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Production Flow Simulation Modelling in the Foundry Industry

Investigation of generic and specific simulation modelling

Master's thesis in Production Engineering

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Gothenburg, Sweden 2017

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Cover: The blackning process at Holsbyverken.

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Abstract

Casting has been a large manufacturing method for very long time, hence the foundry industry have a long tradition of how they are working. Many foundries in Sweden have grown independently and developed their own characteristics. In order to stay competitive on a global market, the Swedish foundry industry needs to modernize and are now investigating the possibilities with production flow simulation.

The aim of this thesis is to evaluate the possibilities of building a specific simulation model which corresponds with the production flow of one foundry, while being generic enough to be able to adapt to other foundries. Possible benefits of production flow simulation in the foundry industry will also be investigated. During the project, two foundries were visited for a comparison, one of which was extensively investigated as it would be used as blueprint for the simulation model. Close discussions were held with industry experts from a research organization and foundries throughout the project where valuable input were received.

The conclusions drawn from this study is that there are benefits to gain for the foundry industry from simulation modelling. However, to profit from this, it is important to know the purpose behind the simulation model. It was also discovered that the traditional nature of the foundry industry and the lack of modern tools obstructs the data collection. This made it more difficult to achieve the right level of detail in the simulation model. Yet, it was noticed that the model functioned as boundary object and that it during meetings opened up for discussions and new ideas.

Keywords: Discrete Event Simulation, Casting, Foundry, AnyLogic, Generic modelling, Specific modelling.

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Christoffer Dawson and Hanna Lindahl
Gothenburg, June 2017

Glossary

Axxos	A software which collects data from two machines at Holsbyverken.
Binder	The substance blended into the sand to make the mold more stable.
Boundary object	An object used as medium through which individuals with different perceptions can communicate to gain common understanding.
Chaplet	The structural support used to keep the core in the desired place in the mold.
Cope	The upper part of the flask.
Core	If the desired product is hollow, a core is made and placed in the mold to create the hollowness in the product.
Core print	The section in the mold that guides the core into right position.
DES	Discrete Event Simulation. An event-based simulation method.
Drag	The lower part of the flask.
Fettling	The process of removing the gating system and risers from the casted product.
Flask	The container where the match plate is placed and sand is poured into to create the mold.
Gate	The hole in the cope that the melt is poured into by a machine or an operator.
Gating system	Canals included in the mold that lead the melt into the cavity that will constitute the product.
Match plate	The plate that the pattern is mounted onto, this is sometimes called the *mounted pattern*.
Melt	The melted metal that is poured into the mold.
Mold	The block in which there is a cavity of the desired shape the product.
MTTF	Mean Time To Failure. Describes how long time there is between the stops.
MTTR	Mean Time To Repair. Describes how long the stops are
Parting line	The line where the cope is separated from the drag.
Pattern	A model of the product that is used to create the cavity in the mold that resembles the shape of the desired product.
Rising System	A melt buffer at the top of the cope from which melt can pour down to refill the space created by shrinkage during the cooling phase. This is sometimes just called the *riser*.
Shake-out	The process where the products are separated from the flask through vibrations.
Sprue well	A chamber in the mold where the melt goes before entering the casting cavity to avoid turbulence in the melt.
HWS-machine	HWS stands for Heinrich Wagner Sinto, and is a german manufacturer of casting machines. This machine is the pace-setter of the production flow at Holsbyverken, and consists of several process steps.

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1 Introduction

This chapter presents the background and purpose of this masters thesis. It also covers the research questions and limitations.

1.1 Background

Swerea SWECAST is a Swedish industrial research organization aimed towards the casting industry. The aim of the organization is to develop the Swedish casting industry by providing their customers with tools and facilities and to assist in research projects. Swerea SWECAST wants to investigate the possibilities with a simulation model which is specific enough to represent the production flow in one foundry, while at the same time being generic enough to easily change to another foundry. A generic simulation model will work as a boundary object for demonstration and open up the discussions for future use of simulation models over the production flow. The generic model will be a bridge between the demonstration facility and the real production system. Swerea SWECAST is currently working with Holsbyverken, a Swedish foundry in Vetlanda, the production system at Holsbyverken will be used as blueprint for the specific but still generic simulation model.

1.2 Aim

The aim of this thesis is to evaluate the possibilities of building a specific simulation model which corresponds with the production flow of one foundry, while being generic enough to be able to adapt to other foundries. Possible benefits of production flow simulation in the foundry industry will also be investigated.

1.3 Research questions

RQ1. What are the challenges when creating a generic and at the same time specific simulation model of the production flow of a foundry?
RQ2. How can the foundry industry benefit from using simulation models when studying the production flow?
RQ3. What is important to consider for future development of simulation models of the production flow in the foundry industry?

1.4 Delimitations

- Focus will be on the production system at Holsbyverken. The production system begins where raw material enters the system and ends when the products leave the factory. The outbound and inbound logistics and processing of products outside Holsbyverken will not be considered.
- The simulation model will reflect the holistic perspective of the production system.
- Two foundries have been visited in this thesis, therefore discussions and conclusions will be based on the experiences learned from these visits.
- The foundry Skeppshult was visited briefly, hence less details and information about Skeppshult.
- The used simulation method will be DES and the used simulation software will be AnyLogic.

2

Theoretical framework

This theory chapter will cover the basics of casting as the casting process will simplistically be described. Then follows theory about simulation methodology, input data management, generic and specific modelling and boundary objects.

2.1 Casting process

Casting is one of the oldest manufacturing processes and have been used for more than 5000 years. From the beginning it was things for decoration and jewellery, mostly made of bronze, that was casted. The use of casted products has since then increased dramatically and is used in several industries. Due to the heavy automotive industry, Sweden is one of the countries that per capita use most casted products. To conclude, casting is an important manufacturing method (Swedish Foundry Association, 2015a).

2.1.1 The production flow of casting

Generally, there are two kinds of casting, casting done with permanent molds and casting done with one-time molds (Swedish Foundry Association, 2015b). The method of interest for this thesis is casting in one-time molds and more specifically, sand molds.

In this process, the mold and eventual core is made out of sand, the sand is is mixed with a *binder* to "glue" the grains together and to gain a more stable structure. The sand is then poured onto a *pattern*, which is a model of the desired product and pressurized to create a steady mold with a cavity in the shape of the pattern. See Figure 2.1 for an overview of the casting process. All processes will be described after the figure.

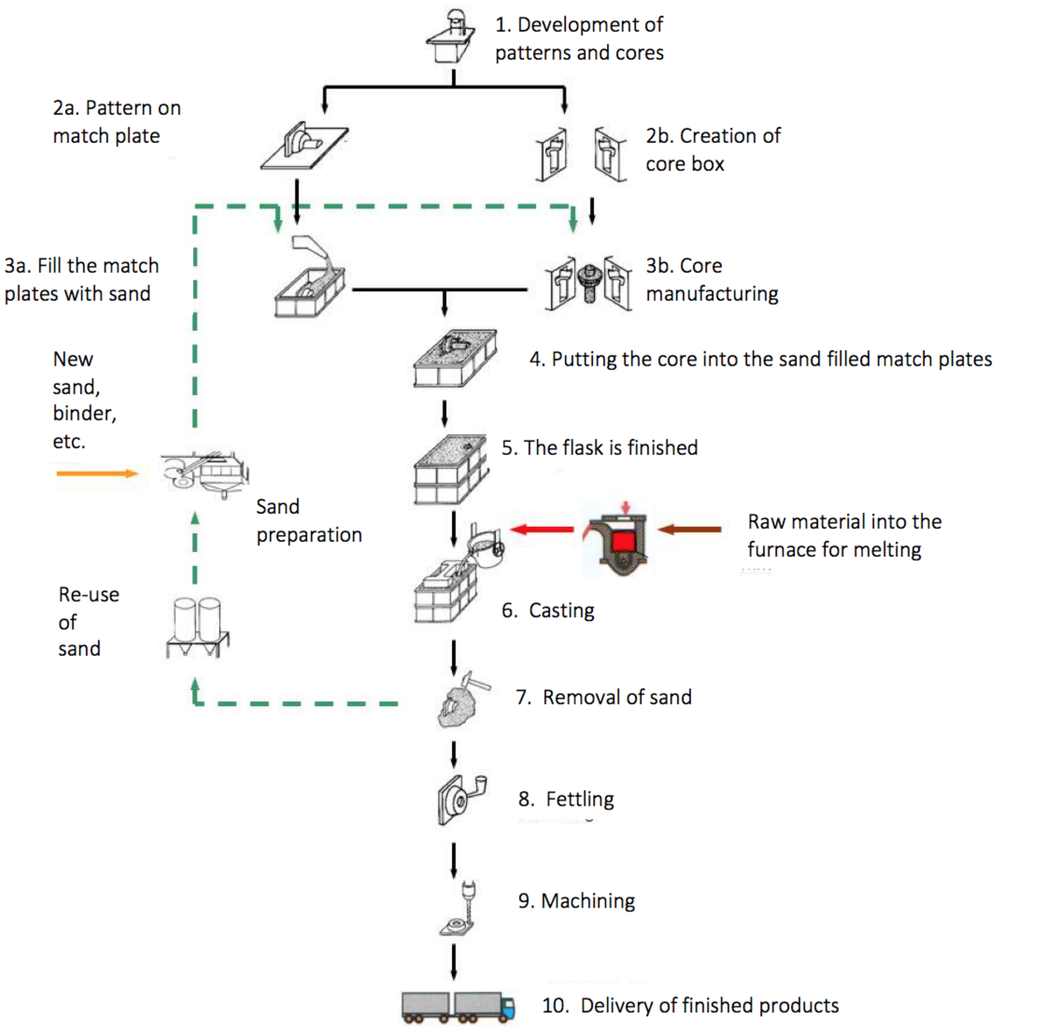

Figure 2.1: *The production flow of casting (Swedish Foundry Association, 2015b). The picture has been modified and translated to english.*

1. As can be seen in Figure 2.1, the casting process contains several steps. Before the casting itself can take place, several preparations need to be made. These preparations include model processing and creation of a *mold* and if necessary, *cores*. When creating a model, several requirements need to be taken under consideration, for example aspects about the machining after the casting, and these limitations and requirements should be designed into the model (Boljanovic, 2010).

2a. The model will be shaped into a physical object called a *pattern*. It is the pattern that will create the cavity in the sand mold. It is into this cavity the melted metal is poured and where the product is created (Boljanovic, 2010). The pattern can either be made of wood (for shorter series, up to 500 casted products), plastic (for larger series than 500 casted products) and for even larger series or mass production, aluminium, iron or some kind of alloy can be used. The choice of material also depends on cost and requirements on the final product (Swedish Foundry Association, 2015c). Since the metal shrinks as it cools, the pattern is usually larger than the desired final object. There are several different patterns: solid pattern, split patterns, match plate patterns and cope-and-drag patterns (Boljanovic, 2010). Solid patterns are usually only used for low quantity production, and the pattern is made in one piece, see Figure 2.2. This kind of pattern is also called loose pattern. Split pattern is more advanced than the solid pattern and is when the work-piece is made in two or more parts, see Figure 2.3. Match plate pattern is when a split pattern is assembled on a so called match plate, see Figure 2.4. The split pattern is assembled on opposite sides, this increases the quality since holes in the plate ensure accurate alignment between the top and the bottom sections of the mold. Cope-and-drag pattern is similar to the match plate pattern, however each half is assembled to each own match plate, see Figure 2.5. This means that separate patterns are used to make the two mold halves. Gating and riser systems are also included in the cope-and-drag pattern. For this thesis it is the cope-and-drag pattern that is of interest.

