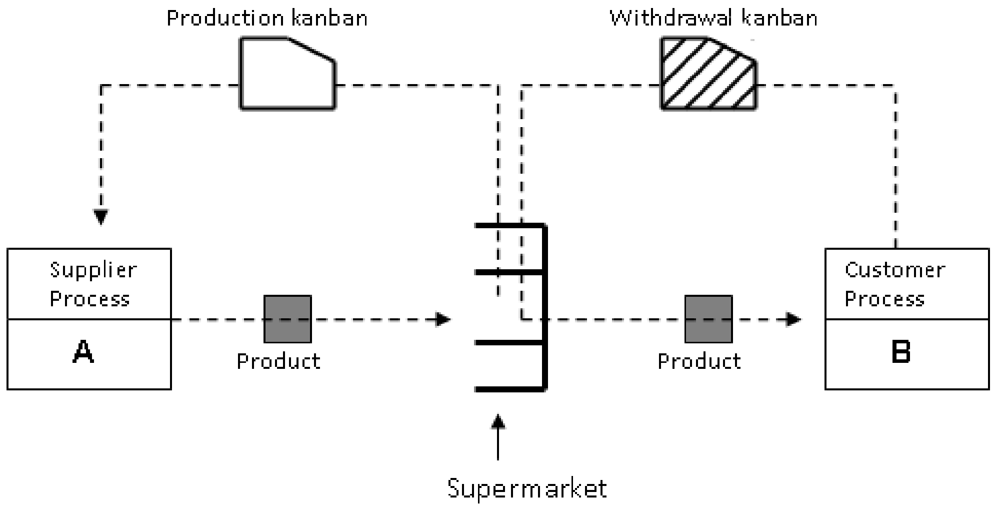

Figure 4.1: Supermarket

Guideline #4: Try to send the customer schedule to only one production process.

By using supermarket pull systems, only one scheduling point is needed in the whole value stream. This point is called the pacemaker process, because it sets the pace for all the upstream processes. Material transfers from the pacemaker process downstream to finished goods occur as a continuous flow. The pacemaker is the production process that should be controlled by the outside customer's orders.

Guideline #5: Distribute the production of different products evenly over time at the pacemaker process.

Producing long runs of one product type and avoiding changeovers, results larger finished goods inventory and/or more lead time to fulfill an order. The more you level the product mix at the pacemaker process, the more able you will be to respond to different customer requirements with a short lead time while holding little finished goods inventory.

Guideline #6: Create an "initial pull" by releasing and withdrawing small, consistent increments of work at the pacemaker process.

Releasing large batches of work orders at the same time causes many problems, for example, the sense of tact time disappears, and the current situation becomes difficult to monitor. Establishing a consistent or leveled production pace creates a predictable production flow, which by its nature warns of problems and enables to take quick corrective actions.

Paced withdrawal

Paced withdrawal is the practice to release only a small amount of production instruction at the time and simultaneously take away en equal amount of finished goods. A pitch is the consistent increment of work, and is based on pack out container quantity, which means the number of parts one finished-goods container holds. Pitch is often calculated by multiplying the tact time upward to a finished-goods transfer quantity at the pacemaker process. This then becomes the basic unit of the production schedule. By scheduling and checking production every pitch, problems can be responded rapidly and tact time is maintained (figure 4.2).

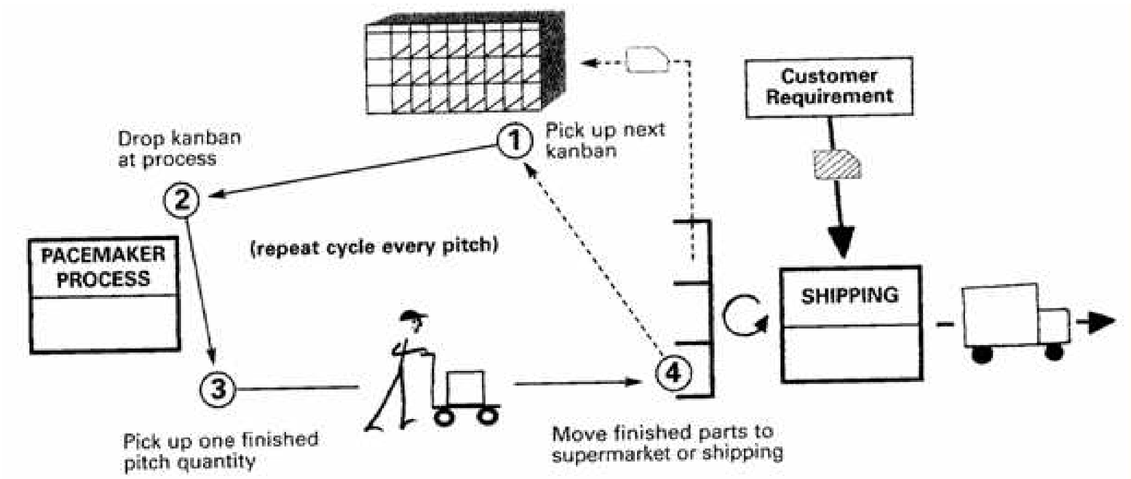

Figure 4.2: Example of paced withdrawal (Rother & Shook, 2003).

Guideline #7: Develop the ability to make "every part every day" in fabrication processes upstream of the pacemaker process.

By shortening changeover times and running smaller batches in the upstream processes, those processes will be able to respond to changing downstream needs more quickly. Leading that, less items in inventory is required. One method for determining initial batch sizes at production processes is to base them on how much time have been left in the day to make changeovers.

4.2 Simulation

Globalization has put great pressure on manufacturers to develop and install manufacturing systems that can deliver high volumes of high-quality goods at low cost to meet customers' needs. This has led to huge investments in manufacturing plants and associated control systems. It is important to ensure that such systems operate as intended, and therefore computer simulation methods have found an important role in the designing and implementing processes. Simulation allows the comparison of alternative designs and control policies on the model before starting to build a physical plant or a production line. It helps to reduce the cost and risk of large-scale errors. Simulation approaches are also used on existing plant to find better ways to operate (Pidd 2004).

A simulation model is a logical description of how a system works in a reality. Simulation is used most often in the planning and design of new or existing manufacturing facilities. The typical cost of a simulation study is substantially less than 1% of the total amount being expended for the implementation of a design or investment. If a manufacturer saves just one piece of equipment, or eliminates a potential bottleneck, the simulation will have paid for itself (Banks 1998). Simulation provides a method for checking the understanding of the world around. A simulation program is an important tool that can be used to: (Extend 2002)

- Predict the course and results of certain actions
- Understand why observed events occur
- Identify problem areas before implementation
- Explore the effects of modifications
- Confirm that all variables are known
- Evaluate ideas and identify inefficiencies
- Gain insight and stimulate creative thinking
- Communicate the integrity and feasibility of the plans.

4.2.1 Advantages with simulation: (Banks 1998, Pidd 2004, Carson 2005)

COST. Experiments in real world may turn out to be really expensive if something goes wrong, and this can be partly avoided by simulation. Simulation allows testing of every aspect of a proposed change, design or investment without committing resources to acquisition.

TIME. Building a model is time-consuming, but once the model is build it can be used years with only minor changes. Sometimes the time scale of the dynamics of the system is not compatible with that of the experimenter (for example: changes in universe). By compressing or expanding time, simulation allows you to speed up or slow down phenomena so that you can investigate them throughout.

REPLICATION. Precise replications of an experiment are often impossible in the real world. Simulations are precisely repeatable.

SAFETY. One of the objectives of a simulation study may be to estimate the effect of extreme conditions, and to do this in real life may be dangerous or even illegal.

LEGALITY. Even when not employed by the mafia there are times when an analyst may wish to investigate the effect of changes in legislation. For example, a company may wish to see what effect would be on its delivery performance of changes in the laws that control drivers' hours of work.

MANIPULATION. Models are easy to manipulate. Parameters can be easily changed to test different assumptions and real-world disturbances can be easily suppressed.

EXPLORE POSSIBILITIES. New operating systems, decision rules, information rules, and so on can be explored without disrupting ongoing operations of the real system.

DIAGNOSE PROBLEMS. The modern factory floor is often very complex, so complex that it is impossible to consider all the interactions taking place in a given moment. Simulation allows understanding better the interactions among the variables that make up such complex systems.

4.2.2 Disadvantages with simulation: (Banks et al. 2000, Pidd 2004, Carson 2005)

TIME-CONSUMING and EXPENSIVE. Simulation can be time consuming to build and therefore expensive in terms of skilled manpower.

ACCURACY. It can be easy to forget the accuracy of the models. Assumptions can be simplified, which should be remembered when analyzing results.

INPUT DATA. It can be very difficult or almost impossible to get a valid input data.

SCECIAL SKILLS. Model building requires special skills, and it takes time to learn to use programs which are often complicated.

Input data can provide a good measure of a model's veracity. Inputting vague data will produce vague results. It can easily be understood how important input parameters are to a model. For instance, without knowing how long an average customer spends per transaction, an ATM simulation for the bank manager will have limited usefulness and very little credibility. A simulation can still be written and run and have its results reported, but these results will be flawed. To insure that this does not happen, it is essential that the input data be realistic, accurate, and relevant (McHaney 1991). The data validation is very important

For most manufacturing systems, one of the reasons to model is the presence of random events. Random events in manufacturing systems are associated with processing time, setup time, downtime, transportation time and yield percentages. For all random events it is important to represent the distribution of randomness accurately in the simulation model (Banks 1998).

5. Mapping the current state

In this chapter, the current state map is presented. All the processes and operation steps needed in the flow are explained. The flow chart and the current state map are studied in order to create a picture of the flow and layout in production.

5.1 Hot flow – process steps and operations

There are two main groups of seamless tubes: hot-finished and cold-finished. Hot-finished tubes are mainly produced by extrusion or hot-rolling. Sandvik uses only extrusion. Cold-finished tubes are produced by pilgering (rolling) or drawing. These both methods are used by Sandvik.

The extrusion bars go through three steps before they are delivered in form of finished tubes. These steps are billet preparation, extrusion, and finishing.

5.1.1 Billet Preparation

Material is in the beginning of the process a bar in diameter from 121 to 468 mm, depending on the required size of the finished tube. The bar steel is normally delivered forged or rolled to the extrusion plant. However, extrusion bar mainly in the most high-alloyed grades is peel-turned before delivery to the extrusion plant. In our case, most of the bars are delivered peel-turned. Nonetheless, black bars are not peel-turned.

Billet preparation includes several operations, but first, the material consumption is optimized in order to utilize the material in the most economical way. All material, which is turned, bored or cut away during the process, is returned to the melting shop to reuse.

First operation in the billet preparation is cutting the bars into billet lengths (figure 5.1). After that the billets go to deep-boring of the center hole. Deep boring means drilling with special equipment for long holes. Next operation is turning of the radius at end, and on the larger sizes, tapering of the hole in order to make expansion possible. Last operation is degreasing. Degreasing is very important, because any remaining oil from the machining will cause carburization[1] during the subsequent heating, which could result in reduced general or intergranular corrosion resistance of the final product (A document from the SMT's internal webpage).

[1] Carburization means when carbon is diffused into the surface of the metal. Too big concentration of carbon makes metal brittle and unworkable (Callister, 2007).

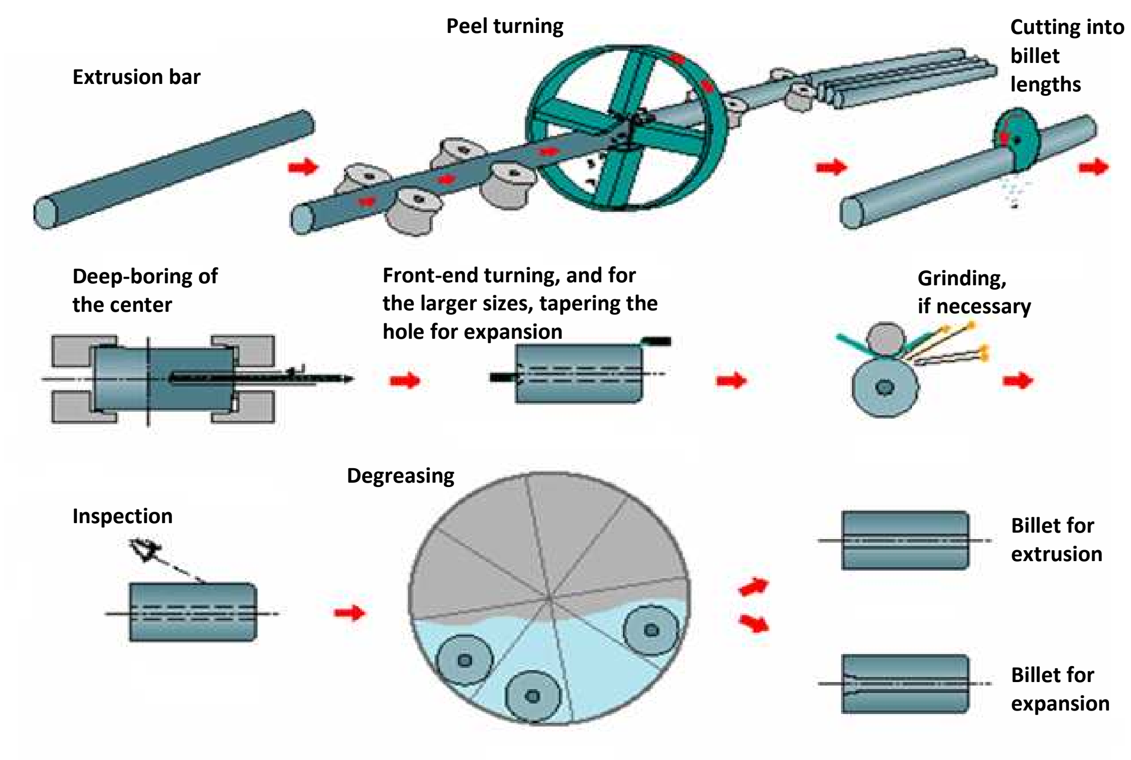

Figure 5.1: Principle for billet preparation.

5.1.2 Extrusion

Extrusion consists of four operations: heating, expanding, extrusion and cooling. The billets are first heated to about 1,200°C. Temperature depends on the material, for example, titanium and zirconium is heated to about 700°C. After heating, the billets are lubricated internally and externally with glass powder, which has the right viscosity for withstanding the demanding conditions during the extrusion process. Lubrication is done externally by rolling the billet in glass powder and internally by applying the glass with a "spoon". Thereafter, the smaller billets go directly to extrusion, whereas larger billets are first expanded.

Larger billets are normally expanded in a 1,200-tonne vertical press. Thus, only a small hole is needed to drill, because the hole is then expanded to the required diameter. This operation reduces yield losses. After expansion, the billets are reheated and glass-lubricated again before extrusion.

There are different extrusion presses with different press force respectively. These presses have a number of different containers. The press and the container are selected to match the size of the finished tube. The steel grade must also be taken into account, because some materials are more resistant to deformation than others and therefore need more press force.

The principle of the extrusion process is shown in figure 5.2 below. A mandrel is inserted into the hole of the billet and then the billet is pushed into the container. When extrusion begins, the billet is pressed out between the hole of the die and the mandrel. Die decides the outer diameter and the mandrel decides the inner diameter. Some material always remains in the container and this has to be cut off.

