MASTER

Business entity lifecycle modelling in simulation-aided analysis
a case study

de Kort, J.

Award date:
2015

Link to publication
Business entity lifecycle modelling in simulation-aided analysis: A case study

by

Jip de Kort

BSc Industrial Engineering
Student identity number 0657923

In partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Supervisors:

Dr. Ir. H. Eshuis, TU/e, IS
Dr. K.H. van Donselaar, TU/e, OPAC
D. van de Wijdeven, Culivers
Subject headings: Industrial engineering, computer simulation, process simulation, food.
Abstract
This research focusses on the relatively new technique of business entity lifecycle modelling. The technique is used to create a simulation model for a food processing company, to be able to have a better insight into their production process and to determine the impact of two redesigns without having a real life implementation. Another purpose is to determine how suitable simulation with business entity lifecycles is and how a business entity lifecycle model can be used as the basis for a simulation model.
Preface

This master thesis concludes my graduation project and my master in Operations Management and Logistics of the Eindhoven University of Technology. With this work there comes an end to my student life and a nice time at the university.

During my time at the university I grew both on a professional but also certainly on a personal level towards becoming an engineer. I thoroughly enjoyed every minute of my life as a student, in Eindhoven as well as during the exchange semester in 대전 (Daejeon, South-Korea). For this I would like to thank all my friends that I made and all the people I met during these years, those wonderful experiences will last a lifetime and will always be in my brains and heart.

For my master and this thesis in particular I would like to thank some people explicitly. First of all my mentor for the past two years, Rik Eshuis. He always had or made time for me on a short notice and during our meetings we had fruitful discussions and I gained a lot of insights. Without his help the thesis you are reading now would not exist.

During my thesis two other people supported in conducting my research. Karel van Donselaar was my second university supervisor and I would like to thank him as well for the fruitful discussions and the fresh viewpoints on the subject. I would also like to thank my company supervisor, Dirk van de Wijdeven, of Culivers. He gave me all the freedom and resources necessary to conduct my research and has a very good, valuable knowledge of the company. I would also like to thank my other direct colleagues; Eric, Ed, Jacqueline and Rakia, for many fun and productive hours at the office that will not be described in further detail here.

But where would I be without my parents, sister and girlfriend. Nowhere, is the answer. I want to specially thank them for supporting me during all these years and giving me the opportunity and freedom to develop myself to where I am today.

Thanks all!

Jip de Kort
Management Summary

The food processing industry is an industry that is getting more complex, due to customers demanding shorter lead times and a greater variety in products. This is of course impacting the performance of companies acting in this sector, which are therefore even more actively looking for ways to improve their processes. Also Culivers, part of the Sligro Food Group, is active within the food processing industry, constantly trying to improve both the internal performance as well as the performance towards customers. This project is executed in close collaboration with Culivers at the company site.

As for the food processing industry, on the academic area there are interesting developments regarding business process management as well. Around one decade ago Nigam & Caswell (2003) introduced the concept of business entity lifecycle modelling which is a relatively new technique for modelling business processes. This technique focusses more on the data that is transformed within the business then the activities that take place within the business. The concept of business entity lifecycle modelling enables greater flexibility in creating and modifying the conceptual model and provides a better understanding towards the business user.

This thesis seeks to combine both the development in the food processing industry and the developments in the academic literature, using business entity lifecycle modelling to answer the questions posed by Culivers. Given the supposed advantages with regards to the previously mentioned flexibility and understanding of the model by the business users.

After one decade of business entity lifecycle models it is certainly a known field of research. However, there are still gaps in the literature. Such as, how can business entity lifecycle models be used to create a simulation of business processes and what are the advantages and disadvantages of doing so? Since business entity lifecycle modelling is promising for creating business process models and workflows it is interesting to know if this also the case for simulation models based on this concept. As simulation models are frequently used for gaining quantitive insight into company problems. This leads to the main research question: How can business entity lifecycle modelling be used to measure factory performance in a simulation aided process analysis?

Given the earlier mentioned trends in the food industry, Culivers is interested in the possible effects of a different scheduling strategy. This resulted in two redesigns that will be judged on the devil’s quadrangle dimensions of costs, time, flexibility and quality (Brand & Van der Kolk, 1995)

The first redesign looks at the impact of having Vendor Managed Inventory (VMI) for a select number of products that have a long time to expiration. Frozen products can be consumed 1 year after production, these are the only products produced at Culivers with a long time to expiration and are therefore selected as the VMI products.

The second redesign studies the impact of having intermediate stock in the production process between the cooking and the assembly step, as the impact is currently not known.

In order to answer the main research question and the company questions, a business entity lifecycle model was created of these production steps in Culivers. The original production
schedules provided by Culivers were modified to represent the possible production process situation if the posed redesign was incorporated in the production schedules.

In order to answer the company questions and to gain insight into the feasibility of using business entity lifecycle modelling as the basis for a simulation, not only a model was made but also a simulation was conducted. *Incontrol Enterprise Dynamics* is used to simulate the processes based on the earlier developed models. It is found that using business entity lifecycle models as a basis for simulation is perfectly possible and also convenient with regards to process insight and the flexibility offered in easily modifying the data, which is an advantage compared to classical simulation. However the software used, which was the best option within this research, did not support this way of modelling totally, which created inconveniences in the sense that creating statistic confidence intervals by having multiple simulation runs for the same redesign was not possible within the scope of this project. This leads to one of the suggestions for further research being the development of a simulation software program that fully supports business entity lifecycle models, enabling a better interaction with the software helping to get meaningful responses of users on the advantages and disadvantages of using this technique.