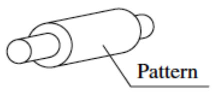

Figure 2.2: *Solid pattern. Picture from Boljanovic (2010).*

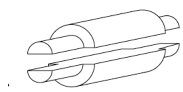

Figure 2.3: *Split pattern. Picture from Boljanovic (2010).*

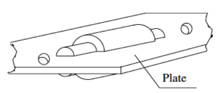

Figure 2.4: *Match plate pattern. Picture from Boljanovic (2010).*

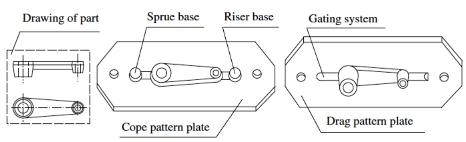

Figure 2.5: *Cope-and-drag pattern. Picture from Boljanovic (2010).*

2b. Parallel with the creation of the pattern, a core box is created. The function of the core box is to create a core. A core is used to define the internal shape of the casted product, and is then removed from the finished part. There are high requirements on the core as it needs to withstand the pressure from the molten material and at the same time be fragile enough to allow easy removal after the melt has cooled down (Zanetti et al. 2003, Boljanovic, 2010). Sometimes the core needs structural support to stay in the desired place. These supports are called *chaplets*. Since the process of manufacturing a core is additional to the regular casting manufacturing process, it is time consuming and costly and, if possible, avoided (Chhabra et al. 2011).

3a. A frame is put around the both match plates and the containers are then filled with sand to create the desired cavities in the mold.

3b. When the core box is created it is possible to create a core. This is done by filling the core box with sand.

4. The core is placed inside the drag and the cope and drag are put together, see Figure 2.6. Now the mold is finished and it is possible to start pouring the melt into the mold and cast the product.

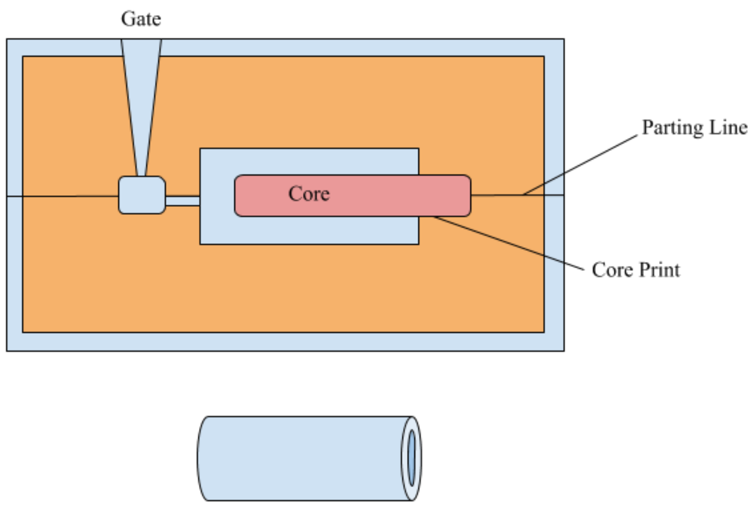

Figure 2.6: *Sketch over inside of a flask, containing core, core print, parting line and gate. Below is the product which will be created in this mold.*

5. Since the cope is the upper part of the flask and the drag is the lower part of the flask, the cope will be assembled on the drag, see Figure 2.7. Locations are added to align the two halves, as well as the other parts: gates, risers, runners and sprue well (Boljanovic, 2010).

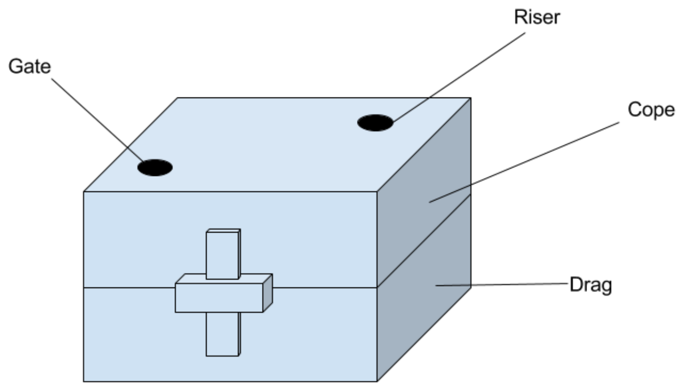

Figure 2.7: *Sketch over a flask, containing cope, drag, riser and gate.*

6. The metal has been melted in a furnace and the melt will be poured into the mold and the solidification will start to take place.

7. Once the metal is solid, the casted product is taken out of the mold and all sand is removed.

8. Fettling is the after work to take away the parts of the product which is not supposed to be there, for example access ports for pouring the metal into the mold. Fettling is cutting, grinding or sanding these parts away (Boljanovic, 2010).

9. Machining is usually necessary after the fettling to get the final desired design and the correct surface finish.

When looking at Figure 2.1, there is a dashed line going from operation 7 up to operation 3. This line shows how sand is re-used in the production system. This part about the re-used sand and will not be covered in this thesis.

2.1.2 Cold box casting

In the process of core and mold manufacturing, one commonly used methodology is *cold box*. Cold box is, a process where the sand is mixed with a compound of binders. The characteristic of this process is however that a catalytic gas is injected to cure the binder (Swedish Foundry Association, 2015d, Zanetti & Fiore 2003).

The injection of the catalyst or amine shortens the curing time significantly to lower than 10 seconds which makes it suitable for mass production applications (Zanetti & Fiore 2003). Depending on the compound of the binders and which catalyst that are chosen, the hardening period can vary. The selection of amine is also dependant of the surrounding temperature as different amines have different evaporation temperatures (Swedish Foundry Association, 2015d). One of the advantages with using this method is that no heating is required which significantly reduces energy consumption (Zanetti & Fiore 2003). This method can also be applied to both core and mold manufacturing and due to it's texture it allows complex geometries (Swedish Foundry Association, 2015d). The method does however emit hazardous gases like benzene and carbon monoxide during the casting and cooling phase which is not good for the working environment (Swedish Foundry Association, 2015d).

2.2 Simulation

This section will cover basic simulation theory.

2.2.1 Discrete Event Simulation

Discrete event simulation or DES as it will be referred to throughout this thesis, is a simulation method that allows a simulation model to mimic a real systems actual dynamics (Ingalls 2011). DES is an *event-based* approach to simulation which means that a new state of the system only is calculated when an event occurs and not according to a decided schedule. The opposite would be a *continuous* system where the state of the system is calculated continuously throughout the course of the simulation (Banks et al. 2005). This enables faster execution of the model since it does not have to perform "unnecessary" calculations where the state of the model has not been changed (Matloff 2008). The state of the system is defined as the set of variables that are necessary to describe the system at any given point in time (Banks et al. 2005).

For an event to occur, it has to be caused by an *entity*. Entities are the subjects of interest in DES and are what executes the activities in the model. Entities can have certain *attributes* which are the properties of the entity. For example, an entity could be a part flowing trough a factory and it's attributes could be the time it enters the system, its color, its size etc. (Banks et al. 2005). When the entity interacts with an activity, an event occurs. An example of this would be when the part in the factory gets to a machine that processes the part (Ingalls 2011). An activity represents a period of time that in this example would be the machine's cycle time (Banks et al. 2005). It is important to note that an entity does not have to correspond with part in a factory, it can also be a guest at a café or even a piece of information running through an organisation. The essential thing to remember about entities is that they are a requirement for the model to run. With no entities, no activities would be executed and no events would occur (Ingalls 2011).

If the part in the factory is considered, it is not always being processed in a machine, it could be lying in a buffer waiting to be processed, the guest at the café might have to stand in line to wait to be served or an email might lie in the inbox for a while (in some persons cases a very long while) before it gets read. This would in the simulation model correspond to a *queue*. The entity is most often placed in a queue when it is waiting for a *resource* to be available. Like a machine in a factory, a barista or an email-reader, a resource has a defined *capacity*, it can only process a limited number of entities at a time (Ingalls 2011). One can say that a resource is a node of the system where some kind of service is being performed, either it it is reading an email, processing a part or serving coffee.

2.2.2 Software selection

There are a number of available software to use for DES. This presents challenges in the evaluation and selection process of which software to use and it requires expertise in the area (Nikoukaran, Paul 1998). However, to gain a structured approach, methodologies that include score-based decision are proposed by Banks (1991). The score is generated by the extraction of criterion (Nikoukaran et. al. 1998) and then weighting of these criterion. The criterion can then be weighted according to their importance to the project. Banks (1991) then suggests that the software that are subject for investigation, are evaluated based on their ability to fulfill the criterion. The software ability to fulfill a criterion is then combined with the weight of the criterion and the software is then scored according to this.

Banks (1991) also suggests that a third party should be consulted during the selection process. Asking a vendor for advice would be like asking a personal trainer if you are obese, they are biased and are most likely to recommend their own product. All software's are optimal for different applications and it is important to note that the criterion's should be tailored for the purpose of the model, it is for example redundant to ask for 3D-animations if it will not be used (Banks 1991). All simulation software's have different strengths and weaknesses which should be taken into consideration when the selection is made (Tewoldeberhan Bardonnet 2002). When extracting the criterion's, system experts and the simulation team should be closely connected (Tewoldeberhan Bardonnet 2002).

2.2.3 Model building

Banks (2005) has developed a methodology for simulation projects. An overview of this methodology can be found in Figure 2.8. Firstly, when building the model, it is of great importance to have a thorough understanding of the actual system. This should not be gained only by observation, it is important to take advantage of the knowledge that the persons working in the system like operators, engineers, managers etc. have (Banks et al. 2005).

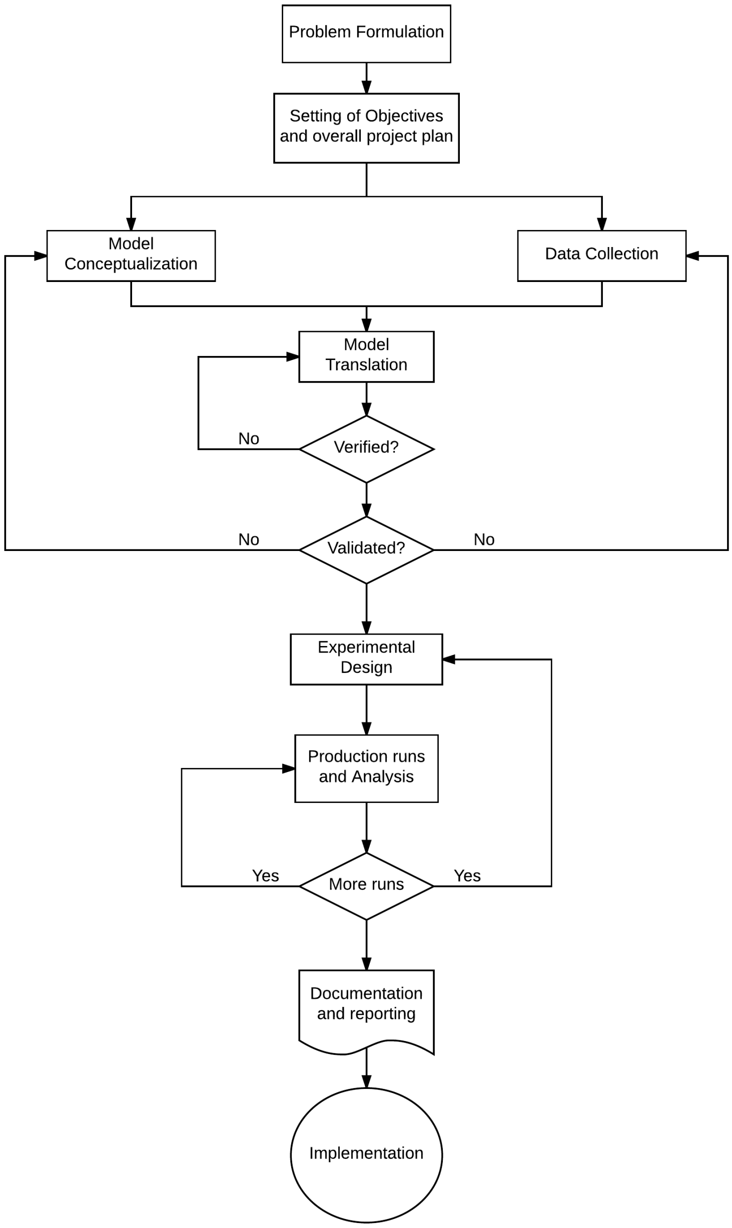

Figure 2.8: *Graphic image over the Banks simulation methodology.*

When it comes to data collection, one can think GIGO - "Garbage In, Garbage Out" (Robertson and Perera, 2002), which makes it needless to say that accurate data collection is of high importance to ensure the models quality and accuracy. The data is used to capture the realities of the system (Robertson and Perera, 2002).