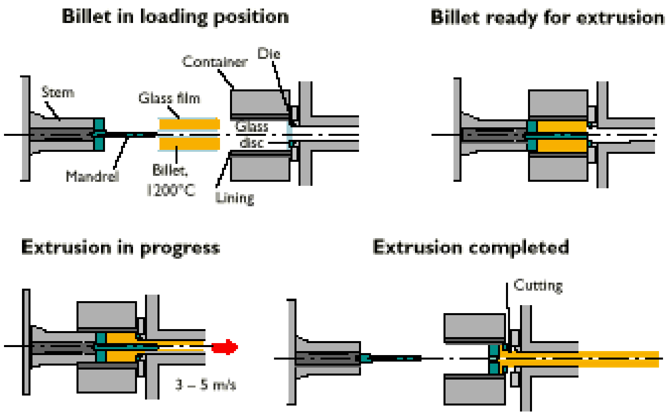

Figure 5.2: Principle for extrusion.

In direct connection with the extrusion is a control station. Tubes are controlled to fulfill the tolerances required. If the measuring result deviates from the close tolerance limits, actions have to be taken immediately, e.g. replacement of the extrusion tools, adjustment of the billet temperature of straightening of the press. At last, the extruded tubes go to cooling in air or water, depending on the size and grade (A document from SMT's internal webpage).

5.1.3 Finishing

A lot of finishing operations are necessary before tubes can be supplied to customers or to be sent to cold working. First operation after extrusion is normally straightening. In this operation the layer of glass and metal oxides on the tube surfaces will crack. Straightening is most often performed with machine with rolls.

The last remains of layer of glass and metal oxides are removed in pickling. Pickling can either be performed in completely enclosed white-pickling units or by dipping the tubes in different baths of acid and water. Thereafter, the tubes are flushed with water to prevent any pickling acid to be left in tubes, because otherwise, there would be a risk of corrosion. In the end, the tubes are rinsed with warm water to prevent water stains. White pickling leaves the tubes with a dull, silver-white surface.

One of the last operations is cutting and deburring. The cutting operation involves end trimming (so that the tube ends conform to the requirements in standards), sampling for testing, division of long tubes into shorter lengths, and, if specified, cutting the tubes to fixed lengths. The ends are deburred, which means that the edges become smooth so that they will not cause injuries to persons or damage to the tubes.

Significant part of the tubes goes to cold pilgering or cold drawing. But depending where the tubes will go, the operations are little bit different. At last, the tubes will be inspected according the standards and specifications required, and transported to the next operation, central stock, or directly to the customer (A document from SMT's internal webpage).

5.2 Layout in the GP

The hot flow at Sandvik is divided in to two separate flows; one, which produces smaller tubes with diameters between 121 mm and 185 mm, and another, which produces larger tubes with diameters larger than 185 mm. Both flows go through mainly the same processes as described earlier, and in some operations steps they might share the same machine, tool or process place. Figure 5.3 shows the drastically simplified flow chart of the layout. The idea with this flow chart is to give an overview of the layout and create a map which can easily show the results of the simulations. Because of the small size of the figure, it is also shown in Appendix 1. All the symbols are described in Appendix 3.

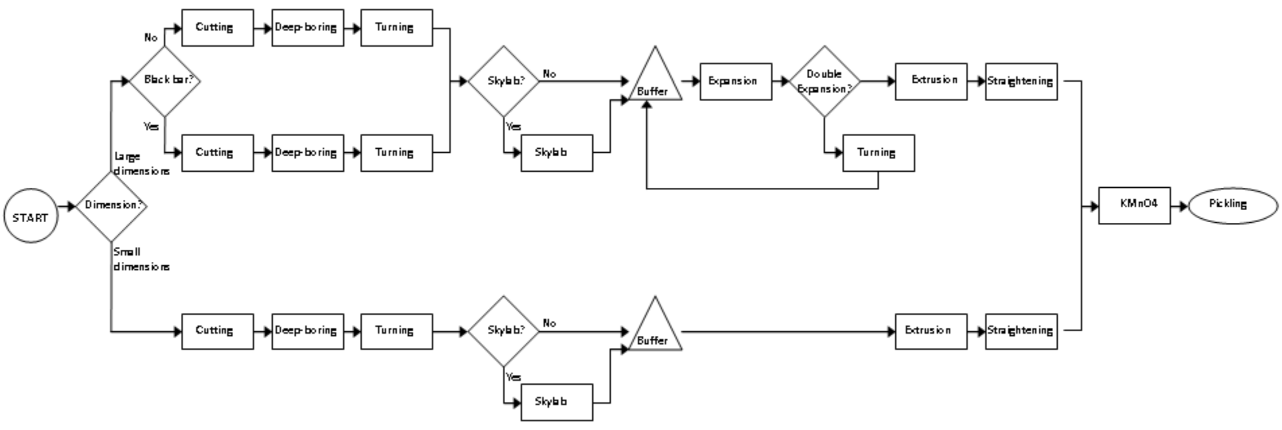

Figure: 5.3: Flow chart of the whole layout.

The flow chart (figure 5.3) shows the both flows. Billet preparation in the large flow is divided into two according to the bar dimension. All the billets go through the first three operations: cutting, deep-boring and turning. After that, around 25 %[2] will go to grinding (Skylab) and the rest of the billets go straight to the inventory. The billets in the large flow are expanded and depending of the dimension the might be turned and then expanded for the second time before the extrusion. The billets in the small flow go directly to the

[2] This number is changed when running the model in order to test if it has any effects on the rest of the flow.

extrusion. After extrusion the billets are going through some finishing operations like straightening and pickling.

This same flow chart is used when presenting results from the simulation, but because of the small utilization grade of the grinding (Skylab), it is left out from the flow chart.

5.3 Value Stream Mapping

A simple VSM was made in order to create a better picture of the flow in GP07. The focus of the VSM was to concentrate in material flow and therefore the sketch of the information flow is quite rough. The picture of the current state map is in Appendix 2. Both flows are drawn in a same picture to show how the material flows differ from each other. The information flow is basically same for the both flows. In the map, the information flow is shown only for the small flow in order to keep the map simpler. Time line can be seen only for the buffers.

Some of the processes and small buffers are summed up into one process box, according to instructions in *Learning to See* (Rother, Shook, 2003).

6 Extend models

In this chapter, the simulation program Extend is introduced as well as the simulation model. The simulation model was tested with three different product mixes in order to study and observe different problems. The problems in the problem statement are laid up and the models made to solve these problems are introduced. Data collection and the some of the assumptions made in modeling are also described.

6.1 Simulation model in Extend

The program used in this simulation is Extend. Extend was chosen, because Sandvik Materials Technology already had a license for the program, and because the supervisor at Royal Institute of Technology has a deep knowledge of the program. Therefore, other simulation programs were not considered for this degree project.

Extend models look like a block diagrams. Each block has an icon and consists of a code, parameters, user interface, and online help. Each block is a diagram of the process and describes one part of the process. Extend includes a large set of basic blocks, which are in libraries of blocks for general and specific application areas, such as manufacturing. Models are built by placing and connecting blocks and filling in the parameters on the dialog window associated with a block. Collections of blocks can be grouped into a hierarchical block representing a sub model such as a particular machine or a subassembly line (Extend 2002, Banks et al. 2000).

The simulation model that was build about the flow is shown in the appendix 5. There is also a description of how the model is build. That model is used in solving all the problems presented below.

6.2 Problems studied

Three different versions of the data sheet are used in order to able to run the model with different data. The simulation model is same in all these versions but the spreadsheet which includes the data varies. The first model is run with 25 % of duplex, the second with 50 % duplex and the last with 70 % duplex. Running conditions are same in all the models; they are run during the same time period, 30 days. Time for reparation and maintenance is counted to be 6 hours per day, and this gives 18 hours available each day. Therefore, the availability is 75 % in every model.

Problem 1 – Studying the bottle necks of the flow

The utilization for all the operations are shown in the model so that the bottlenecks easily can be located. When all the three product mixes are tested, it can be seen if the bottlenecks shift with different product mixes. Once bottlenecks are identified, the next step is to find out if they can be avoided. Some changes are made in the simulation models in order to test if the bottlenecks can be moved or totally avoided.

Problem 2 – Studying the inventories before extrusion

The same three variants of the model are used here. The focus is on the inventories before extrusion presses and if the different product mix has an effect on these inventories. Running sequences for extrusion presses are also important factor when studying the inventory levels. Different sequences are tried in order to see what effects they have.

Problem 3 – Studying the product mix

The same three product mixes are used even here as a starting point: 25 %, 50 % and 70% duplex of the material. But some changes are made in these simulation models in order to level out the production and make it flow smoother through the processes. In finishing part of the production, all the materials go through the pickling process but only duplex material needs the $KMnO_4$ –process. When 25 % or 50 % of the material is duplex, some capacity from the $KMnO_4$ -process is moved to the pickling process, and hopefully the capacity is slightly increased.

6.3 Data collection and assumptions

Data collection is an essential part in making a successful simulation. Some assumptions made concerns the material. When models are run they get the information from the Excel – spreadsheet that contains all the information regarding orders and material. There are many different sorts of material used at Sandvik, but in these simulations all the different material sorts are divided into two different groups: austenitic and duplex. This means that for one dimension there are just two possible cycle times depending if the material is austenitic or duplex.

Another major assumption regards the extruded tube lengths and weights. For each dimension there are three variations used. These variations have an effect only on the cycle time for straightening. So the weight has not been taken into consideration. This means that weight for a tube with a certain dimension is always the same regardless of the material or length.

All these assumptions and simplifications mean of course that variations are smaller. The result of the simulations is more of an average result and doesn't test any best/worst case scenarios.

7. Results from simulations

Results from running the models are documented in this chapter. The results for all the problems mentioned in chapter 6 are presented here.

Problem 1 – studying bottlenecks of the flow

The first problem studied is about the bottlenecks of the flow. Three different product mixes were run in a model in order to see if the amount of duplex material has an effect on the bottlenecks. The basic simulation model is same in all cases but the sequence of the extrusion might have small changes in the large flow. These changes are done in order to keep the inventory levels acceptable. This problem is handled in the next section.

Below, the results of the three run are shown. The percentages mean how much of the time material is available to the machine, when producing the quantity mentioned in a picture. A red number means that the process is a bottleneck and a yellow number means that the process is likely to be a bottleneck.

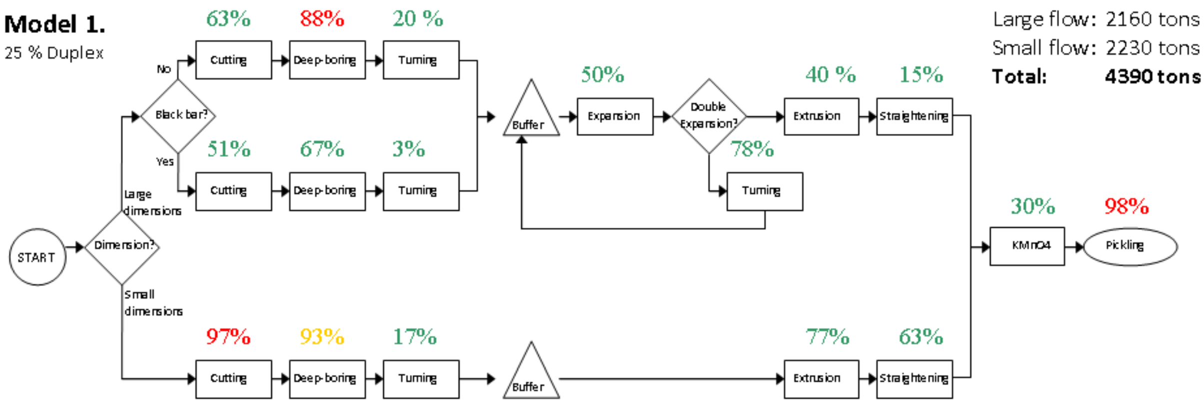

Figure 7.1: Model 1, 25 % Duplex

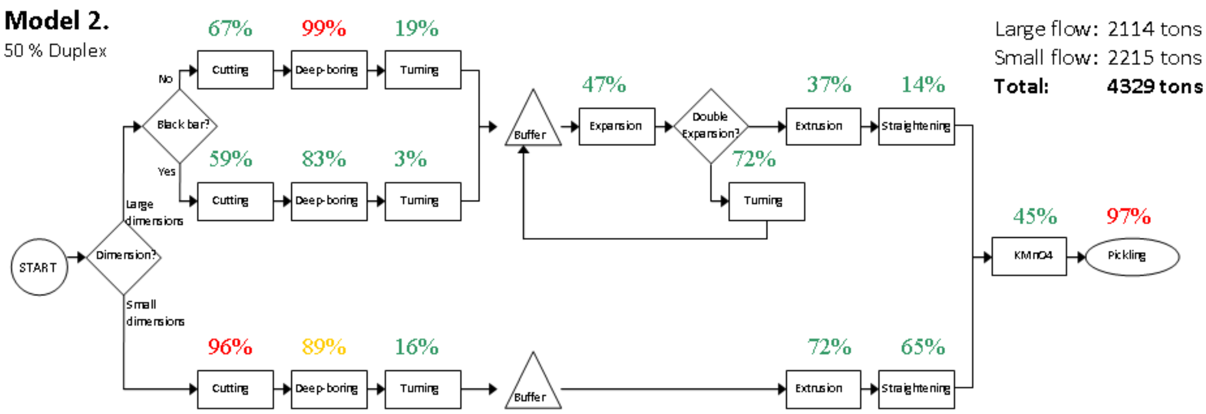

Figure 7.2: Model 2 – 50 % Duplex

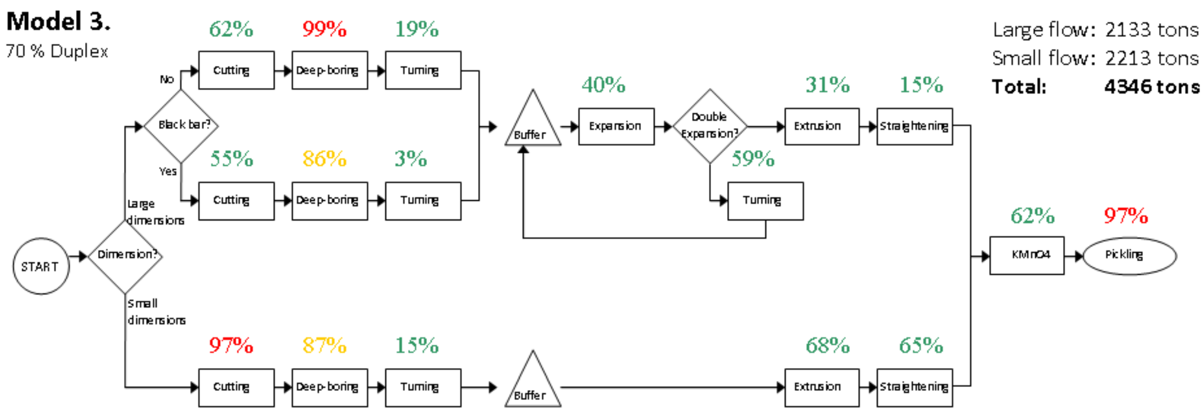

Figure 7.3: Model 3 – 70 % Duplex

The first model was run with the product data where 25 % of the material is duplex. The model was run in 18 hours per day during 30 days. The output from the large flow was 2540 tons and from the small flow 2566 tons. The total capacity of the whole production system was 4390 tons.

The second model was run under same conditions. The only difference was that 50 % of the material was duplex. The total capacity of the production flow was 4329 tons, which 2114 tons comes from the large flow and 2215 tons comes from the small flow. In the third model, 70 % of the material is duplex. The total capacity of this model was 4346 tons. The large flow had capacity of 2133 tons and the small flow produced 2213 tons.

	25 % Duplex	50 % Duplex	70 % Duplex
Small flow	2230 tons	2215 tons	2213 tons
Large flow	2160 tons	2114 tons	2133 tons
Output total	**4390 tons**	**4329tons**	**4346 tons**

From the figures can be seen that cutting in the small flow and the pickling are clear bottlenecks with all the product mixes. If the percentage of the duplex material is increased, the deep-boring in the large flow is also a clear bottleneck.

Problem 2 – studying the inventory levels before the extrusion

In the large flow, there are two cells that produce billets with dimensions between 235 mm and 310 mm, and one cell that produces the larger dimensions (385-430 mm). As a result of this, there are different dimensions coming to the buffer. In the buffer, the orders are batched and then send to the extrusion according to a specified sequence. This sequence is very important when studying the inventory levels.

In the figures below (figure 7.5 and 7.6), there are presented two diagrams about the same flow. The only thing that differs is the extrusion sequence. In the first diagram, it clearly shows that inventory level (blue line) shoots up to the level that blocks the whole inventory. It is very difficult to make any limitations to the inventory level in the large flow, because that easily blocks the whole flow. The inventory level is limited to 380 billets but this level is overrated in all the models and with all the tested sequences. In all the models, there is the basic sequence which is used, and if the inventory levels became too high the smaller changes were made to that sequence in order to get the billets flow better through the inventory. That basic sequence can be found in the appendix 5.

The problem with the inventory levels in the large flow occurs mostly because of the long sequences of the certain dimension. For example, the dimension of 430 mm is extruded in a sequence of 120 billets. All these billets come from one cell in the billet preparation and because of that large dimension, the processing times in are quite long. At the same time when this cell is producing these 120 billets, there are two other cells that produce billets for the next sequence. These new billets have smaller dimension, which means that these two cells have time to produce over twice as much as the cell producing for the current sequence. The inventory level, therefore, gets higher and is more unpredictable.

Inventory levels are not a big problem in the small flow because all the cells can produce all the dimensions and that's why the flow is more even and predictable (red line in the diagrams 7.5 and 7.6). The inventory level is limited to around 600 billets and the actual level stays under that in all the models and with all the tested sequences.

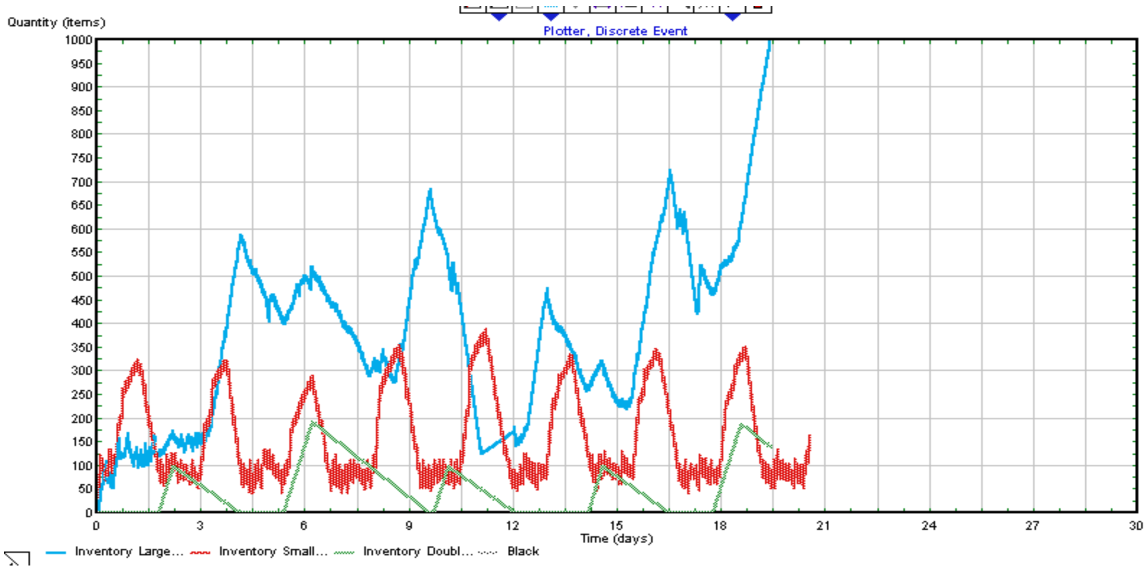

Figure 7.5: Model 1, 20% of the material is duplex and the sequence used is the basic sequence which can be seen in the appendix 5.

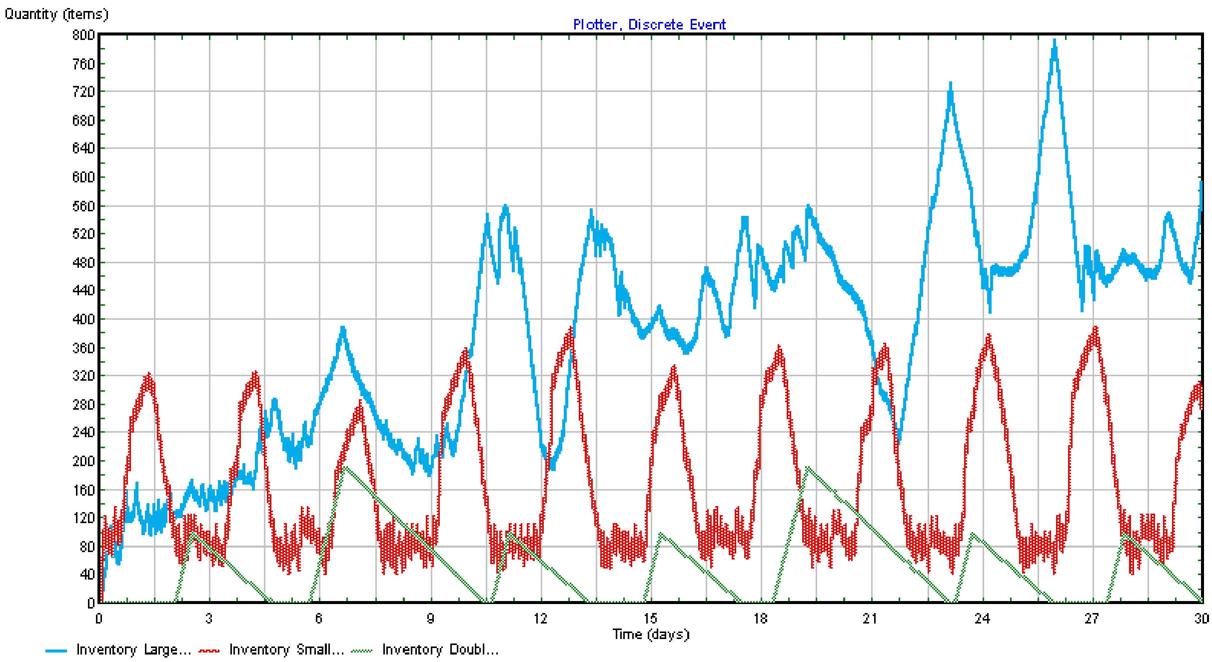

Figure 7.6: Model 1, 20% of the material is duplex and sequence used is a modified version of the basic sequence.

Problem 3 – studying the product mix and capacity

From the earlier results, it can be seen that pickling is a bottleneck. Models are changed so that one of the KMnO4 tanks is taken away and one extra tank for pickling is added. When pickling is not a bottleneck, the output from the flow is a lot bigger. The output is a lot bigger in model 1, where only 25 % of the material is duplex.

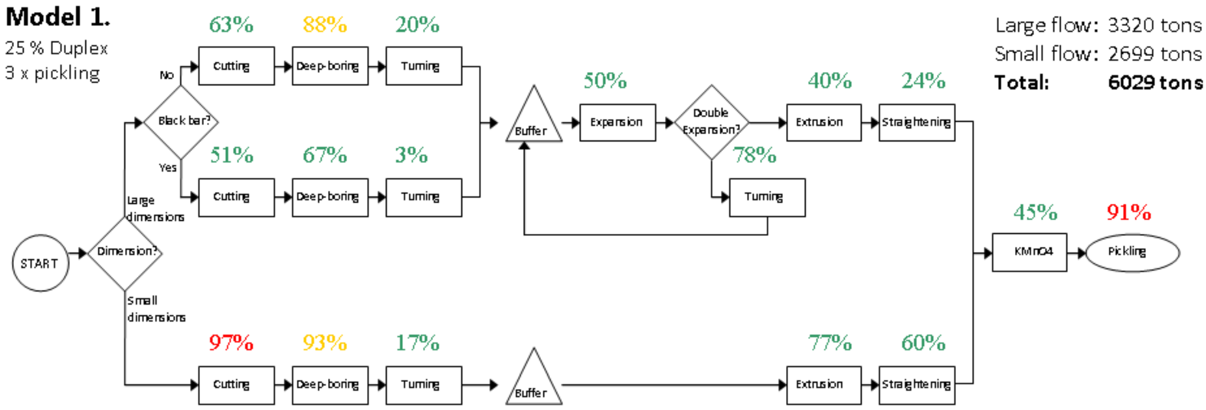

Figure 7.7: Model 1 with 3 pickling instead of two

In the figure 7.8, there are four tanks for pickling and only two for KMnO4. This doesn't have a big effect on the output tons. The output is almost as much as in the model with three pickling tanks (figure 7.7).

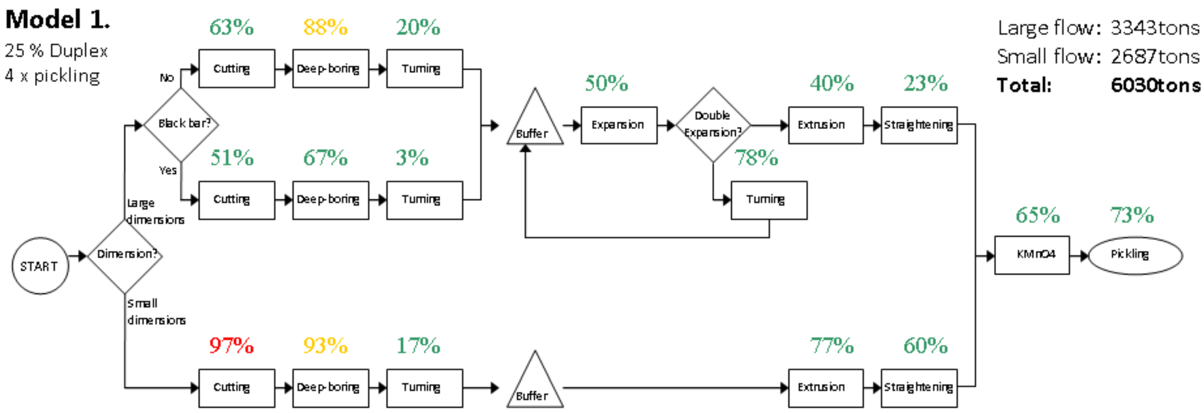

Figure 7.8: Model 1 with 4 pickling instead of two

Pickling was the bottleneck even in the model 2 with 50 % duplex. In the figure 7.9, there are results of the model 2, when one of the KMnO4 tanks was moved to pickling. Output is bigger even here when pickling is not blocking the flow anymore.

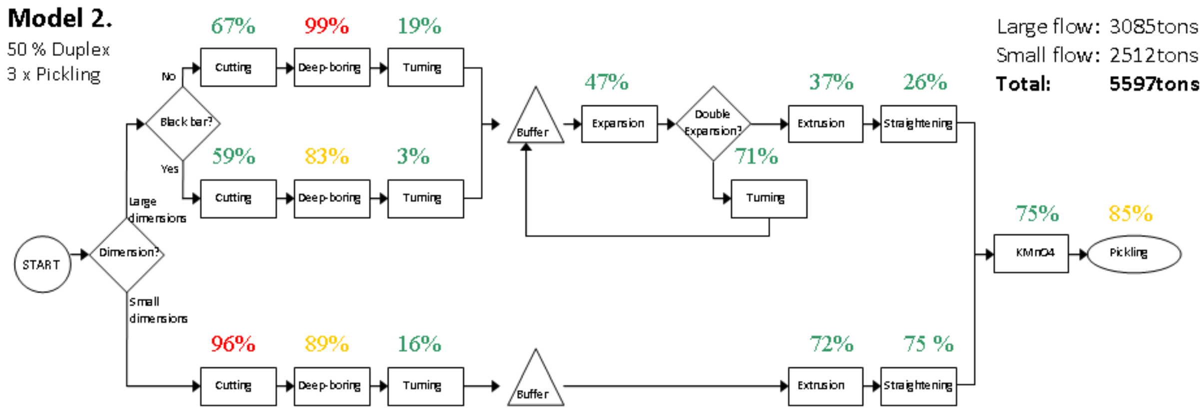

Figure 7.9: Model 2 with 3 pickling tanks instead of 2.

8. Conclusion and Discussion

The discussed problem statement for this study was to verify the capacity, study the bottlenecks and effects from different product mix. These simulations can verify that the counted capacity is right and that the output from the production is confirmed to be the counted capacity under the given circumstances.

However, the capacity is limited by the bottlenecks. Bottlenecks, which can be seen in the simulations, are cutting and deep-boring in the small flow, deep-boring in the large flow with some product mixes, and pickling. Bottleneck in the beginning of the flow, like cutting and deep-boring in the small flow, determines the beat for the rest of the flow, and therefore, limits the whole capacity.

Pickling is the other bottleneck in the flow for all the tested product mixes. Because it is the last operation in the simulation model it has also a big influence on the output. It blocks the whole flow backwards, if the buffer before the operation is limited. This causes the inventory level in the buffer before extrusion to rise, because the extrusion process is blocked. To avoid this bottleneck, the extra capacity from $KMnO_4$ was moved to pickling. From the result of these simulations, it can be seen that the output is a lot larger and the production flows smoother. The capacity is improved from 4390 tons to 6030 tons.

The effects from the different product mixes can be seen the mostly on the large flow. When the percentage of the duplex material is increased, the operation time on the billet preparation gets longer and deep-boring turns into the bottleneck. When the amount of the duplex material is high, there are smaller possibilities to move capacity from the $KMnO_4$-process to pickling and that's why even the pickling limits the capacity.

The bottlenecks in the billet preparation are harder to avoid, if no extra capacity is added. This option is not tested in this study. In the small flow, the inventory level in the buffer before the extrusion is acceptable. It has a limit of 600 billets, but in all the simulations the actual level is under that limit. Actually, it never goes over 400 billets. Thus, if the production functions without breakdowns in billet preparation, the inventory level in the small flow is good. Nevertheless, in these simulations, it is not tested how long the buffer holds if something unacceptable happens and one of the lines in the billet preparation stops.

In the large flow, this same buffer is much more complicated. The inventory level depends on the extrusion sequence. This sequence is much longer for the large flow because there are more different dimensions. It is complicated also because all the cells in the billet preparation don't produce all the dimensions. If the order sequence is poor, the buffer might exceed its limit and block the whole line. The limit of this buffer was set to 380 billets, but this level is topped in all the simulation runs with all the product mixes.