The process of data collection has several inherent dilemmas, which needs to be handled (Robertson and Perera, 2002). First there is the *data accuracy, reliability and validity* of the system. It is the model builder who is responsible for acquiring the appropriate level of these three. Secondly there is the issue with *data sources* which there usually are many of and that these are widely distributed across the organization. Third, there are three different *data systems* to use to enable the capture of data. These are Computer Based Systems (e.g. database or spreadsheet application), Paper Based System (e.g. logbook for productive maintenance) and People Based System (e.g. interviews with individuals). When there are several sources to for the same data item, the fourth problem appears, *data duplication*. It is then up to the model builder to decide which source is the "best" for the simulation model. The last issue mentioned is the *timeliness*, which is the problem concerning that when collecting the data it is hard to collect data from the same time, and that some data might take longer time than others to gather. That is why it is an advantage to use iterative model building, hence one can add more details to the model as the data is gathered.

When all data is collected and received, it is important to make sense of it. As Davenport and Prusak (1998) says - there is no inherent meaning in data. This means that in order to make the data useful it needs to be transformed into information. To do this Davenport and Prusak (1998) suggests some methods. First of all it is important to understand the purpose of the data - *contextualization*. Secondly, it is necessary to understand the characteristics of the data, like which units of analysis is used and which are the key components - *categorization*. Third is to calculate new parameters from the existing data by analyzing it mathematically or statistically - *calculations*. Fourth, the data might need some modification and some data might need to be excluded for several reasons - *correction*. Finally, the data might have been summarized into a more concise form, e.g. statistically represented - *condensation*.

Next step is building the *conceptual model*. The conceptual model is the model from which the simulation model will be constructed. It contains assumptions about the system and hypotheses of input parameters. Then comes the actual building of the *simulation model*, this is when the assumptions from the conceptual model are translated into the simulation software to correspond with the real system (Banks et al. 2005). When building the simulation model Mussleman (1994) proposes that it is better to start building a simple model to capture the essence of the system, and then add complexity over time. This is a way to maintain freedom in the building process as it is more likely that the model will be harder to change if the there is to much complexity to it at an too early stage.

To ensure the quality of the conceptual model and the simulation model, there is need for *verification* and *validation* of the simulation model. The verification process is to control that the simulation model corresponds accurately with the conceptual model. The conceptual model often contains assumptions and simplifications from the real system and the verification process makes sure that these assumptions are correctly represented in the simulation model (Banks et al. 2005).
The process of validating the model is then to make sure that the simulation model corresponds with the actual system. One important aspect of this is the matter of *credibility*. Credibility is that the users trust the model enough to use the information acquired from it (Sargent, 2010). The validity of the model should also be dependant

of the relevance to the purpose of the model. The model is created with a purpose and simplifications and assumptions should not interfere with the models ability to answer the questions asked by the users (Sargent, 2010).
It is important to note that the process of verifying and validating the model is iterative and that it often is done simultaneously with the building of the model (Banks et al. 2005, Sargent, 2010), see Figure 2.9.

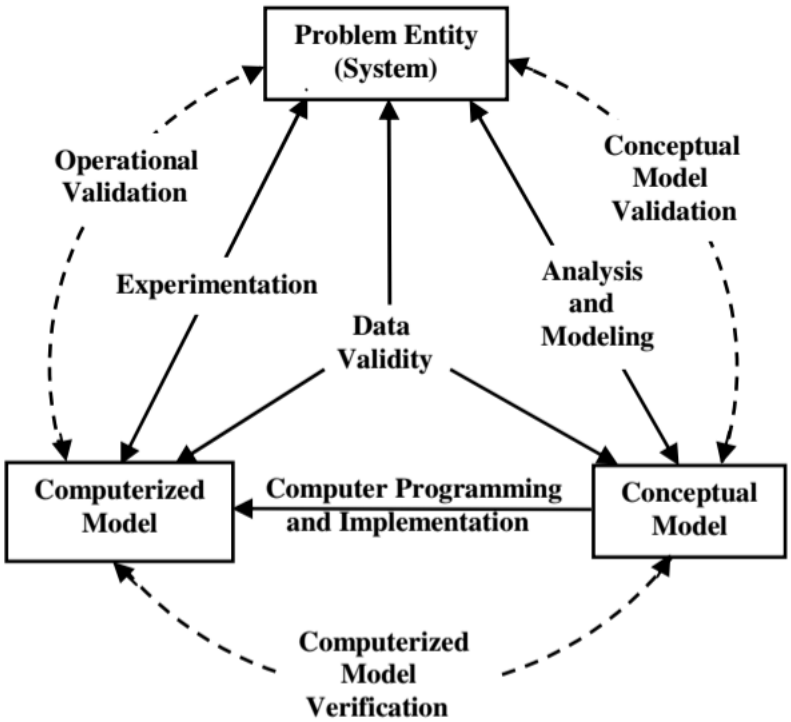

Figure 2.9: *Simple image of the model building methodology (Sargent, 2010).*

2.2.4 Generic vs. specific modelling

The creation of simulation models can often be a time consuming and thereby expensive process. The competitive pressure and fast-paced development of production theories and technologies creates a need for faster and more efficient methodologies for developing simulation models (Steele et al. 2002). In order to cope with this, Mackulak et al. (1998) suggests that a generic predefined model can be reused. Mackulak et al. (1998) further explains that generic models are computer programs consisting of pre-defined simulation models and that the use of these can shorten the model build cycle time. The ability to reuse components to build more specific models will then be beneficial when building special purpose models of different systems and scenarios.

Every simulation model will incorporate some level of abstraction and the level of detail must be decided to fit the specific purpose of the model (Mackulak et al. 1998). If a too high level of detail is chosen, chances are that the model building process will be too costly and time consuming. If the level of detail is to low, the accuracy and fidelity of the model will most probably suffer. This issue is also addressed by Steele et al. (2002), who state that a too high level of detail will make the model to complex to maintain and and understand.

2.3 Input data management

Input data management is a vital part of the project in order for the simulation model to be correct. Data is necessary to create the simulation model, as well as to test its validity (Robinson and Bhatia, 1995). It is possible to divide the data into three categories to aid the collection, see Table 2.1. A methodology developed by Skoogh and Johansson (2008) will be used as a framework for the input data management.

2.3.1 Input data methodologies

There are currently four input data methodologies or practises for how to store and process the collected data (Skoogh et al, 2012). Methodology A is practiced when the input data is manually entered into the simulation model by the model builder. This can be seen as the simplest method, however there are certain disadvantages like scattered information and that the method is time consuming. Methodology B is practised when the input data is manually collected but stored in an external source, e.g. a spread sheet. There are several advantages with this method compared to Methodology A. The processing and verification of the data becomes easier, which increases the flexibility in the model. However, the data collection is still pretty time consuming. Methodology C can be seen as an extension of Methodology B. In this methodology one link external data sources to simulation model's data storage, and since the data is gathered automatically, the time for data collection is decreased. Having an automatic data collection is not only beneficial though, and a difficulty is to ensure the data quality. Neither Methodology C or Methodology D have been implemented much in the industry. Methodology D is when there is no intermediate data source between the simulation model and the data sources. This is a bit tricky though, since there is a need of substantial amount of connections to different data sources, the risk for data duplication is high. Also, there is limited availability of all needed parameters for the simulation model.

2.3.2 Framework

Skoogh and Johansson (2008) have developed a structured methodology which links the activities of input data management. This methodology is based on a survey among 15 previously completed simulation projects. The methodology consists of 13 steps, see Figure 2.10. A short description of each step follows below.

Step 1 is to identify and define relevant parameters. All identified parameters needs to be defined based on how they shall be represented in the model and what each parameter consists of. Different companies might measure the same parameter in two different ways, and it is important to be consistent and follow the same way of measuring as the company where the model will be applied does. A part of this step will therefore be made in collaboration with a representative from the company. In this step a classification of the parameters will be made as well, based on the estimation of availability.

Step 2 is to specify the accuracy requirements. In this step it is important to define how many samples that will be needed to reach the desired accuracy. A rule of thumb is to collect at least 230 samples of all parameters.

Step 3 is to identify available data. Available data is data that belongs to Category A. This is data that can be extracted from computer systems. It is important to make sure the required data is measured in a proper way and possible to extract.

Table 2.1: Classification of data based on availablity (Robinson and Bhatia, 1995).

Category A	available data
Category B	not available but collectable data
Category C	not available and not collectable data

Step 4 is to choose methods for gathering not available data. In this step no data will be collected. The focus will be on *how* to gather and estimate data that belongs to Category B and Category C. A common way of collecting data for Category B is to use a stopwatch to measure parameters. To ensure good data, it is important with instructions for how the measurements will be made, so different people can measure the same thing and get the same results. When measuring parameters involving people, it is important to be extra cautious to ensure co-operation.

Step 5 is to answer the question "will all specified data be found?". To answer this question one must take certain things under consideration; will there be enough data points and how is the data's accuracy and quality? If these aspects not are good enough there will probably be trouble later in the project. If some important parameters are impossible to collect according to earlier requirements, these have to been re-evaluated.

Step 6 is creation of data sheet. According to Skoogh and Johansson (2008) it is important to collect all data in the same place to ensure structure.

Step 7 is to compile available data. All data in Category A will in this step be collected and analyzed. Some parameters will have to be calculated out of the raw data. Pre-analyzed data (data which has been used in earlier projects etc.) may be used right away.

Step 8 is to gather not available data. In this step an effort will be made to turn data that belongs to Category B and Category C to data that belongs to under Category A. Category B data will be collected, which might be time consuming considering the number of data points needed. Category C data will be estimated, preferably with help from process experts. The result from this step should be more sheets of raw data to analyze.

Step 9 is to prepare statistical or empirical representation. Depending on the data, different measures need to be taken. For data describing variability, efforts to find the correct statistical representation will be needed.

Step 10 is to see if there is sufficient representation of the data. This means deciding whether or not the statistical representation in Step 9 will suffice for the model. It is important to ensure that the calculated and gathered parameters and their statistical representation corresponds with the real world. If not, additional data collection and analysis is needed.

Step 11 is to validate data representations. This step is important to ensure that the raw data is correctly measured, filtered and analyzed. A sensitivity analysis can be made once the model is built to validate the data further.

Step 12 is to use the validated data in the simulation model. To use validated data in the model might prevent unnecessary future iteration of data collection, however there might still be failure in model validation later in the project.

Step 13 is to finish final documentation. The result of this step should be a document containing everything concerning the data analysis and data gathering and the completed data sheet. This information is important for future referencing and reuse.

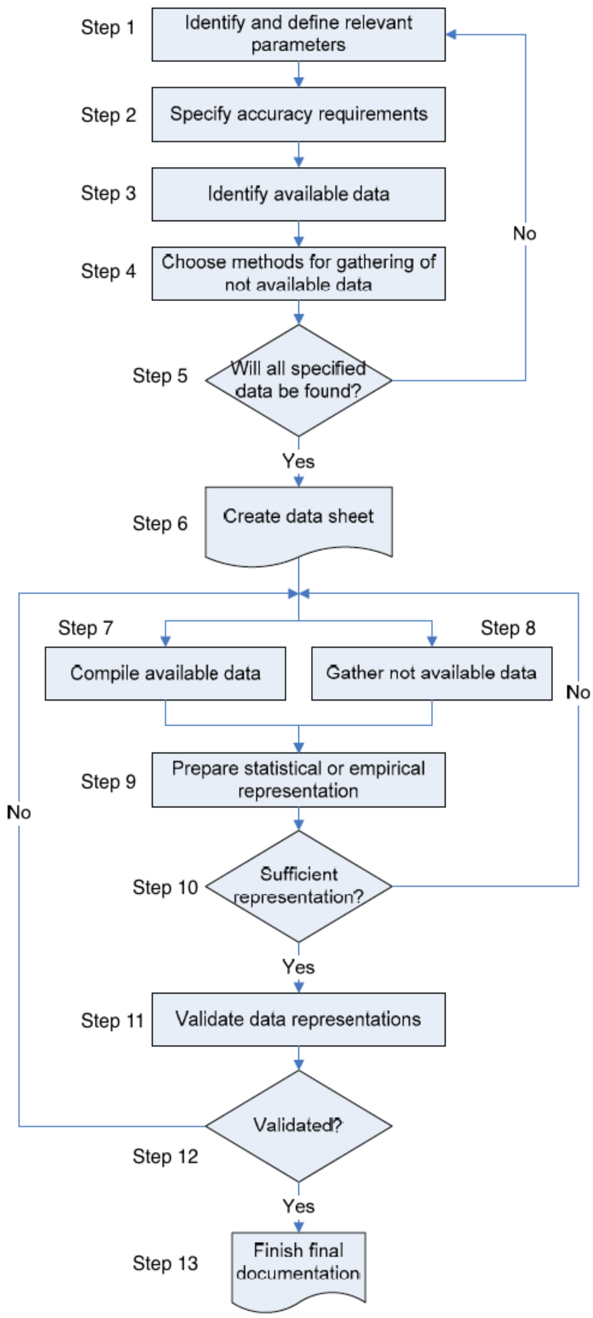

Figure 2.10: *Input data management methodology (Skoogh and Johansson, 2008). The picture has been edited to clarify each step.*

2.3.3 Statistical distributions in simulation

When modelling real-world systems with real-world system dynamics, disturbances will have many different causes which leads to large variations in length and effect of any disturbance. These different causes often appear to happen randomly and cannot be predicted. To cope with this, the model builder sees the world as probabilistic rather than deterministic (Banks 2010). Some statistical and probabilistic models can be used to resemble the real-world behaviour of the system. A way of doing this is to observe the phenomenon of interest, sample it and analysing it. Through analysing the samples, the model builder can make an educated guess to choose an appropriate distribution model. This educated guess is most often done by using software developed for this purpose (Banks 2010). As a part of the validation process, the chosen model should then be tested to see how well it resembles with the real system.

2.4 Boundary objects

In product development projects, ambiguity is a common issue which can lead to confusion and lack of understanding (Lindlöf, 2014). However, a way to decrease ambiguity is to use visual tools as a mean of communication. One of these tools is the use of boundary objects. Lindlöf (2014, p. 18) describes boundary objects as "*...objects, often physical artifacts that mediate communication between individuals or groups of individuals with different perceptions of the topic or content that is communicated...*". Individuals can still have different interpretations of the boundary object, however the boundary object facilitates between these interpretations (Lindlöf, 2014). Using boundary objects in organizations is a way to find a common ground which most people can relate to.

3

Factory descriptions

In this chapter, the production flows in Holsbyverken and Skeppshult are described. The production flows are described step by step and follows the order of the production flows. The identified differences are presented in the last section of this chapter.

3.1 Visit at Holsbyverken

The visit at Holsbyverken was made in order for the group to gain an understanding of the production flow. During this visit, tours were taken around the factory and the group talked to workers and asked questions to understand how the processes work. Below follows a description of the factory flow at Holsbyverken.
Holsbyverken has a capacity of 10 000 tons casted products per year, and most customers come from the engineering industry. Holsbyverkens strong side is the possibility to cast a high variety of products in sizes from 1 kg to 10 000 kg.

3.1.1 The production flow at Holsbyverken

Step 1 - The core making First step of the process this thesis will cover is the making of the cores. This is done in the core making area where Holsbyverken has four machines available for this purpose. Three so called Disco-machines and one Laempe-machine. The differences between these machines is the size of the cores. Also, the Disco-machines can make 3-4 different cores simultaneously while the Laempe-machine only can handle one core box at a time. One of the Disco-machines is connected to a computer system named Axxos, which logs the events, such as stops and change-over times, and makes the operator write a note about why the machine has been standing still if the stop lasts for over 120 seconds. The cores are then put on an EUR-pallet with three collars before it is either moved to a storage before the blackning process or before the HWS-machine. About half of the cores need to go through the blackning process. In order for the binder in the cores to cure properly, the cores are held i storage for at least 24 hours before they are blackened or used in the HWS-machine.

Step 2 - Blackning To make the core stronger and more resistant and to improve the resulting surface finish of the casted product, some cores are "blackened". This means that they are dipped in blackening-fluid and then burned to remove the water in the blackening-fluid, see Figure 3.1. The blackened cores are then stored for at least 24 hours before they are used in the HWS-machine, this is to make sure that the cores are dry and cured before they reach the HWS-machine.

Figure 3.1: *Cores that are burning to vaporize and remove the water in the blackening-fluid. In the background is the storage with cores waiting to be blackened.*

Step 3 - HWS-machine This machine contains several process steps. The first process step is the *creation of molds*, which is fully automated. One mold is created each minute. The second step process is putting the cores into the mold, see Figure 3.2. This is a fully manual process and also contains a quality check of the molds and cores.

Figure 3.2: *Cores that have been put into the molds. The flask containing the cores is the drag and the one next to it is the cope, later the cope and drag is put together to create a whole flask.*

The third process step is casting. This is done manually with an operator pouring melt into the flasks one-by-one, see Figure 3.3.

Figure 3.3: *The manual casting process.*

After the casting has been done, the products need to cool down, to do this the flasks are moving along the cooling line for about an hour before the sand is removed from the flask along with the casted product. The products are gathered in a container and then transported to the next step in the production flow.

Step 4 - Abrasive blasting In this process step residual sand is removed by tumbling the products together while blasting them with abrasive particles. This is done in batches and is a fully automated process.

Step 5 - Fettling and Quality control The last step is for the operators to "break of" the gating and the rising system from the casted products. This is called fettling. Before the products are being packed, the operators perform a quality control. The products are then transported to another foundry for machining and finishing.

3.2 Visit at Skeppshult

Skeppshult produces consumer goods. The product portfolio consist mainly of kitchen utensils.
Skeppshult have also kept assembly and processing in-house and delivers directly to customers or retailers. This however was not considered since this is not done at Holsbyverken and is not subject to this paper.

3.2.1 Production flow at Skeppshult

Step 1 - Making of molds The molds at Skeppshult does not consist of any flasks, the molds are just pressurized sand i.e, the sand is not in a container. This is a semi-automated process that need an operator to clean between each mold.

Step 2 - Mold buffer The molds are gathered in a small buffer where they wait to be filled with melt.

Step 3 - Casting The molds are manually filled with melt in batches of 24 molds.

Step 4 - Cooling The molds that are now filled with melt, are placed in a buffer to cool down before they are moved to the shake-out process.

Step 5 - Shake-out and Fettling The products are separated from the molds, manually fettled and batched together in a basket that is transported to the blasting.

Step 6 - Abrasive blasting The casted products are placed in a basket that is moved into the blasting container where the products are blasted with abrasive particles to remove residual sand from the molds.

Step 7 - Machining After the blasting the products are machined several times. The machine processes are milling, grinding and lathe turning.

Step 8 - Surface finishing The products are covered in oil and then burnt in an oven, this creates a black surface that is more suiting when cooking.

Step 9 - Assembly and Packaging Handles and other accessories are assembled to the products before they are packed and sent to retailers.

3.2.2 Differences between Skeppshult and Holsyverken

The differences in the foundry processes are mainly due to the product differences. Skeppshult produces very few products that are hollow, which results in a close to non-existing core production. At Skeppshult there is one machine for core manufacturing but it is rarely used, while at Holsbyverken half the production flow is the cores. The machining and assembly of the products are done in-house in Skeppshult which is not the case in Holsbyverken, where the products are sent to a different foundry for this. The mold making is done differently at the two foundries, at Skeppshult, this is done with a match-plate pattern in a semi-automated process. In Holsbyverken, this is a fully automated process that is done with cope-and-drag patterns. The molds at Skeppshult are not contained in flasks as opposed to Holsbyverken where the sand is poured into flasks and pressurized to create the molds.

4 Methodology

In this chapter the work process is described. The chapter also contains information about the data collection, the factory visits and the development of the simulation model.

4.1 Work process

The work process was divided into five phases; project planning, company visits, development of generic simulation model, meeting at Swerea SWECAST and rounding up. See Figure 4.1 for a schematic picture over the project process.

In the planning phase, the main activities were planning the project and performing a literature study. Through this first phase, the scope, the purpose and the research questions for the project was formulated. This created the foundation for the master thesis. A time plan in the shape of a Gantt chart was also created for all main activities. An extensive literature review was conducted, which created the theoretical framework for the project and the thesis.

The second phase of the project was company visits. Two foundries were visited; Holsbyverken in Vetlanda, Småland and Skeppshult in Skeppshult, Småland. Since Holsbyverken was supposed to be the blueprint for the simulation model, the visit there was much more thorough and detailed than the visit at Skeppshult. Both visits played an important role in the development of the generic simulation model.

The third phase was the development of the generic simulation model. The two main activities in this phase were the data collection and building the simulation model. Due to geographical distance and safety regulations, the whole data collection could not be performed by the group itself. Help was received from Holbyverken. When building the model, a simulation software called AnyLogic was used. Phase three was an iterative process, where the data collection and the building of simulation model was iterated.

When the model had taken its shape it was time to enter phase four which was meeting Swerea SWECAST and representatives from the foundry industry. The model was shown and used as a boundary object for further discussions. It was during phase three and phase four results for the master thesis report was gathered.

In the fifth and final phase, rounding up, it was time to summarize the results and put them into the masters thesis report. From the results conclusions could be drawn. Once the report was finalized, it was both presented at Swerea SWECAST and at Chalmers University of Technology.