All the same, the simulation model doesn't function like the real production line, when regarding these buffers. In these models, the orders are batched in the buffer before they are send to extrusion. In the real world, the first billets from the order might be already on their way to extrusion while the last billets of the same order are still processed in the billet preparation. It is also easier for the operator to stop one line or make priorities between lines in order to create more space in the buffer.

The inventory levels in the other parts of the production are quite small and limited, which is in line both with lean principles and SMT Business System. Problem occurs, if pickling is the bottleneck. The buffer in front of the process grows, if there are no limits set. On the other hand, if there are limitations for this buffer, it will block the upstream processes. This statement supports that it is very important to avoid pickling to become a bottleneck.

Simulation doesn't give any complete answers to the difficult problems. And the output from the simulation is never better than the data input to the model. Assumptions and simplifications used in these simulations make the result to diverge from the reality. There is not as much deviation in the variables like for example processing times and material orders as in the reality. The model and the results are used for quality assurance, and therefore only give an estimation of the real situations.

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10. Appendices

Appendix 1: The flow chart

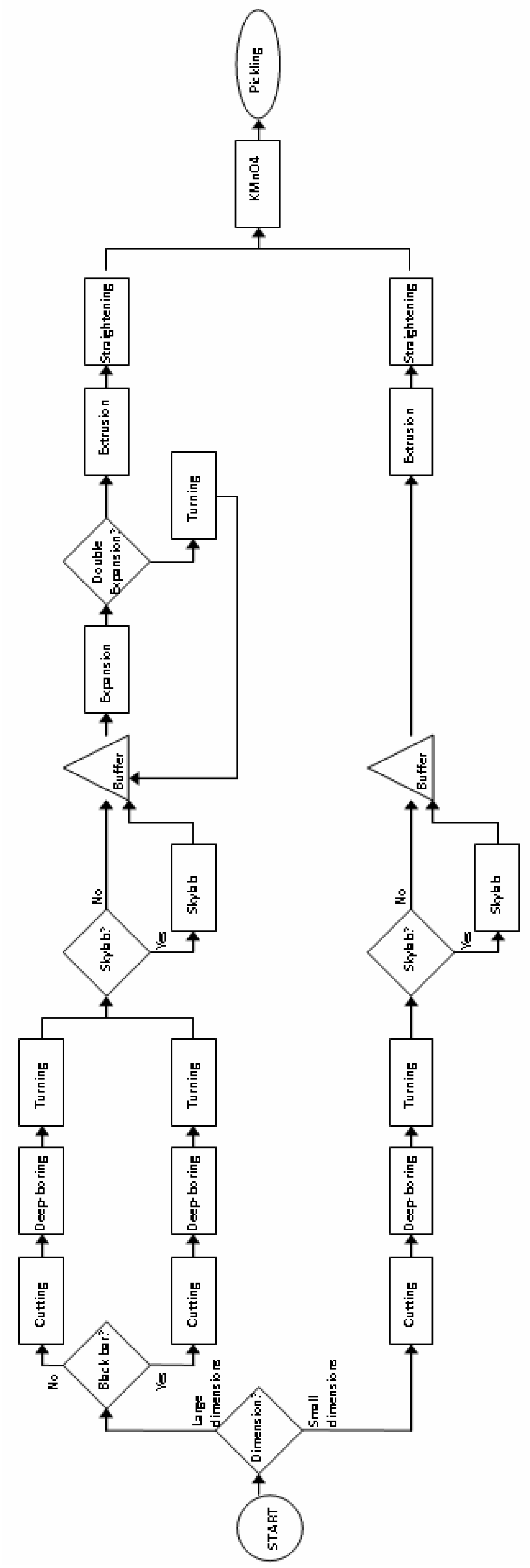
Appendix 2: The current state map of the GP

Appendix 3: Symbols used in the flow chart and current state map

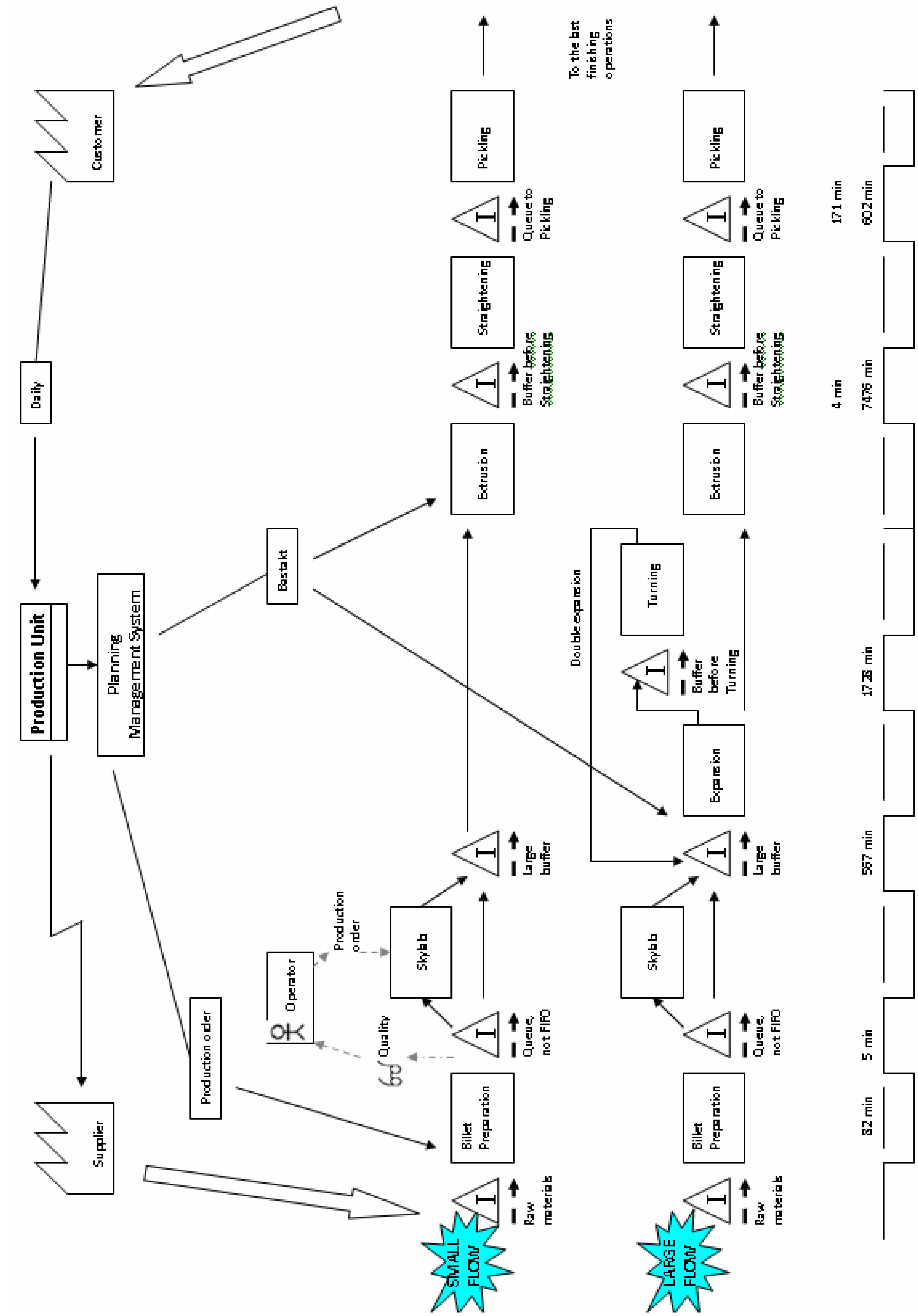
Appendix 4: The Extrusion Sequence

Appendix 5: Extend models – how the models were build and how they work

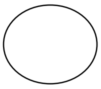
Appendix 1: The Flow Chart

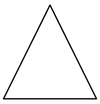


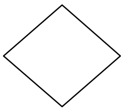
Appendix 2: The Current State Map of the GP



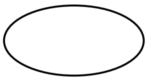
Appendix 3: Symbols used in the flow chart and current state map

 Start of the flow

 Inventory

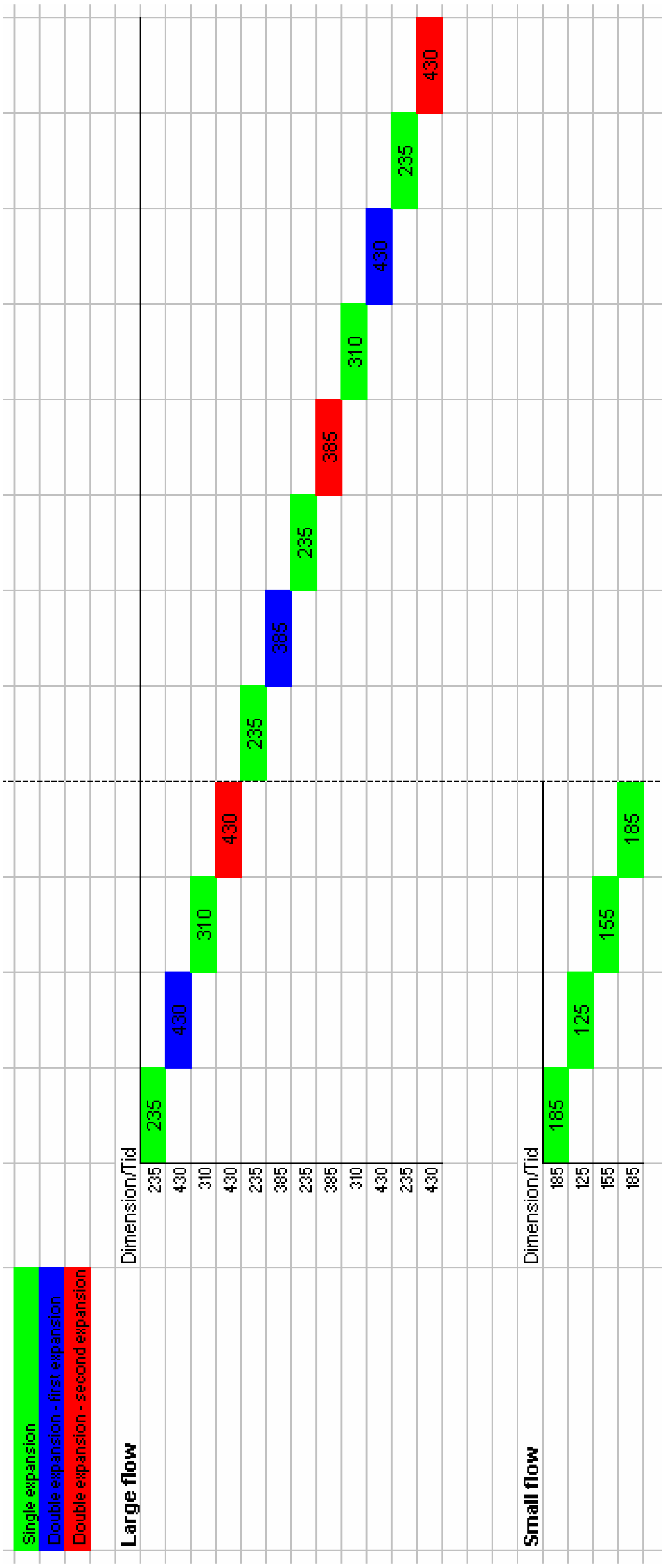
 Decision

 Operation

 End of the flow

 ”go and look” for yourself

Appendix 4: The Extrusion Sequence



This picture shows only in which sequence the orders are going to the extrusion. The setup times are not considered in this picture, because the simulation model counts them automatically. One cell means one set of order in the dimension mentioned. The number of orders this campaign includes and the number of tubes one order includes are mentioned in the appendix 6.

Appendix 5: Extend models – how the models were build and how they work

The Extend model is created to correspond the hot flow at Tube. In this chapter the model is gone through in small parts so that everybody who wants to use the model in the future will understand how it is build.

Here are some of the assumptions made when building the model. It is not taken into consideration that some parallel machines could be utilized better if some of the changeovers were avoided. This is fairly easy in the real world, because the operator can easily see if a changeover is eliminated when choosing a machine that has processed the same dimension earlier. When machines are parallel, Extend chooses the first machine available. The speed of the conveyors is estimated to be 0,5 m/s in the large flow and 1 m/s in the small flow. The speed in all the conveyors is set after this estimation, even if it's not that truly that all the conveyors have exactly the same speed.

In the upper left corner, in the figure 10.7.1, there is Executive-block witch all discrete models in Extend have to have. The purpose of this block is to tie the model into a timeline. On the right side of this block is Manage attribute -block and this is the block which connects the model to an Excel spreadsheet. All the orders and information about the cycle times and materials is in that Excel file. The next block to the right is Clear statistics, which clears the statistics in various blocks in a model. Simulation of the flow starts from the block in the left which is connected with several other blocks. The first block generates the orders to the model and defines some of the variables or attributes (like they are called in Extend) of the orders. Orders are then send into the model as items and if the model is run visually, these items look like green bolls. Orders go on to the Attributes –block which is explained more detailed below. In the end, the orders go to the Throw –block which sorts the orders by dimension of the bars into two separate flows. Large bars with dimension over 185 mm go to the upper flow which is called "Large flow" and the bars with dimension under 185 mm go to the small flow which is called "Small flow".

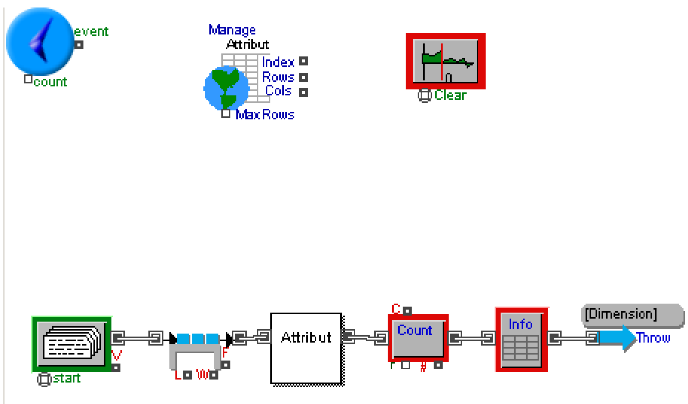


Figure 10.7.1: Beginning of the model

The Attributes –block is a hierarchical block, which means that the block includes a smaller part of the model (Figure 10.7.2). Hierarchical blocks are used to simplify the model visually. The first block is Get attribute and it reads the order identification from the Excel file. This order identification corresponds to a row in the file. The row number is read in and used together with specific columns so that the right data is given to right order. All the columns are defined to correspond to different attributes. In the same way all the other attributes are imported to the model. In this block, the length of the billet, weight, all the operation times and changeover times are defined.