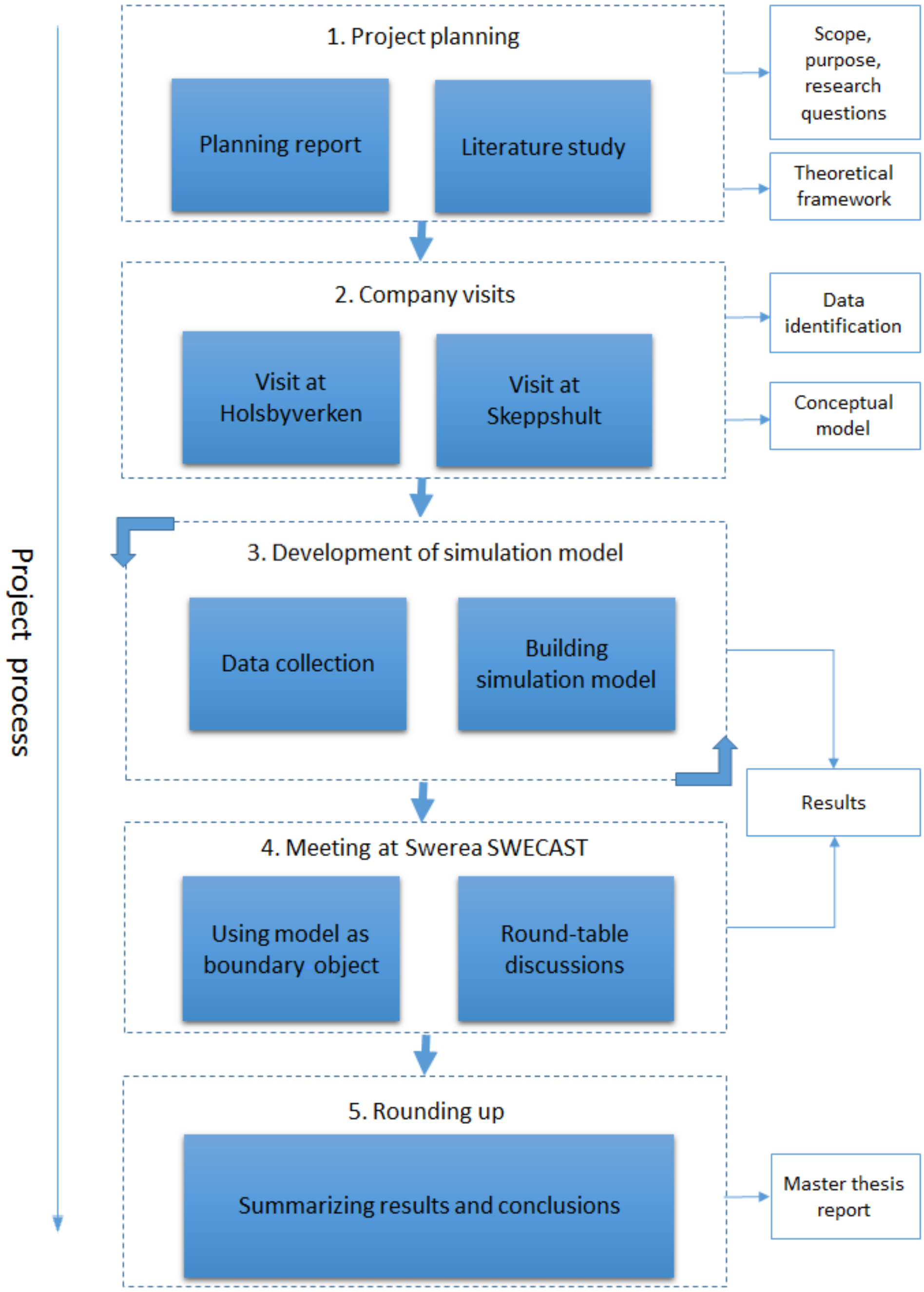

Figure 4.1: *Image over the project process, with its five phases and main activities.*

4.2 Company visits

In this section the company visits will be described. The section also contains a section about identified data from Holsbyverken. In order for the group to gain further understanding of what parameters that differ between different foundries, a visit was made to the foundry Skeppshult in Skeppshult.

4.2.1 The visits

The visit at Holsbyverken was during three days. The group was introduced to the production system and had a thorough walk-through through the production flow, guided by two representatives from Holsbyverken, an engineering consultant and a development engineer. Operators were talked to and many questions asked and answered during these three days. At the end of the visit, the conceptual model and the data identification was presented and discussed with the two representatives from Holsbyverken, who approved of it.
The visit at Skeppshult was significantly shorter and less detailed. The visit lasted for two hours and was a quick walk-through through the production flow. The group only talked to the quality manager which showed the group around.

4.2.2 Data identification

As mentioned in the theory chapter, a way to make some sense of the data is to categorize it into three different categories; A, B and C depending on availability. This was done while walking around the production system and looking at the processes. As mentioned earlier, Holsbyverken has four different machines for core manufacturing, three Disco-machines and one Laempe-machine. The group decided that the Laempe-machine differs from the Disco-machines to such a degree so it should be excluded from the model. Hence, only the three Disco-machines are in the conceptual model and the simulation model.

4.2.2.1 Category A data

The data which was considered appropriate in Category A was the data which was possible to derive from Axxos. Axxos is a system which registers stops from certain machines, and if the machine stands still for too long the operator needs to write a note where it is described why. At Holsbyverken, two machines were connected to Axxos; Disco 4200 and the HWS-machine. From these machines the following data was withdrawn.

Parameters possible to receive from Axxos to Disco 4200

- **Changeover time** - since these stops are being logged as they are, it is possible to derive the changeover times from the log. Since the three other core making machines are not connected to Axxos, it is assumed that this changeover time is the same in all four machines.

- **MTTR**[1] - when the machine has stopped. These stops has been gathered together and counted as MTTR.
- **MTTF**[2] - the time the machine is up between MTTR and changeover times. This parameter was calculated.

Parameters possible to receive from Axxos to HWS

- **Changeover time** - this is the changeover time it takes to change match plates in the creation of flasks process.
- **MTTR** - the time the machine, the creation of flask process, has stopped for reasons change of pallet, short stop, machine stop and sand processing.
- **MTTF** - the time the machine, the creation of flask process, is up between MTTR and changeover times.

To ease the modeling of the HWS-machine, the machine was divided into several processes and buffers; creating of flasks, putting the core in place, buffer before casting, casting, cooling buffer, shake-out and buffer after shake-out. The cycle time for the HWS-machine is pre-determined and is 60 seconds. This is the time it takes to create one flask.

4.2.2.2 Category B data

The data that was considered appropriate in Category B was the data which was possible to study, clock or in other ways collect. The parameters connected to this data was discussed and decided together with system experts to ensure that it is possible to go through with the collection. Most of this data is gathered by Holsbyverken due to security and convenience. These parameters were the following:

- Number of products in buffers.
- The time it takes to make one batch of cores in "blackning".
- Cycle times on the core making machines.
- Speed of casting process, e.g. how fast the melt is running into the flask.

The parameters are gathered through observations and time taking. There are no further information on how each parameter was gathered due to adjustment to Holsbyverkens available time for the project.

4.2.2.3 Category C data

The data that was considered appropriate for Category C is the data which is not collect able and not possible to represent correctly in the model due to high variance of products and cores. Instead this data was categorized based on assumptions. The assumptions are the following:

1. All cores can be divided into four groups depending on their size. Large, medium, small or non-existing. Connected to these groups follows certain parameters, see Table 4.1. Cores come in many different appearances, however due to the high variation, the cores are only grouped depending on the size of their core box.

[1]Mean Time To Repair (MTTR). Describes how long the stops are. The stops does not necessarily need to be due to maintenance.

[2]Mean Time To Failure (MTTF). Describes how long time there is between the stops.

2. All products are divided into groups depending on size. Similar to the groups with cores, these groups have certain parameters connected to them, see Table 4.2 .

Table 4.1: Groups of cores and their respective parameters.

	Small	Medium	Large	No cores
Parameters	batch size size cycle time core machine	batch size size cycle time core machine	batch size size cycle time core machine	

Definition of parameters:
Batch size - How many cores can fit on a EUR-pallet with three collars. This definition was found appropriate as the cores are usually gathered in a EUR-pallet like this before taking to storage.
Size - The size of the cores are defined by the largest size possible for the core box in the different core machines. This gives the small cores the maximum dimension of 300x300x300 mm, the medium cores the maximum dimension of 400x400x400 mm and the large cores the maximum size is 600x600x600 mm.
Cycle time - The time it takes between putting one core box into the core machine and taking out another.

Also, when representing the products in the system, a lot of assumptions needed to be made. Similar to the assumptions made with the cores, the products were divided into different categories depending on size. Parameters of importance for each category of products were:

Table 4.2: Parameters to each category of products.

	Each category of products
Parameters	volume and dimensions how many cores and of which size batch size when going to blasting the amount of products which fits one flask order size order frequency casting time

Definition of parameters:
Volume and dimensions - What is the volume of the products. Products may have very different shapes and appearances, however focus will be on their volume, which will make it possible to calculate how long time it takes to cast one product.
How many cores and of which size - How many cores does each group of products require, and from which size of cores?
Batch size when going to blasting - How many products fit into a batch when

going to blasting?
The number of products that fit into one flask - Unless the products are big, it is rare to only cast one product in one flask. Therefore it is necessary to know for each category of products how many products that fit into one flask.
Order size - When each category of product is ordered, how large is the order?
Order frequency - How often does each category of product get ordered?
Casting time - The casting time is dependent on how much volume of melt that the flask needs, i.e. the volume of the total amount of products in one flask. The melt is entering the flask with 3.5 kg/second.

4.2.3 Development of conceptual model

Based on the visit at Holsbyverken, a conceptual model was be created that contained the logical structure of the production flow. The model was created on a big paper to get the full picture of the system and to use as a boundary object when discussing it with the system experts at Holsbyverken. Pictures of the production system and data from Axxos served as base for the development of the conceptual model and guided the group in the process of conceptualizing the structure of the flow. The conceptual model was used as a blueprint for the simulation model.

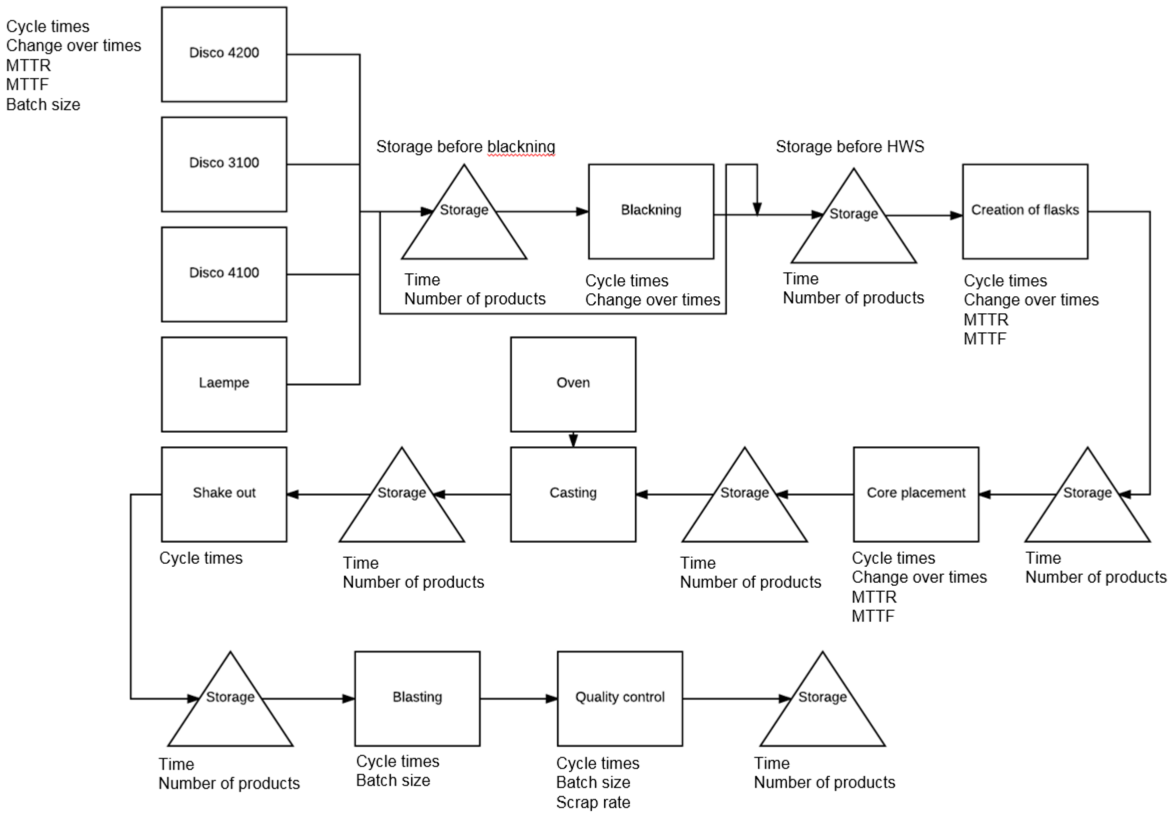

Figure 4.2: *Conceptual model over Holsbyverken.*

The conceptual model consists of the different processes and buffers in the production flow and served as background for the construction of the simulation model. In each step of the production flow in the conceptual model, the important parameters are listed, which was discussed with system experts. In order to get data on these parameters, the parameters were evaluated based on the availability of the data.

4.3 Development of simulation model

In this section it is possible to read about the simulation software and the simulation process.

4.3.1 Simulation in AnyLogic

AnyLogic allows the user to "drag-and-drop" pre-defined blocks when building the model. The program is grounded in the object-oriented language Java, which facilitates the process of learning AnyLogic, as long as the user is comfortable with Java.

AnyLogic allows a multimethod simulation approach. This means that the program combines three different simulation approaches which can be used together or individually. The three simulation approaches are *Systems Dynamics*, *Discrete Event Modeling*, and *Agent Based Modeling* (AnyLogic, 2017a). Even though the focus of this masters thesis is on Discrete Event Modelling, the possibility of other simulation methods is always an advantage. System Dynamics is a method mostly used when there is a high level of aggregation of the objects being modeled (AnyLogic, 2017b). Agent Based modeling puts focus on the individual objects in e.g. an organization and take their actions and behaviours under consideration as well, instead of all objects being passive and "only moving around in the system" (AnyLogic, 2017c).

When using DES in AnyLogic, the model is graphically specified as a process flowcharts which the entities then move through. Every process flowchart begins with a *source* and ends with a *sink*. From the source, entities enters the system and then leaves the system through the sink. The blocks in the flowchart represents operations and the entities may represent products, clients, phone calls etc. There are also *Resources* which represents operators, doctors, servers, etc (Borshchev, 2013).

4.3.2 Modelling Holsbyverken i AnyLogic

When modelling Holsbyverken in AnyLogic, it was not clear what the entities should represent though the whole production flow since there are no concrete products flowing from the start to the finish of the system. The group then decided that the entities should be represented by different things through the model. The first thing that is produced in the flow in Holsbyverken are the *cores*. The model then starts with the production of cores in three parallel flows representing the three core manufacturing machines. The entities represent the cores through the blackning up until they are put in the flasks. The process where the cores are being put in the flasks in the flow is where focus is drawn from the cores to the flasks and the entities

now represents flasks. Each flask can contain different number of products but up until the shake-out process, each flask is represented by one entity.
The shake-out process is where the entities starts to represent actual products instead of cores or flasks.

Due to the high variance and complexity of the products produced by Holsbyverken some generalizations and segmentation needed to be made. Firstly, the cores are separated in to four segments or categories, the first three categories consist of actual cores and the fourth is no-existing cores. This category is there to represent the products that do not require a core. The existing cores, divided into three categories are divided based on which machine they are produced in. This estimation was considered sufficient since the three machines can handle different core sizes and that the calculations on the product costs are based on which machine that will be required.
The flasks are also divided into categories based on the amount of products that fit into one flask. This in turn depends on the product size or product type. The product type is what decides how many cores that are required per product and how many products that fit in one flask. The segmentation of products is based on the size of the product. The product order will assign the flask types that correspond with the amount of needed cores per flask and then how many products it will generate in the end. To cope with this complexity, parameters are assigned to all categories of cores, flasks and products that will determine cycle times, amounts and batch sizes that varies with the different products.

4.3.3 Validation of the model

In order to get an adequate comparison between the model and the production at Holsbyverken, the model needed to run under the same circumstances as in reality. The results from this could then be compared to determine how well the model mimics the real system.
The circumstances included the product data of the products that was produced during a month. This was the quantity of products produced, the amount of cores required to produce the different product types and of what size the cores were and how many products that fit in to one flask. With this data, the model could be run in a way that would generate comparable results and thereby a degree of validity. The group also left room in the model for this data to easily be changed in the model after it was built.

4.4 Meetings at Swerea SWECAST

In order to get feedback on the model and basis for discussion, two meetings were held at Swerea SWECAST. The first meeting was mid-April and the second meeting was in the beginning of May. At these meetings, the model was presented in its current state, the presentations were followed by round table discussions where industry representatives asked questions and provided input on the model. The group wanted to invite as many representatives from the foundry industry as possible to get as broad spectrum of input as possible. The attendants for the meetings can be found in Table 4.3 and Table 4.4. The discussions were recorded in order to document what was said. The discussions were on a semi-structured level where focus was on the research questions and anyone could ask questions and give comments.

The model, when it was presented, functioned as a boundary object that everyone could relate to during the discussions. The model allowed everyone round the table to get a common understanding and communicate around the model across the boundaries of their area of expertise within the casting industry.

Table 4.3: People attending meeting 1.

	Professional title	**Company/Organization**
Person 1	Research leader Resource efficiency	Swerea SWECAST
Person 2	Manager Test and Demonstration	Swerea SWECAST
Person 3	Reserach engineer production development	Swerea SWECAST
Person 4	Development Engineer	Holsbyverken

Table 4.4: People attending meeting 2.

	Professional title	**Company/Organization**
Person 1	Research Leader Resource Efficiency	Swerea SWECAST
Person 2	Manager Test and Demonstration	Swerea SWECAST
Person 3	Research Engineer Production Development	Swerea SWECAST
Person 4	Research Engineer Environment and Sustainable Industry	Swerea SWECAST
Person 5	Research Leader Material Development	Swerea SWECAST
Person 6	General secretary	Swedish Foundry Association
Person 7	Quality Engineer	Skeppshult

5
Results

In this chapter, the results will be presented, brief reflections upon their relevance and backgrounds will also be included.

5.1 Data collection

When it came to the data collection, it proved useful to divide the data into the three categories A, B and C to keep it organized. The data which was collected from Axxos and identified to Category A reached the desired level of accuracy and reliability, which the data that was identified in Category B and Category C did not. As mentioned in the theory chapter, the wanted sample size is 230 samples, and as this could not be acquired, the importance of a large sample size became clear. For most parameters in Category B and Category C the sample size was 1-5 samples which lead to many estimations and less reliability.

Thus some information that belonged to Category C could be assumed, there was gaps in the assumptions. Data about the cores was possible to receive, however there was no way to connect the cores with the products. As a matter of fact, it was not possible to collect any information about the products at all, as the relevant information needed for the model was stored in three different data bases which seemed to be existing independently. Due to this, the knowledge needed to do the desired categorizing of the products was missing and no estimations from the system experts could be made on this matter. This left the group with no choice but to decide for themselves how the products should be categorized and how the parameters in each group of parameters should be defined.

There were not only gaps in the assumptions concerning data for Category C. Information gaps existed throughout the whole organization due to a lot of tacit knowledge in the organization and among the operators. Tacit knowledge is knowledge which is hard to verbalize and write down to a person on the outside. An example of this tacit knowledge was discussed during the meetings with Swerea SWECAST where a representative from Holsbyverken described the production system and core manufacturing as “there is always a shortage of cores, yet everything is always running”.

5.2 The simulation model over Holsbyverken

In this section, the model will be described along with an example of how the model can be used. The model is in Swedish since it was developed for a Swedish company.

5.2.1 Overall model description

The model is developed to graphically reflect the production flow in Holsbyverken as can be seen in Figure 5.1. The flow in Figure 5.1 describes the logic of the flow in the simulation model and each block represents a step in the production flow. Green blocks are processes, yellow are storage's and buffers. The blocks will be referred to as *passive agents* in the continuation of this thesis and are merely collections of the standard building blocks provided by default in AnyLogic.

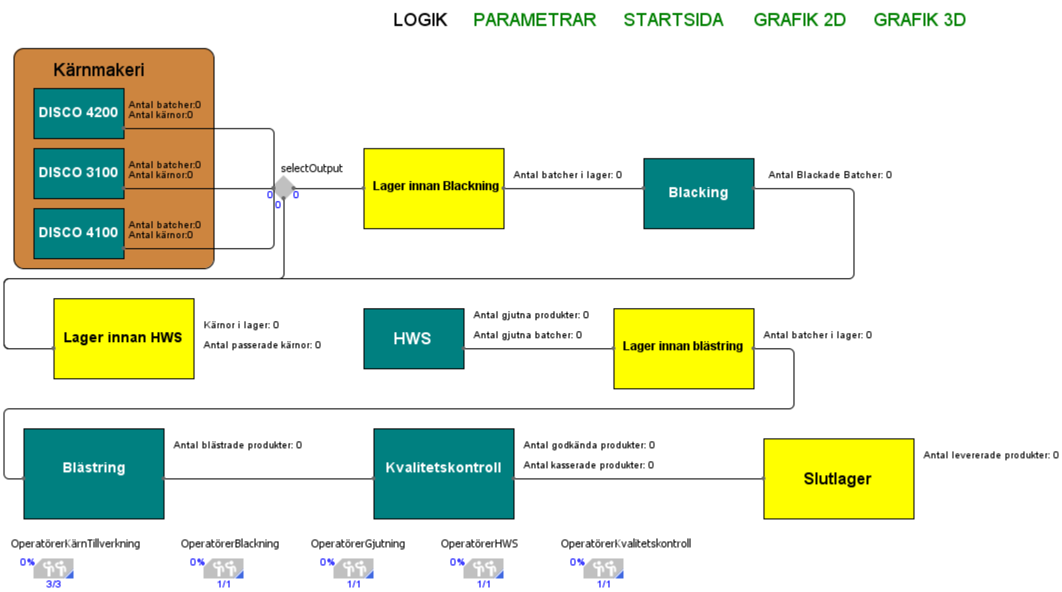

Figure 5.1: *Picture of the production flow in the simulation model. The yellow and green blocks are called agents, and work as building blocks.*

As in reality, the processes involve internal logic for cycle times, setup times etc. This internal logic is represented by the smaller blocks that can be found underneath the icons. An example of this can be found in Figure 5.2, where the logic of the HWS-machine is gathered under the block that says "HWS". This process in particular is where the cores of different categories are picked up by the flasks. The flasks then move into the casting process on to the conveyor that represents the cooling phase. When the flasks leave the conveyor, they arrive to the shake-out, which is represented by the triangular shape, called "split" before the products are batched and sent out of the HWS block. The connecting line between the batching and the rectangle is there to represent that this is the output port of the HWS. This means that the output from the HWS block is products in batches, which is also the case in Holsbyverken.