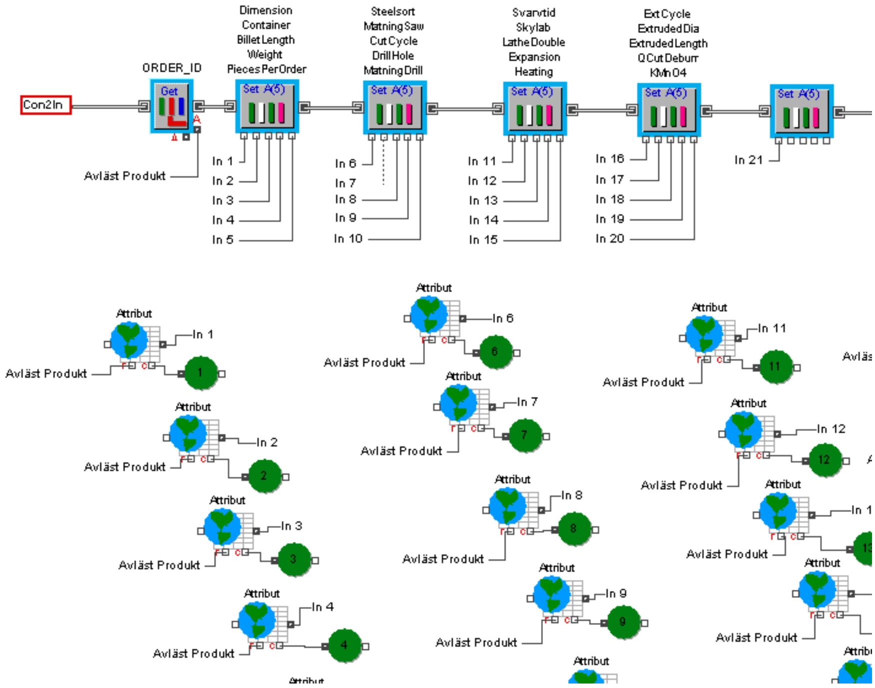


Figure 10.7.2: Part of the hierarchical Attributes -block

The small flow starts with sorting the orders to right buffers (figure 10.7.3). The principle is to choose the buffer with the shortest queue. Inventory –block counts the waiting time for the orders in the queue. This is based on the number of pieces in every order and the cutting time for each piece. This waiting time is used when new orders come to the system and choose the shortest queue. The shortest queue is not the one with lowest quantity of orders and pieces; it is the queue with the shortest waiting time. In Inventory-block, the orders are replaced by pieces or billets. One order is multiplied by the quantity of billets it includes. Billets go one by one to the cutting operation and after that, they are transported by using material conveyor. Utilization grades can be seen for every machine.

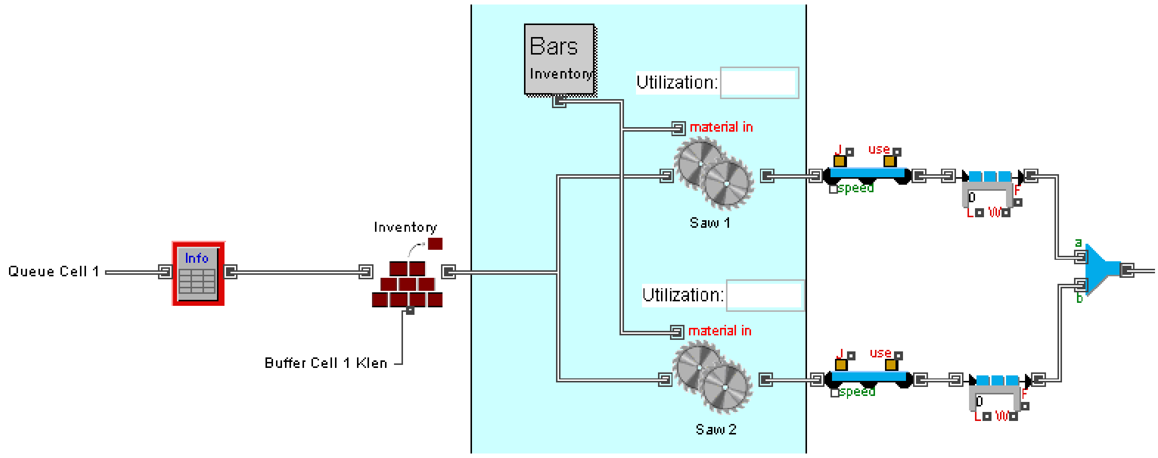


Figure 10.7.3: The beginning of the billet preparation in the small flow.

Inventory-block is also a hierarchical block which contains three Get Attribute-blocks, a buffer and a Holding tank (figure 10.7.4). Get Attribute-blocks read the cycle time for cutting and the quantity of billets of each order. The cycle time is multiplied by the quantity in order to get the operation time for the whole order. All the operation times of different orders are summed in the holding tank. This total waiting time is reduced one by one when the billet leaves the Inventory-block.

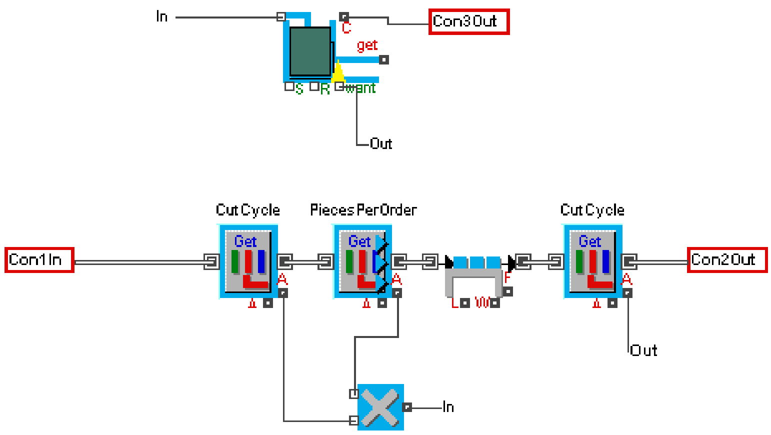


Figure (10.7.4): The structure of the Inventory-block

Bars inventory is a hierarchical block which is functioning like an inventory for the raw material (figure 10.7.5). It defines a length of each bar leaving the stock. Bar lengths are defined by using random input number. Distribution is chosen to be triangular. The values of minimum, maximum and most likely lengths can be changed at any time on the display.

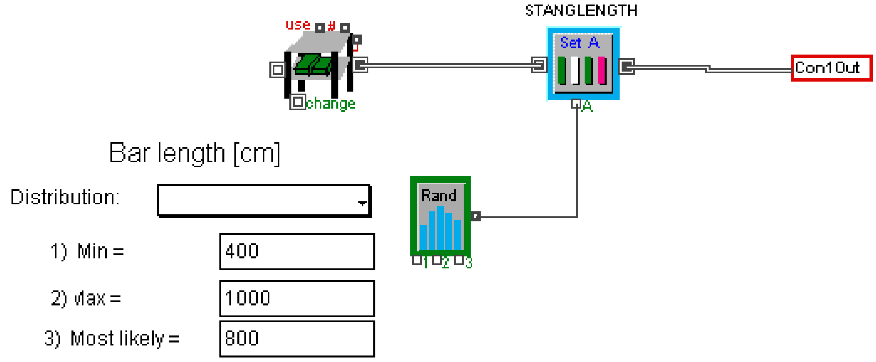


Figure 10.7.5: The structure of the hierarchical Bars –block

The saw is also a hierarchical block (figure 10.7.6). Bars come to the block from the bars inventory and the end is cut. After that the billet is cut. The block is measuring the bars after each cut and counting if the length is enough to cut one more billet. If that's correct the next piece is cut and so on. If the bar is too short, the new bar is pulled from the stock. If the steel type is changed, the new bar is also pulled from the stock. The meaning of the block is to take into account that bar ends have to be cut sometimes and that this also takes some time.

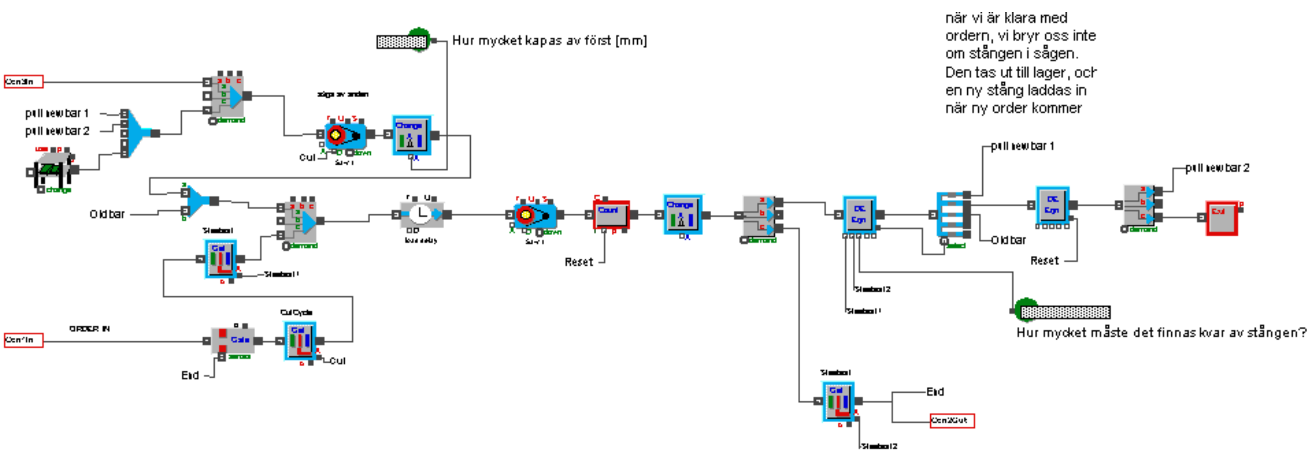


Figure 10.7.6: The structure of the Saw-block

After the billets are cut they are transported to the deep-boring. Utilization for each drill machine can be seen on the screen. After drilling, the material conveyor transports the billets to washing machine which is illustrated by an Activity delay –block (figure 10.7.7).

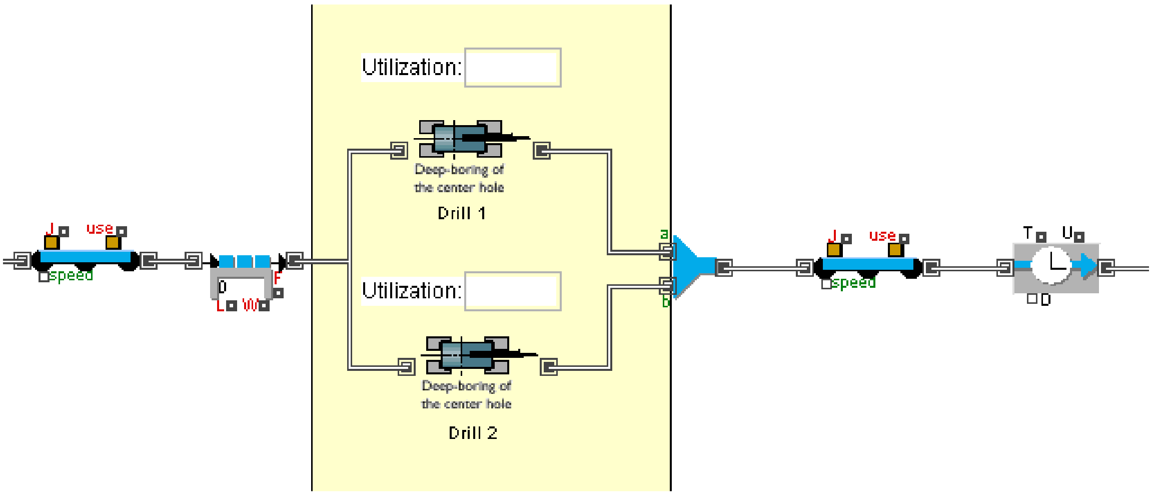


Figure 10.7.7: Drilling operation

Drill is also a hierarchical block (figure 10.7.8). The Gate-block in the beginning is insuring that there's just one item at the time in the block. Get Attribute-blocks are reading the information about the item when it passes the blocks. The attribute values for machine feed and the length of the billet are used to count the cycle time for the operation. When the first piece of the new order enters to the block, the changeover time is added to the cycle time.

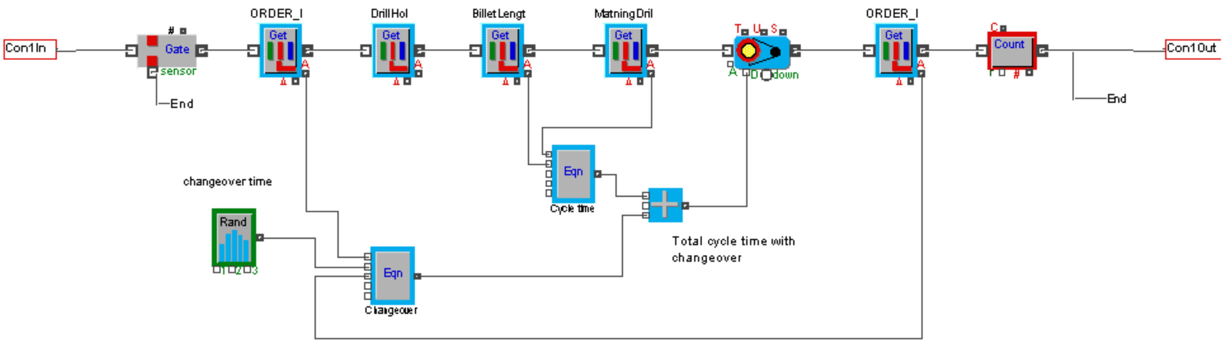


Figure 10.7.8: The structure of the hierarchical Drill-block

Last operation of the billet preparation is turning. Utilization grade for turning machine can be seen on the screen. Conveyor takes the billets to the small buffer and another conveyor takes billets to the holding buffer –block. In that block a certain number of billets are waited to be in the buffer first before releasing them one by one (figure 10.7.9). This illustrates the waiting time before the grinding machine. All the small billets utilize the same machine and because of the different dimensions of the billets, the orders cannot be released to that machine at the same time. Thus, some billets are waited to be ready before releasing them one by one.

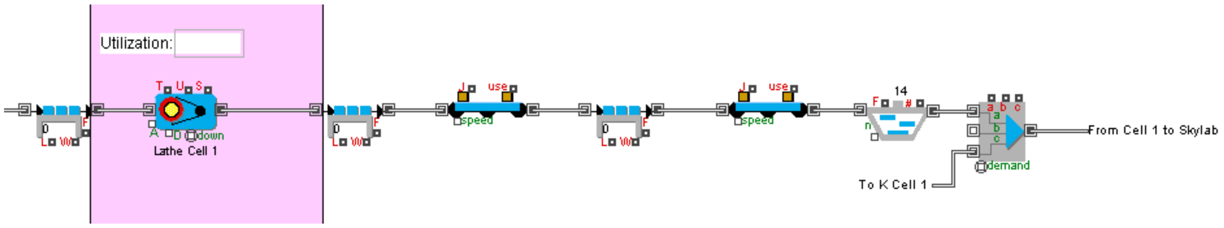


Figure 10.7.9: Turning and conveyor to grinding.

An assumption is made, that 25 % of the billets need grinding. This percentage can be easily changed by changing the percentage on the display (figure 10.7.10). The Select DE Output-block sends billets to the grinding or washing randomly. The billets which are not grinded go directly to conveyor which takes them directly to further operations.