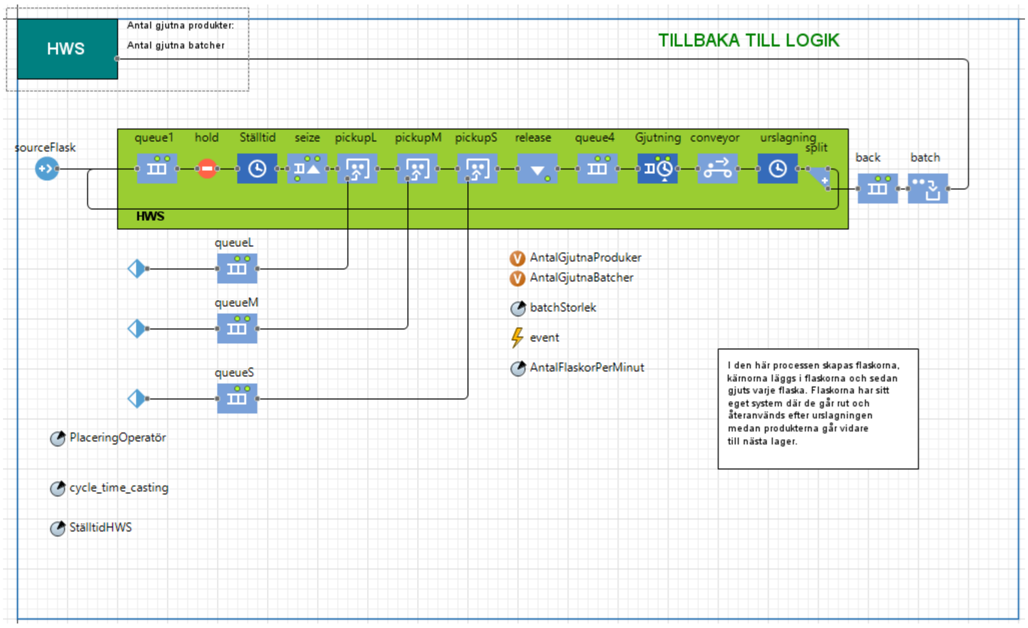

Figure 5.2: *The logic behind the HWS-machine at Holsbyverken. This logic is found behind the passive agent.*

To get a more accessible view over the factory in Holsbyverken, more graphical presentations of the production flow can be seen either in 2D or in 3D, shown in Figure 5.3 and Figure 5.4.

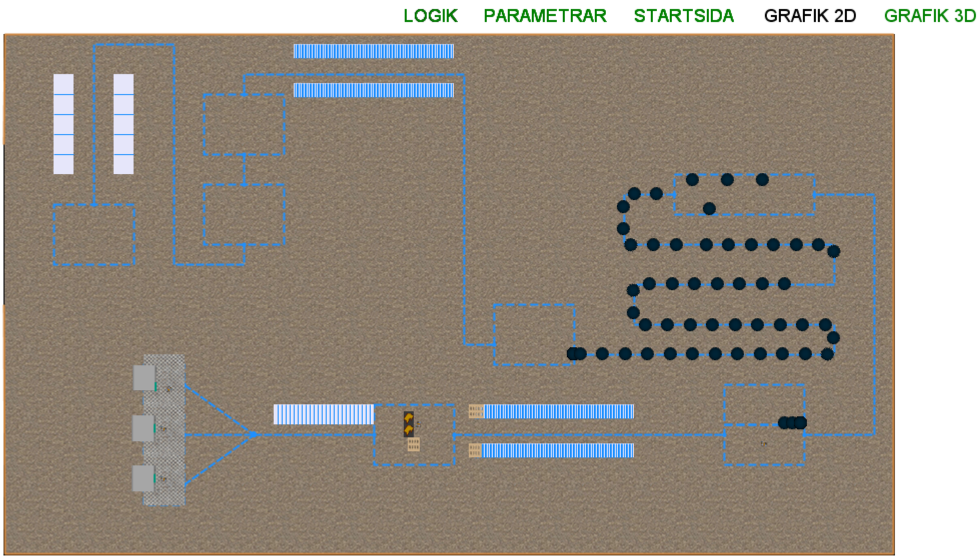

Figure 5.3: *The 2D graphical representation of the flow.*

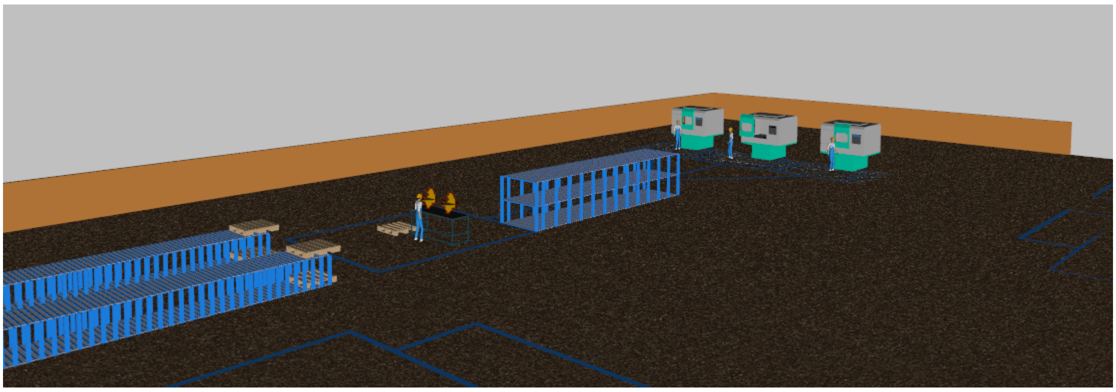

Figure 5.4: *3D representation of the flow showing the core making and Blackning.*

To start the simulation, the model has three different options to start;

- Simulate with Excel parameters
- Simulate with manually entered data
- Simulate with default-values

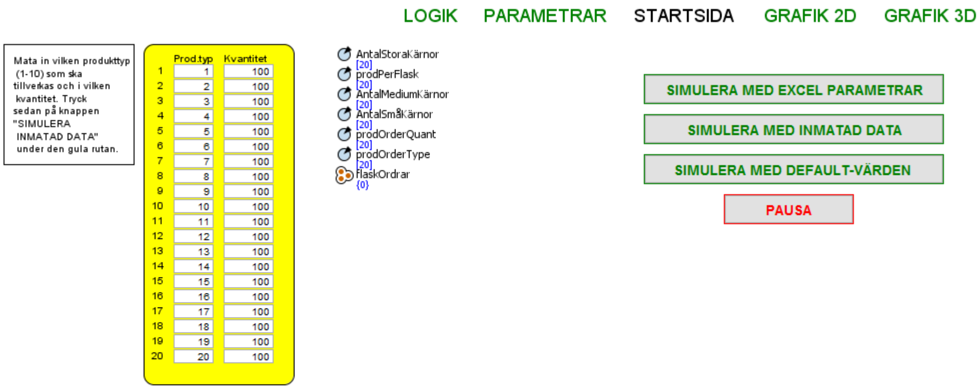

Figure 5.5: *The start page where it is possible to choose how the simulation should be runned.*

The information the simulation model requires to start running is:

- Which product? At the moment they are identified with numbers 1 to 20.
- How many cores does the product contain, and of which size?
- How many of these products fit into one flask?
- How many products of each type is desired?

Depending on which option to start the simulation the user chooses to use, different amounts of data need to be entered by the user him- or herself. When simulating with default values, the user does not need to enter any data by him- or herself. The simulation model will randomize the product order sequence and quantity. Each product type is predefined with the number of cores and of which size. How many products that fit into one flask is also predefined. If the user wants to decide the order sequence and quantity, it is possible to enter the order sequence manually, and the desired quantity. However, similar to when running the default values, the number of cores and how many products that fit per flask is already defined.

If the user wants to define the products by him- or herself, it is possible to do so when simulating using the Excel spreadsheet. When simulating with Excel parameters an Excel spreadsheet needs to be used. In the document it is possible for the user to define the product types. The order sequence is decided by the order the products are entered. Each product needs to be defined with how many cores is should contain and of which size, how many of the products that can be casted per flask and in which quantity. See Figure 5.6.

There are parameters that effect the logic of the production flow e.g. cycle times, batch sizes and scrap rate etc. These parameters are possible to change in the interface shown in Figure 5.7. The parameters can easily be changed either before the simulation starts or during the simulation run.

Ordersekvens och produkttypegenskaper

Produkttyp	Produktnamn	Antal stora kärnor	Antal mellan kärnor	Antal små kärnor	Produkter per flaska (Int)	Kvantitet
1	Produkt1	1	2	3	2	100
2	Produkt2	2	4	5	3	353
3	Produkt3	1	1	2	1	632
4	Produkt4	1	3	3	2	634
5	Produkt5	1	2	4	3	240
6	Produkt6	0	0	3	3	362
7	Produkt7	2	1	1	1	948
8	Produkt8	4	2	2	2	123
9	Produkt9	1	1	0	1	45
10	Produkt10	3	1	1	1	343
11	Produkt11	2	1	3	1	24
12	Produkt12	0	3	0	2	245
13	Produkt13	2	0	1	3	14
14	Produkt14	4	4	0	0	52
15	Produkt15	1	0	1	2	524
16	Produkt16	0	3	0	5	62
17	Produkt17	0	1	2	3	67
18	Produkt18	0	2	3	1	865
19	Produkt19	3	1	2	2	96
20	Produkt20	0	3	0	4	29

Figure 5.6: *An overview of the Excel spreadsheet.*

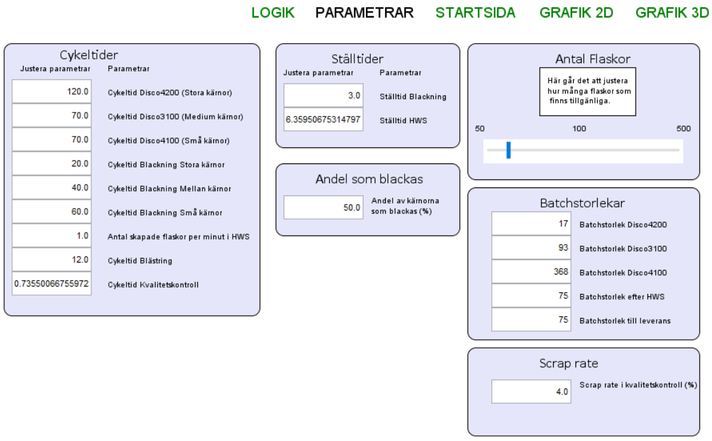

Figure 5.7: *An overview of the interface in which the parameters can be altered.*

5.2.2 Adapting the simulation model to Skeppshult

When trying to adapt the model to Skeppshult, the second foundry that was visited during the thesis work, it was noticed that even though the foundries look similar at first sight, they are quite different. The similarities was foremost due to the high variance of products and the old kind of production system. However, they are more different than similar. First of all, the products casted at Skeppshult rarely contains any cores. In the simulation model created with Holsbyverken as a blueprint, half the model represents the manufacturing and flow of the cores. This means that when trying to adapt the simulation model to the production system of Skeppshult, half the simulation model would be of no importance. Secondly, the machine in which Skeppshult creates their flasks, could at first sight look similar to the HWS at Holsbyverken. However, as was discovered by the group the hard way, things may be similar in real life, but different as day and night when created in the simulation model. To adapt the existing HWS in the simulation model to the one in Skeppshult was impossible, and it would have been easier to create a new agent instead which represents the machine at Skeppshult. (Note: this was not done due to not enough details about the machine at Skeppshult.) Third, Skeppshult does not only cast products, they do all the finishing work and packing necessary to deliver the products to customers, which are other processes that, if added to the model, would change the model tremendously.

5.2.3 Example of how the model can be used

To demonstrate how the model can be used, an experiment with how the number of cores in each product affects the output. The goal with the experiment was to see which category of cores that affects the output the most. First the large cores were studied. By changing the number of large cores in one product, it was possible to see how the output varied. Medium cores and small cores were constantly one core in each product. Then the same thing was done with medium and small cores. The number of products per flask were held at a constant 3.

The simulation time for each run was one month (30 days). The result of this experiment can be seen in Figure 5.8. As can be seen, increase in large cores effect output the most.

This is an example on how a generic simulation model can be used to get a hint of direction of the changes one might want to make. As touched upon earlier, this result is due to the general nature of the model and the insecurities that are spread over the model. As the output of the model is not accurate in terms of hard numbers, these results should not be used as proof or basis for economic decisions. However, analysis of different changes can be made in order to get a notion of what the changes in result would be in terms of tendency or trend. It was implied during discussions with Swerea SWECAST that the 3D-printing technology will effect the core quantities and experiments on this was therefore considered to be of interest.

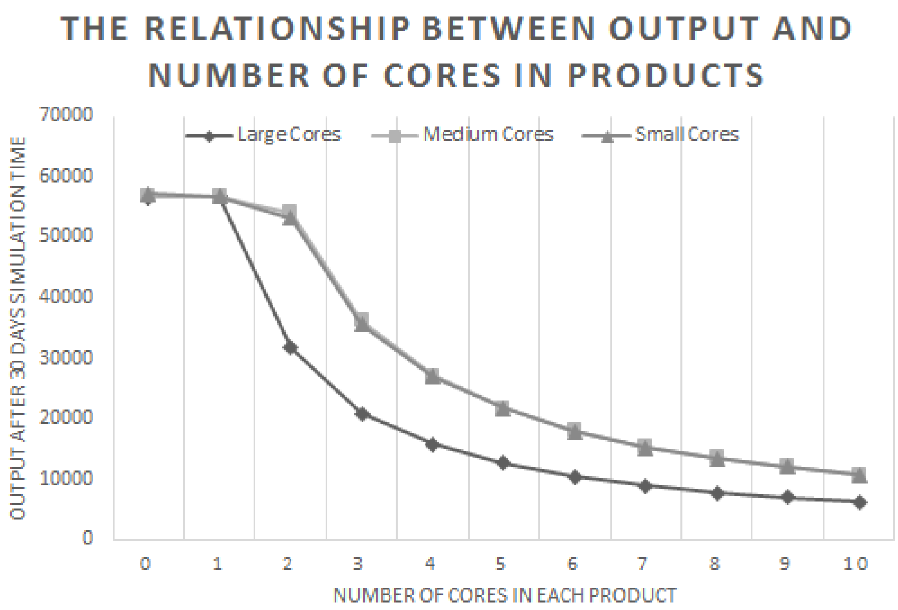

Figure 5.8: *Graph displaying the results on output obtained by varying required core quantities.*

This experiment indicates that the large cores are the ones that would mostly improve the output of the model if they were to be reduced in occurrence in the products. The experiment does not tell how much it would be improved, just that the large cores are the ones that are effecting the output negatively and that improvements efforts in this area would generate best results.

5.3 Benefits of simulation models in the foundry industry

Using the simulation model as a boundary object to ease the round-table discussions with Swerea SWECAST opened up to new ideas concerning changes and possibilities in the foundry industry.

5.3.1 Boundary object

Learned from the round-table discussions with Swerea SWECAST and through observations during the company visits is that in many places the foundry industry in Sweden is conservative. To use a simulation model as a boundary object can be beneficial in many ways. It can help people with different perception understand each other. It can also help people with different roles in organizations find a common ground for discussions.

5.3.2 Pedagogical purposes

It was realized from the round-table discussions with Swerea SWECAST and the casting industry that a model of a general nature can be used in pedagogical purposes. A fairly simple model which illustrates the production flow as a whole and how production flows through the factory allows a more comprehensive view over the factory flow without the need to go and visit a foundry. Swerea SWECAST offers introduction courses to the casting industry for possible future foundry workers. A model that allows the user to easily change input parameters and see how they effect the production provides a good support to gain a better understanding of the production dynamics. By understanding the production dynamics it is easier to see and understand the consequences of what e.g. disturbances do to the system.

5.3.3 Investment

A new technology that is emerging in the casting industry is 3D-printing of molds and cores. As this is an area Swerea SWECAST is doing research on, it was discussed during the round-table discussion. This is however yet untested in a more industry oriented environment, mostly because it is a substantial investment needed and that the benefits are not quite clear in terms of production efficiency. An analysis like the example with the relationship between output and the number of cores in each product, but in a more specific model with higher accuracy could work as decision basis. It would make it possible to look at both how output is affected, and how e.g. the occupancy for operators and machines would change if the large cores was printed in the 3D-machine instead of manufactured at the foundry. A specific model with a substantial data collection, will have the ability to present the monetary benefits of investing in such a technology.

5.3.4 Planning

During the round-table discussions, the need for a good planning tool was discussed and that simulation models over the production flow would be a good alternative. The ability to test run a week or a months production sequence and to optimize it according to output is something that would be highly beneficial according to industry experts. The model the group has built during this thesis serves as a good demonstration for what this could look like. It can also be used to investigate how new products will affect the production system.

6 Discussion

This chapter covers the challenges about data collection and input data methodologies and generic and specific modelling. It also covers future recommendations based on these challenges and the result.

6.1 Data collection and input data management

A common issue in the foundry industry is that there is no systematic way of collecting and storing data. If data is collected, it is usually stored at different places and collected without a purpose, which increases the risk for data duplication dramatically. The high level of tacit knowledge that is used by the operators and engineers to keep the production operating, does not simplify the situation. That the foundry industry is pretty conservative has been noticed through the project and emphasized by Swerea SWECAST during the round-table discussions. A consequence of this is that e.g. digitalization has not had a big breakthrough in the foundry industry so far. Thus, during the discussions with Swerea SWECAST it was a wish that more of the data collection could be automated. When it comes to input data methodologies, the methodology for input data used in this project and is Methodology A, which is when the input data is manually entered in the model. To some extent Methodology B was used as well, which is when the data is collected manually and then gathered in a separate data source, in this case an Excel spreadsheet. Thus, in this project the product data like quantity of cores and number of products per flask, in the Excel spreadsheet was not gathered but decided by the user. Production data like cycle times and stops times were collected by using the system Axxos. However, during the discussions, the vision to use a simulation model that is directly connected to the data source was formulated. This would be Methodology D, which is not very common yet in any industry. The aspiration was to be able to virtually run the production system simultaneously as the real system.

6.2 Generic and specific modelling

As mentioned in the theoretical framework, to build a simulation model that is specific requires a high level of detail, while building a simulation model which is generic requires a low level of detail. Therefore, to combine these requirements in the same model is unmanageable.

The work with defining all relationships between the different parameters is a complex task. To start building with a high level of detail and complexity and not knowing what specific problem that is to be solved or what specific question that should be answered, might risk that a substantial amount of data have to be estimated. This level of uncertainty will then propagate through the model and influence the validity of the credibility of the model negatively. The work with building this model will thereby run the risk of being in vain, since the model will not generate any results of particular accuracy. If the models purpose is to be merely demonstrative, then the accuracy and complexity can be compromised in order to get a comprehensive view over the production flow.

When building a generic model, as noticed when trying to adapt the simulation model over Holsbyverken to Skeppshult, it proved to be rather difficult. To build one model that has the objective to fit a variety of different foundries, a "one size fits all" oriented way of thinking, will not fit perfectly anywhere. One observation the group did during the company visits was that each foundry is unique, and that each foundry has its own characteristics. This observation was confirmed by Swerea SWECAST during the round-table discussions.

6.3 Future recommendations

Here follows a discussion on how the presented challenges can be addressed in future projects. The future recommendations are also reflections from the group on how the foundry industry should work to gain from the benefits of using production flow simulations.

As mentioned previously, the processes in Holsbyverken are mostly controlled by the tacit knowledge of the operators. The utilization of tacit knowledge and how much the production relies on it generates a substantial amount of data that cannot be measured and is thus categorized as C data, which in turn cause higher levels of uncertainty. The group believes that the processes often lack standards and can be perceived as unstructured at a glance, a standpoint that is shared with system experts at Holsbyverken and Swerea SWECAST. In order to properly translate the decision making into the logic of a simulation model, it would be highly beneficial to use standards as basis for this. Tacit knowledge is often times hard to verbalize and even harder to translate into the logic of a computer, if it could be used as basis for the creation of standards, it would not only be easier to translate and use in a simulation model, it would also be much easier to teach new workers and to find sources of deviations. Standardizing processes is something that is widely used in other industries such as the car manufacturing industry, which makes improvement efforts easier and to teach new operators is often a matter of 1-2 weeks rather than months as is the case in the casting industry. Standardizing the processes would also benefit the data collection part of any project that needs data from the production system. As mentioned in the section *Data collection and input data methodologies* the aspiration to virtually run the production system simultaneously as the real system was expressed. Thus, for this aspiration to become reality, the recommendation from the group is to make the input data process more automated. A realistic ambition that would entail significant time savings is to start using Axxos as standard tool to a larger extent than it is today for data collection and to link it to an Excel spreadsheet that can be linked to a model. However, before automating more data collection, standardized processes should be implemented. When collecting data it is important to know the reason behind *why* the data should be collected. When having more standardized processes, it will be easier to overview the production system and find the *why's*.

In the theory chapter it was learned that to avoid several inherent dilemmas the builder should be responsible for the data collection. At the end of this project, this is believed to be true. The data collection would probably have looked a bit differently if the group were to collect the data by themselves. Mentioned in the framework by Skoogh and Johansson (2008), step 4 is concerning *how* the data in Category B and Category C should be collected. During the actual data collection, the defined *hows* were overlooked which effected the received samples. Also, the theoretical framework states that the number of samples should be 230 to get sufficient accuracy, which is substantially more than the sample size of five that the group could receive because of prioritization and access issues regarding safety and geographical distance. The group could have allocated the time necessary and knows how many samples that are needed on the different parameters.

When building a specific model the work behind the data collection process and building process could be decreased if there is a clear problem formulation the model should answer, as the builder can direct the focus in one direction. Also, if the work processes were standardized, it would benefit the builder, as the relationship between parameters and processes would be easier to see. If building with no specific problem formulation in mind, the model should be of a lower level of detail from the beginning and then the details could be added over time, depending on what should be investigated.

When it comes to using models to describe different foundries, in order not to lose the characteristics of the individual foundries, it is better to build simulation models from scratch. However, to decrease the building time, it would be possible to use predefined building blocks, passive agents, which represents the different processes in foundries and use these as foundation for simulation building. Modifications can be made to the blocks to fit the real processes in terms of cycle times, batch sizes and setup times.

7
Conclusion

In a conservative industry like the foundry industry, there are many benefits to gain from production simulation modelling, however the road to get there might be long. To collect and gather data and information is in many foundries seen as something redundant, while it should be seen as something that opens up for many new possibilities.

Some of the possible benefits to gain from using simulation modelling of production systems is that a simulation model can be useful from a pedagogical point of view, it can aid the production planning and help investigating whether or not to make new investments. Also, it can be used as a boundary object to aid people with different perception understand each other and find a common ground.

Thus, when creating a model the purpose of the model should be known from the beginning, to enable the right level of detail. Also, a model that is both generic and specific at the same time is a contradiction. A generic model requires a low level of detail while a specific model requires a high level of detail and to meet both these requirements at the same time is difficult. The groups conclusion is that to have one generic model that will be adapted to different foundries is more difficult to create than one specific model for each foundry. However, it is possible and favorable to use generic building blocks to help the builder and decrease the building time.

Although, to be able to benefit from the simulation models, foundries needs to see the value in information and data gathering and develop a systematic way to collect and save this in one place.

8
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