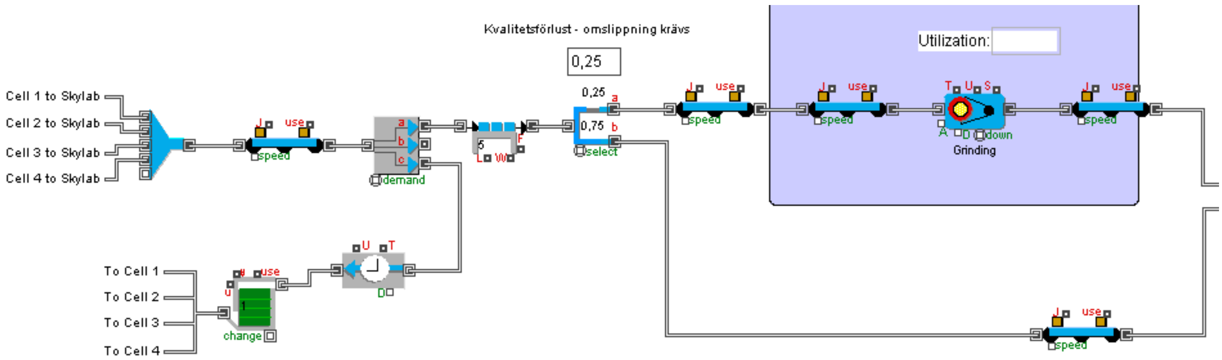


Figure 10.7.10: Selecting which billets go to grinding and which ones go directly forward.

All the billets, grinded or not, need to be degreased (figure 10.7.11). After degreasing, a conveyor takes the billet to the buffer. This is the end of the billet preparation. The buffer is meant to level out the variations between operations times in billet preparation and extrusion. The buffer is a hierarchical block and it's presented below. Plotter, DE –block plots down the buffer levels in three big buffers in the same diagram. It can be easily seen how many products are in these buffers all the way through the simulation run.

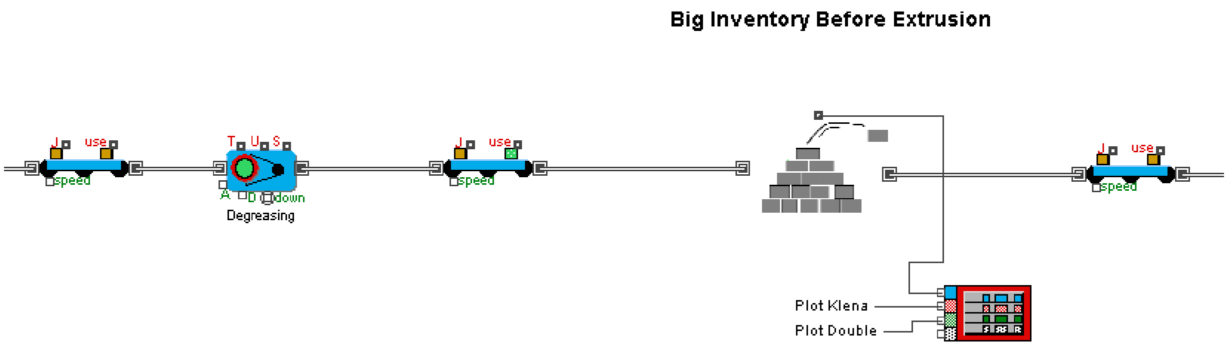


Figure 10.7.11: Degreasing and the big inventory before extrusion.

The purpose of the hierarchical Inventory –block is not just to buffer items; it is meant to buffer items by the orders and decide in which order the orders are sent to extrusion (figure 10.7.12). The extrusion process has longer setup times and that's why the order sequence is a specific. The Gate –block, in the beginning, limits the amount of items in the whole hierarchical block. There is a specific amount of space in the buffer, and because Extend pushes the items forward, the buffer would overfload without this limitation. The number of billets in the buffer is the input for the plotter in the figure 10.7.11. The billets are batched in orders in the Matching –block and released when the whole orders is in the block. Program –block in the upper right corner includes the order list according to which the orders are released from the Queue, Matching –block. The orders are not released from that block before the corresponding "order" is released from the Program –block. For that reason, some orders might be waiting longer than others. When the orders are released from the queue, they are unbatched in Get attribute –block, so that items leave the buffer one by one.

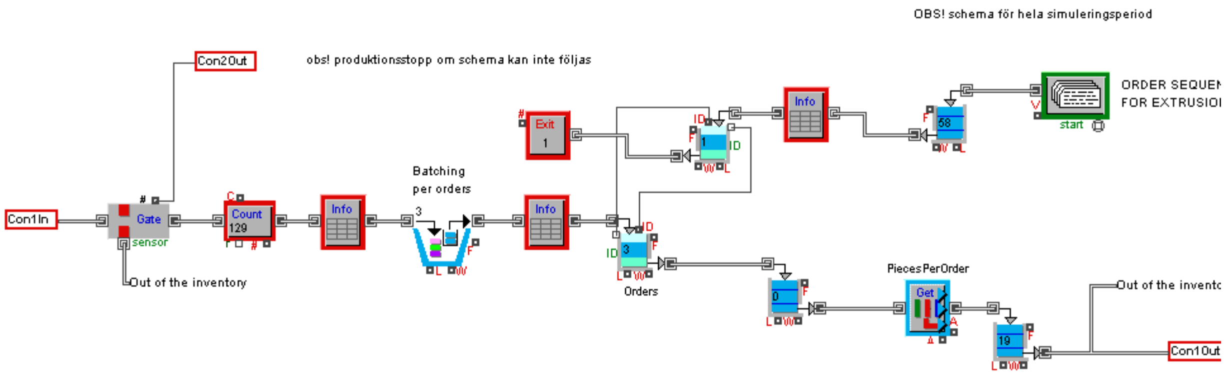


Figure 10.7.12: The big inventory before the extrusion.

The main difference, between the small and large flow, is the heating operations before the extrusion. The large dimensions are heated in ovens; first in a carousel oven and then in vertical oven (figure 10.7.13), whereas the small dimensions go through the induction heating process (figure 10.7.15). The figure 10.7.13 shows the beginning of the large flow. Billets go first to the carousel oven, which is illustrated by a Conveyor, Carousel –block. The second operation is a vertical oven, which is a hierarchical block (figure 10.7.14). The last operation is the expansion, which is demonstrated by a Machine –block. The flow continues in a figure 10.7.16.

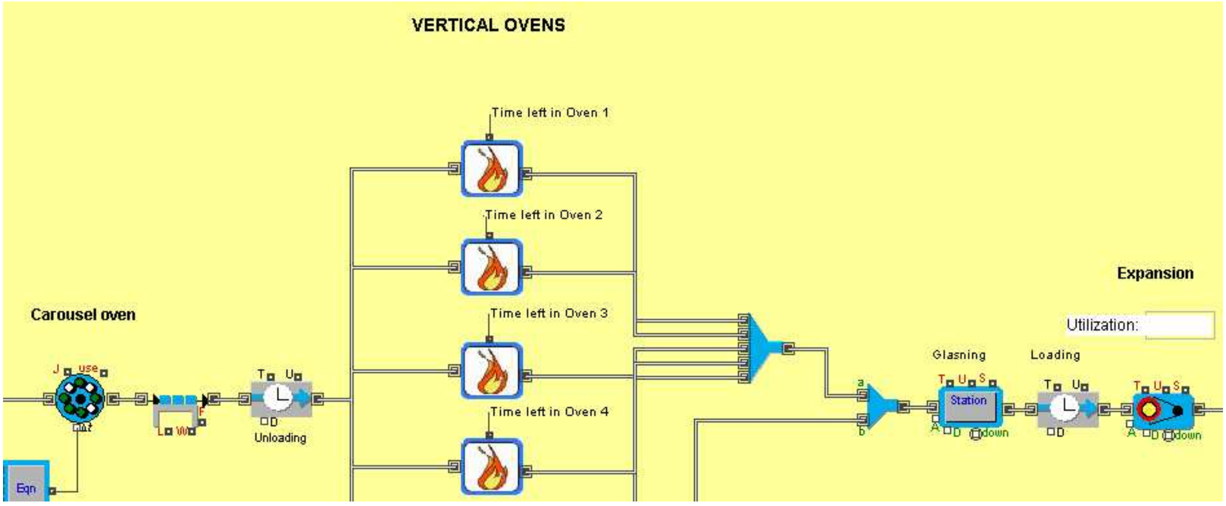


Figure 10.7.13: The large flow from the inventory to the expansion.

A Vertical oven is a hierarchical block (figure 10.7.14). It includes two conveyors, one to the oven and another from the oven. The Gate –block in the beginning limits the number of items in the block to one so that items are not able to queue inside the block. The Holding tank –block counts how much time the billet has left in the oven. It starts from the cycle time and goes down to zero when billet leaves the oven. The next item takes the oven which has the less time left in the oven.

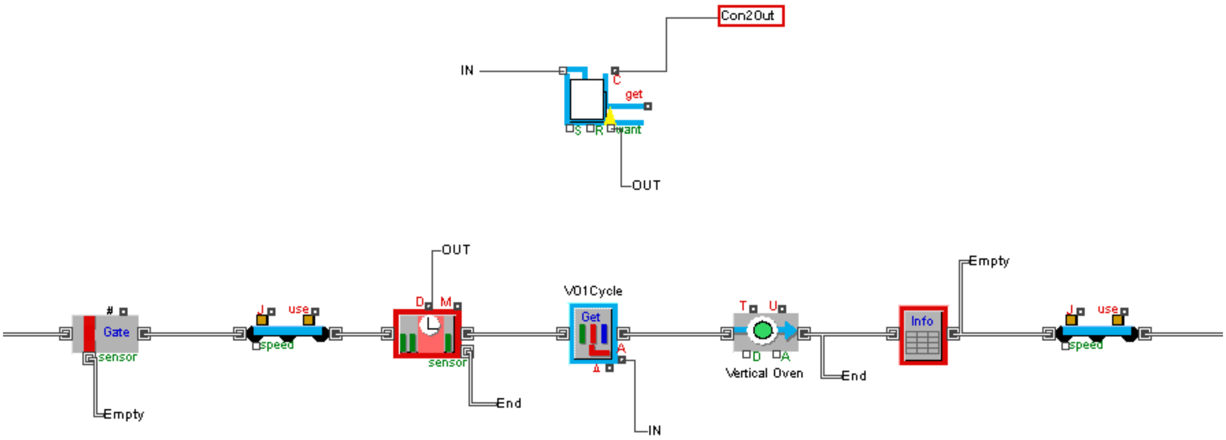


Figure 10.7.14: The structure of the hierarchical Vertical oven -block.

In the small flow, the induction heating is used (figure 10.7.15). There are two "ovens", which function in the same way. These ovens are illustrated by Activity, Multiple –block. The small dimensions go through only the upper oven, and bigger dimensions go though both ovens. The ovens act like a conveyor where the capacity is determined by the length of the billets: shorter billets, more places in the oven. The capacity of the oven is calculated by the Equation –block. The decision –blocks with the Activity, Service -blocks are used in order to prevent billets going to the process before the previous order is processed. Without these blocks the FIFO –rule is jeopardized. Especially, there's a risk that smaller dimensions goes to the first oven before the last billets from the second oven are processed, which causes the extrusion process to change over from order to order between every billet. Due to these blocks, the problem is avoided. In the reality this is not a problem, but Extend pushes items wherever there is empty space, and that's why the problem like this occurs. The Gate –blocks count how many billets are currently in a process, and send this information to the Decision –block. After induction heating, billets go directly to the extrusion. The extrusion is a hierarchical block (figure 10.7.18). The rest of the small flow is pretty similar with the large flow, and therefore, there is just one figure of every step showed in this chapter and those figures come from the large flow.

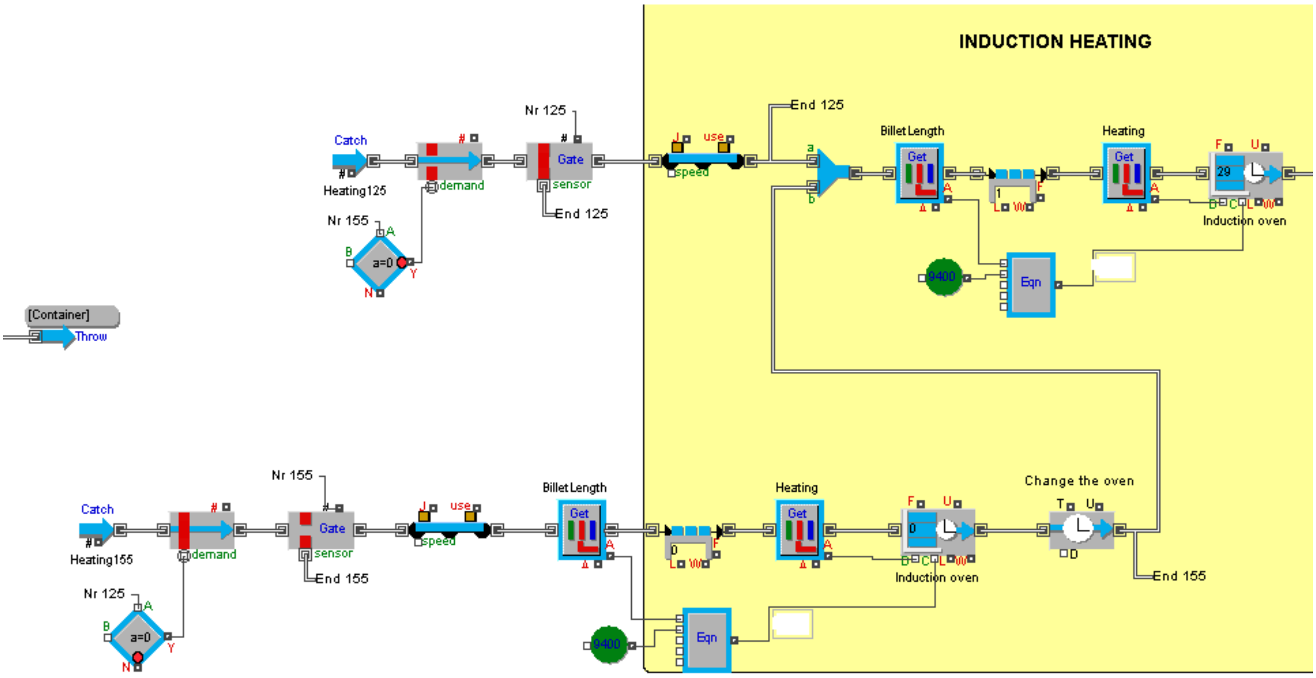


Figure 10.7.15: The heating process in the small flow.

In the large flow, some billets have to be expanded twice, for that reason; they have to be sended backwards (figure 10.7.16). Thus, the billets are first divided by the dimension; smaller dimensions go directly towards the extrusion, whereas larger dimensions go the second Select Output –block. Decisions are made by reading the billets attribute first in Get Attribute –block. Equation –block uses that information to decide which output is going to be chosen in the Select Output –block. For the larger dimensions, the second selection checks if the billet is already expanded twice. If the billet is already expanded twice, it is send to the extrusion; otherwise, it is send to back. Being able to recognize the billet, when it comes to the selection point for the second time, a Set Attribute –block is added in the end. This block changes an attribute value from 1 to 2, so when the billet arrives to the block for the second time the attribute read is different and the billet is send to the extrusion.

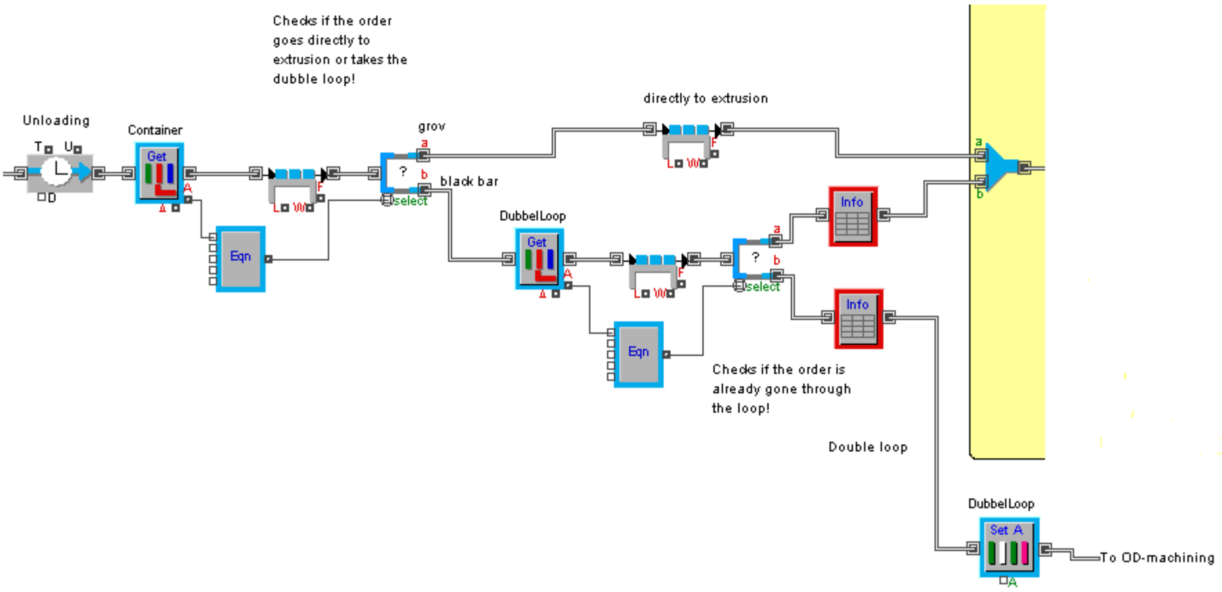


Figure 10.7.16: Selecting the right route for the billets that are supposed to be expanded twice.

If the billets are sended to extrusion, they have to be heated again, and this is done in vertical ovens (figure 10.7.17). Vertical ovens are illustrated by hierarchical blocks that are shown in figure 10.7.14. The extrusion process is hidden into the hierarchical block (figure 10.7.18).Utilization grade for the extrusion can be seen on the display. After the extrusion the tube is taken to the quenching which is a conveyor.

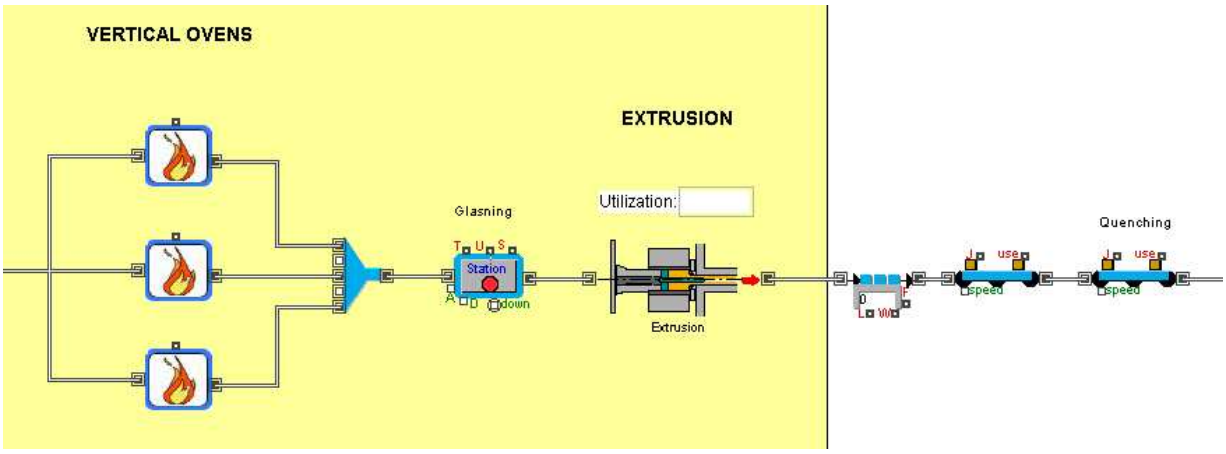


Figure 10.7.17: Extrusion and quenching in the large flow.

The hierarchical Extrusion –block (figure 10.7.18) counts the different setup times and adds the setup time to the billet's cycle time. The setup and changeover time is always added only to first billet's cycle time. The Gate –block in the beginning ensures that there's just one billet in the block at the time. Setup times vary depending if the next order has a different dimension or material or both.

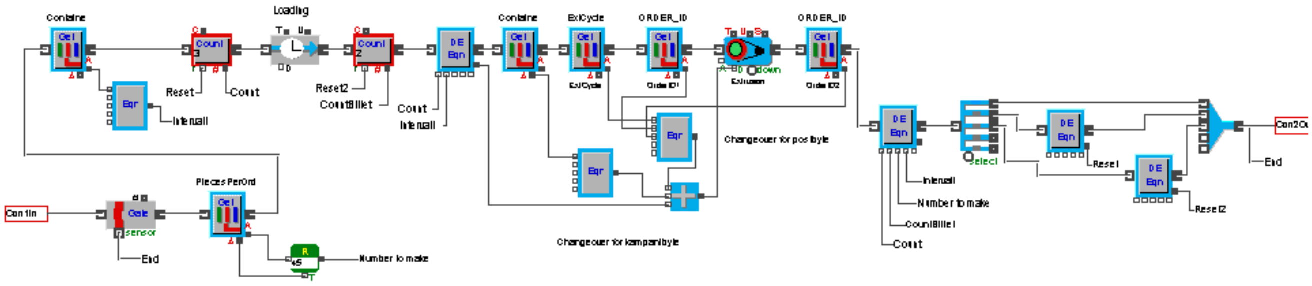


Figure 10.7.18: The Extrusion –block.

After quenching, the tubes are lifted either to a buffer or directly to the straightening (figure 10.7.19). But first the tubes have to be batched in a Batch Crane –block (figure 10.7.20). Lifting is done by a crane, which is inside the hierarchical Crane –block. Tubes are lifted in batches, because lifting them one by one is too time-consuming.

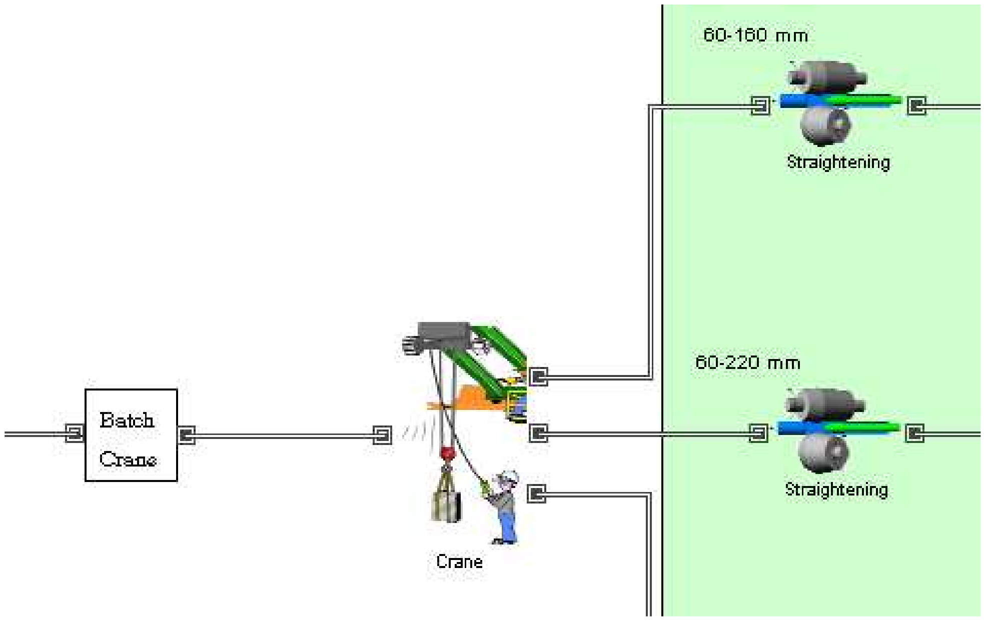


Figure 10.7.19: Batching tubes before straightening.

In the Batch Crane –block, the tubes are batched for the crane lift. It is not very likely that tubes are lifted one by one to the straightening process or to the small buffer before straightening. This block waits until there are few tubes ready to be lifted, and then releases them to the next process. The number of tubes to be batched is decided in the Constant –block. This number can't be random because there is a risk that some tubes of an order are left over, which causes that inventory grows and model is blocked further down in process.

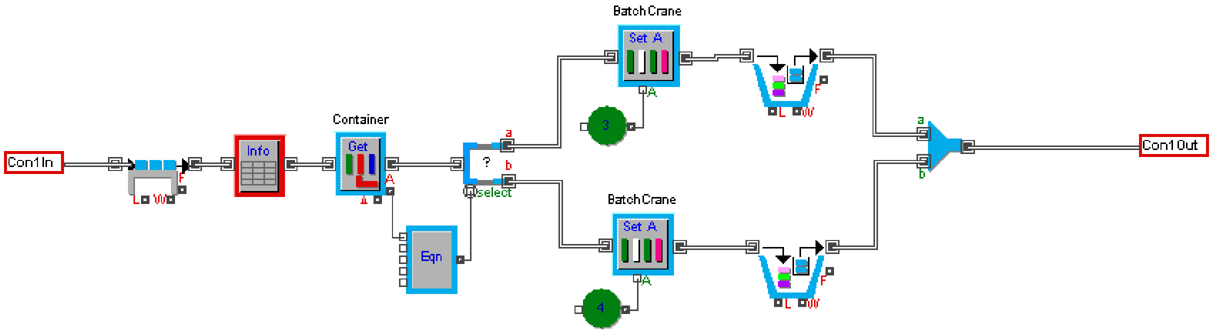


Figure 10.7.20: Batch Crane –block.

In the Crane –block (figure 10.7.21), the dimension of the tubes is checked in the Get Attribute –block. This dimension is used when deciding to which straightening machine the tubes are going to go. The machines can operate tubes with several dimensions and the limits of these dimensions are overlapping. Therefore, the tubes are lifted to the suitable machine with shortest queue. Max & Min –blocks, downward in the figure (10.7.21), are comparing the lengths of the queues and sending a signal to the Select Output DE –blocks to which queue to choose. The Labor –block ensures that only one batch is lifted at the time, because there's just one crane in reality. Without this block, there could be several lifts at the same time.

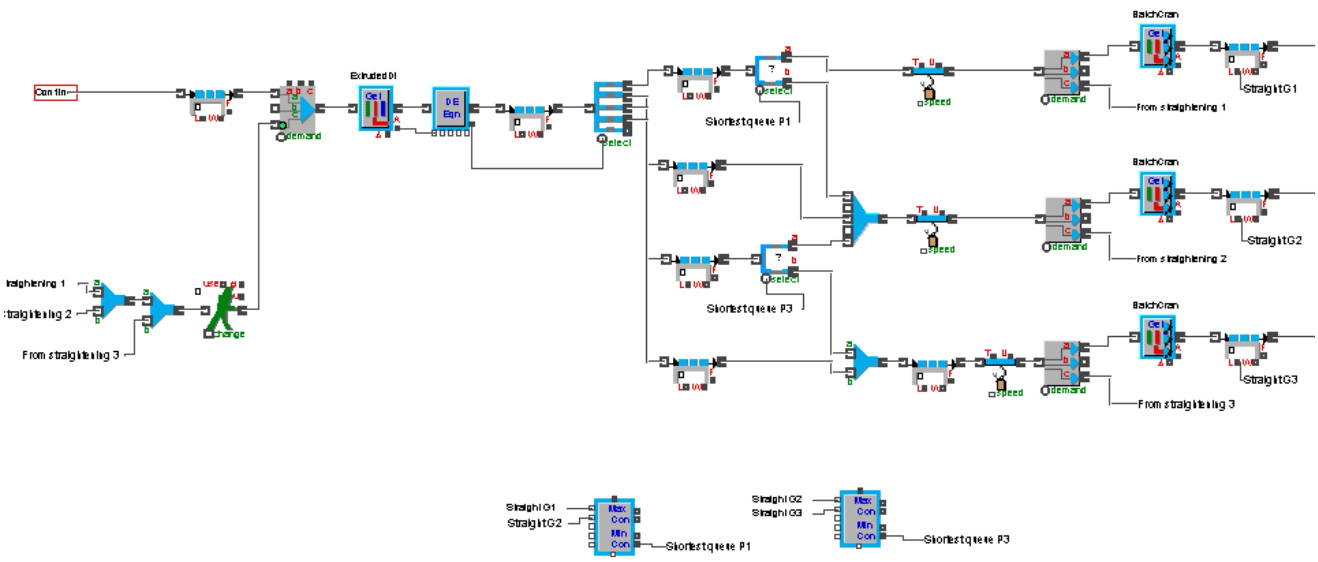


Figure 10.7.21: The hierarchical Crane –block.

The Straightening –block (figure 10.7.22) contains several Get Attribute- and Equation –blocks. The purpose of these blocks is to calculate the operation time of the machine and the changeover time between different dimensions. The operation time of the straightening depends on the length of the tube. Changeover time is added to the first item coming to the block with different dimension. The Gate –block releases items to the block one by one.

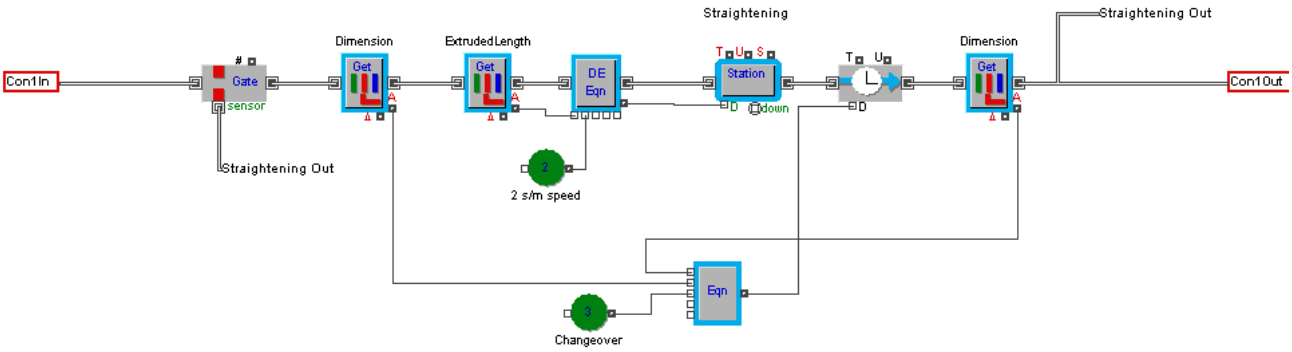


Figure 10.7.22: The hierarchical Straightening –block.

In the figure (10.7.23), there is the end of the straightening process with the two stations for quality control, cutting and deburring. Tubes are batched in to the bundles in Bundle for Pickling –block.

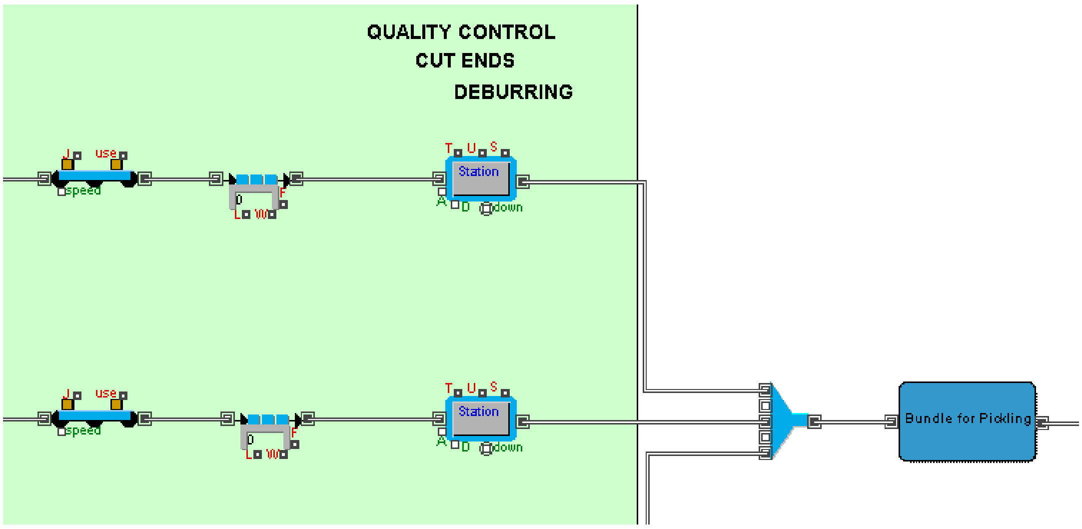


Figure 10.7.23: Finishing operations before pickling.

The tubes must be batched into a bundle before pickling, and this happens in a hierarchical block called Bundle for Pickling (figure 10.7.24). A bundle size is limited to 6 tons, and this weight ceiling determines how many tubes a bundle contains. A tube weight depends on material and dimensions. The bundle size is calculated in the Excel spreadsheet.

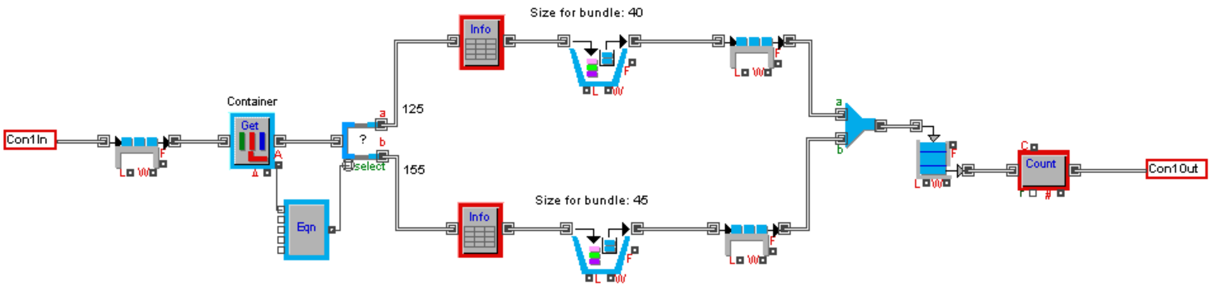


Figure 10.7.24: Bundle for Pickling

The figure 10.7.25 shows the beginning of the pickling operation. A bundle of tubes is lifted by a crane through a serial of operations. These operations are illustrated by the Station – blocks. Depending if the material is austenitic or duplex, it is send to KMnO4-process. Tubes of austenitic material continue directly to pickling. The figure 10.7.26 shows the end of the pickling process. In this study, it was also tested to move one of the KMnO4 stations to pickling. This was simply done by changing the connections and attributes in the dialog of the block.

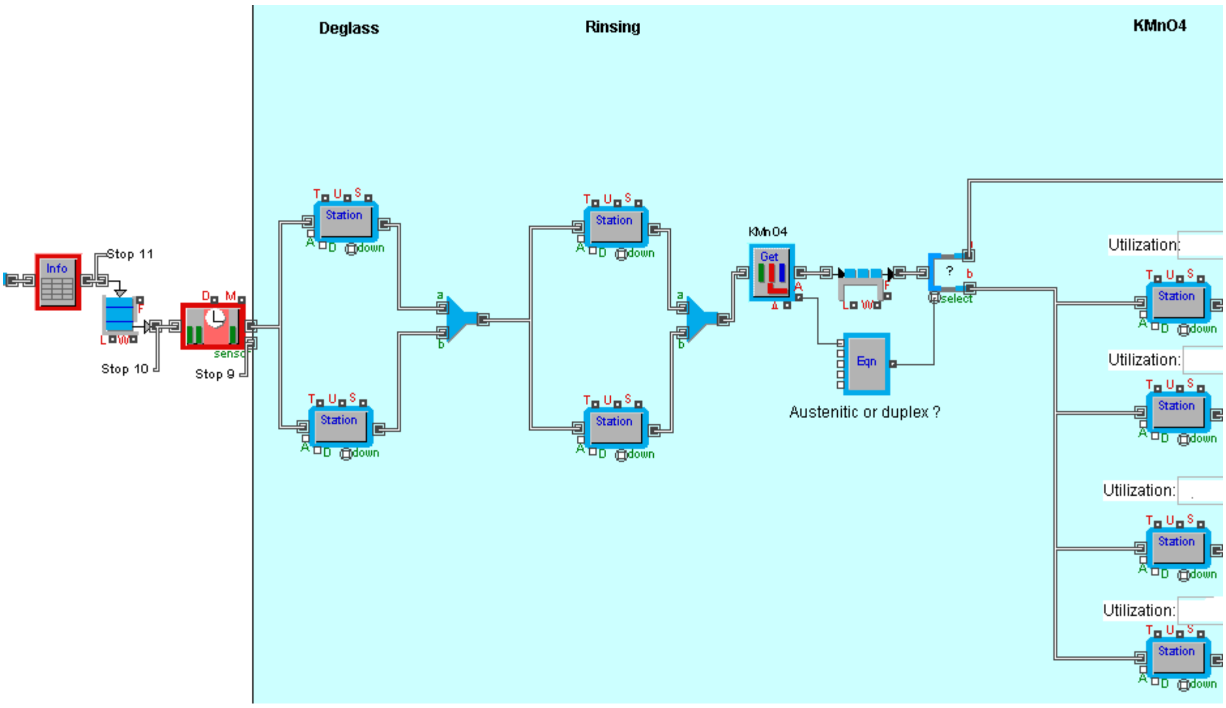


Figure 10.7.25: The beginning of the pickling process.

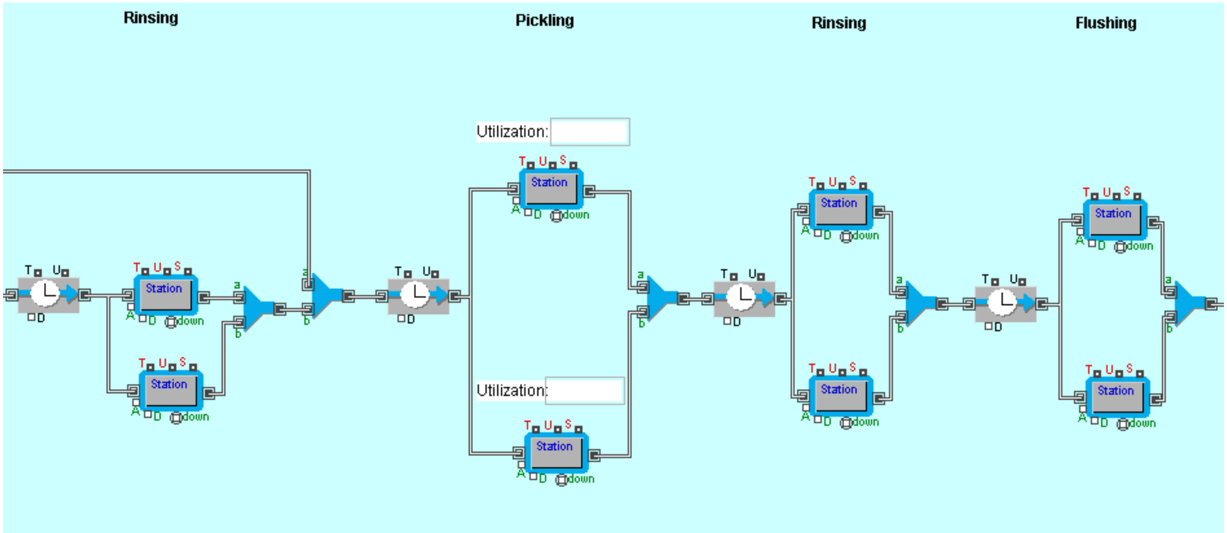


Figure 10.7.26: The end of the pickling process.

In the end of the model (figure 10.7.27), the tubes are separated by the dimension, so that it can be counted output for each dimension. But before that, the bundles are broken into the items. If this is not done, the program counts the weight only for one tube even if the whole bundle should be counted. Breaking the bundles into the tubes happens in a Get Attribute –block. The weight of the tube is also counted in the Get Attribute –block. Last block is called Exit, and it collects the items that are ready to exit the model.

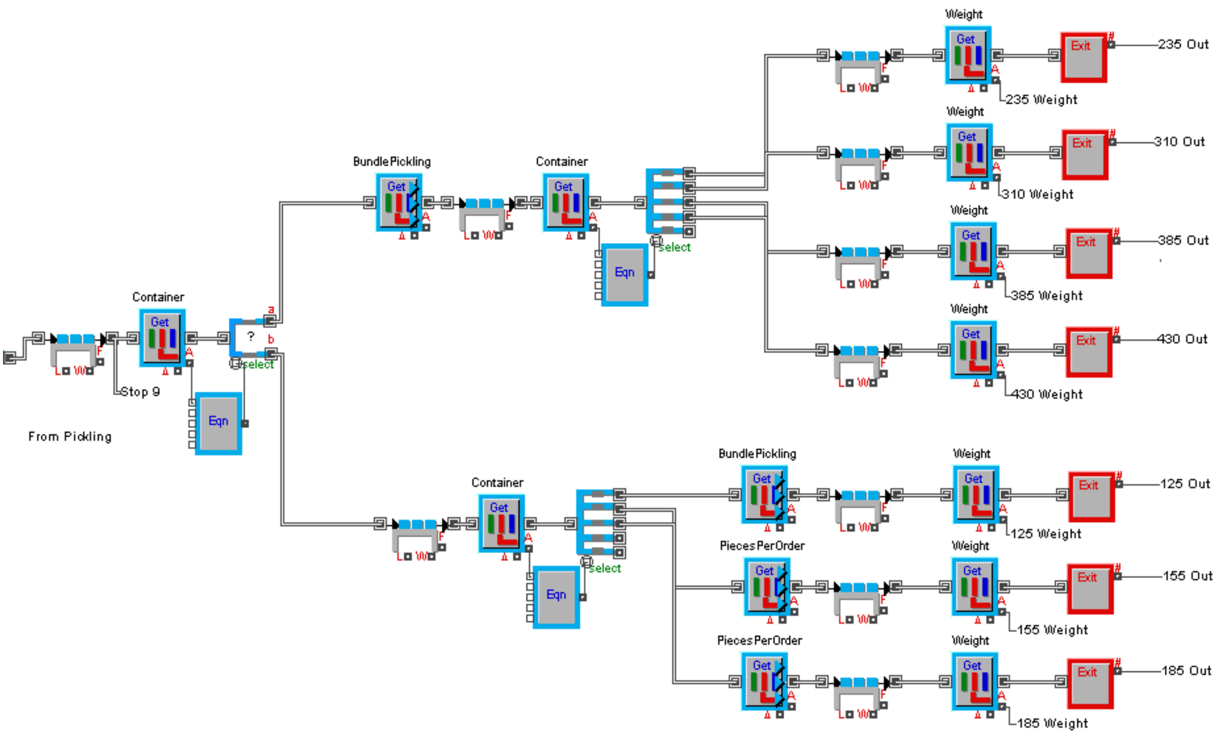


Figure 10.7.27: The end of the pickling and the whole model.

The weight of tube, when it passes the Get Attribute –block (figure 10.7.27), is send to the Holding Tank –block (figure 10.7.28). These blocks sums up all the weight and displays the total weight, which is the output from the model. There is a Holding Tank for every dimension. Output from these is summed in Equation –block, first separately for large and small flow and then for the whole production.

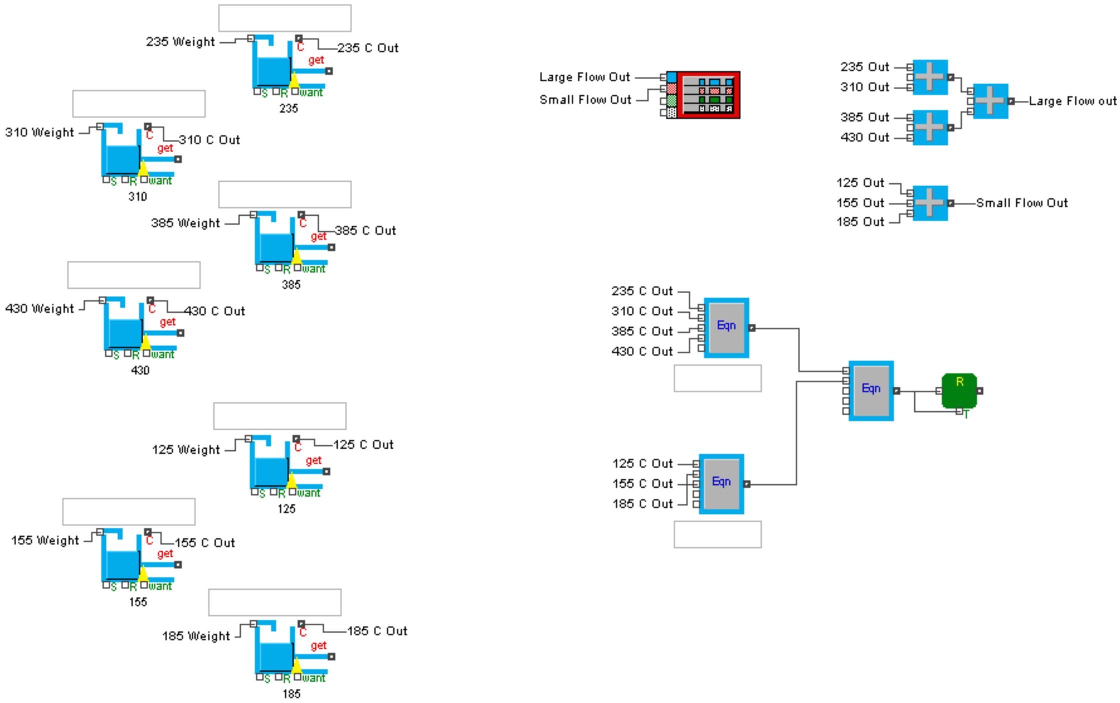


Figure 10.7.28: Counting the output of the run.