The simulation results show that redesign 1, the use of VMI for selected products, does not have a significant financial advantage. The savings in production costs were offset by extra inventory costs. This is not to say that it might not be beneficial to implement VMI since it creates more flexibility for the company in scheduling their production. Furthermore a better redesign of the production schedule could lead to a financial advantage, this is something that should be researched further.

Redesign 2 however showed a clear advantage in costs, cooking orders for the considered products almost halved by having two days’ worth of intermediate stock. However this comes at a loss of flexibility for the company in scheduling their production. Also here the level of financial gains depends very much on the exact production schedule that is determined and thus the optimality of this schedule should be researched further.

The simulation results provided more insight into the advantages and disadvantages of both redesigns. Where redesign 2 has a financial advantage and redesign 1 an advantage with regards to production scheduling flexibility. It should be noted that a production schedule for the redesigns that is more advanced could show further gains that can be made.

In answering the main research question it can be concluded that both the classic and business entity lifecycle modelling and simulation techniques are suitable for business process management and simulation. The advantage that business entities are easier to recognize by the business owners seems to hold, as at least in this research they were easily identified. The flexibility of using business entities did not fully show because of rigorous software limitations. Note that the software providing little flexibility could be overcome by better software and therefore it is not stated that simulation techniques using BEL modelling are disadvantaging. Currently the marginal support by the software was a disadvantage in using this simulation technique. However this does not mean it has no potential, far from it, an effort should be made to intrinsically support the modelling technique in the simulation software.
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1. Introduction

Customers are seeking ever-improved lead-times and a broader assortment, especially within the food industry (van Donk, 2001). Companies need to adapt to this new reality in order to keep the customers satisfied. This, among other things, requires a critical look at their business processes since these are key in how the company is organized and therefore how the company can respond to the ever changing environment and requirements.

1.1. Introduction to the organization

This master thesis project is executed at Culivers. It produces yearly around 7.5 million finished meals and meal components that are ready for consumption for a variety of business-to-business customers. There are around 100 employees active within the company of which the vast majority is allocated to production.

Culivers is a part of the Sligro Food Group (SFG). The SFG consists of various companies within the food industry. The main company is Sligro itself. They supply a wide variety of around 60,000 food and food related non-food products for institutional consumers, bars and restaurants. The products are supplied through both stores (46) and delivery services (10). Institutional users are catered to via their daughter company Van Hoeckel, which supplies meals to institutions like prisons and to elderly people that receive meals while still living at home. The turnover of the SFG was €2.5 billion in 2013 with around 5800 FTE. In the food retail market SFG is the owner of 130 supermarkets.

Furthermore the SFG has specialized production facilities for convenience products, fish and a meat processing factory. Culivers is a part of this group of specialized production facilities (Sligro Food Group N.V., 2013).

Food processing industry

The food processing industry is different from other processing industries. The most important difference is the fact that food is perishable. Not only the final product is perishable but also the intermediate products and most of the stock is perishable. This limits the amount of stock that can be kept throughout the supply chain and limits production flexibility.

Van Donk (2001) describes some of the trends in food processing industry that are still present today. One of these trends is that consumers preferences seem to change more often, which causes an increase in packaging sizes, the amount of products, as well as the quantity of new products introduced. Furthermore there is pressure from the retailers, mainly supermarkets, which demand faster replenishment, shorter lead times and lower prices. In some cases lead times have already reduced from five to two days and further reductions could become a reality.

Van der Vorst et al. (1998) state that there are different ways of coping with the uncertainties that are common in supply chains. These uncertainties are for example caused by unpredictable customer demand in various stages of the supply chain and quality variations. One way of coping with these uncertainties is providing excess capacity or inventories within the supply chain, however this is regarded as both costly and inefficient. The problem of
demand variance is exacerbated upstream in the supply chain, this effect, of variance amplification, is called the bullwhip effect and has serious cost implications. Another way of coping with these uncertainties within the manufacturing and thereby also within the food processing industry is a further integration of supply chains. For example by sharing production scheduling or inventory information. This creates a feed forward flow of information and thereby reduces the uncertainties.

1.2. Factory operations

Different types of products can be identified in the portfolio of Culivers. On the one hand a clear distinction in three categories can be made in the consume-by date that products receive:

- 8 days
- Circa 1 month
- 1 year (frozen products)

Clearly, for products with a consume-by-date of a year in the future there is more margin to work with stocks and thereby a greater ability to optimize the production schedule. Apart from this distinction in consume-by-dates, another difference is that for around half of the products Culivers holds inventory while the other half of the products are purely made to order. All the products with a consume-by-date of 8 days or 1 year are made to order. While of the products with circa 1 month consume-by-date, some are made to order and some are made to stock.

After a customer order is received, or if the inventory requires a replenishment, the production of the final product is scheduled. The scheduling of the production leads to assembly orders for the relevant products and calls for an integer number of final products to be created. Based on this required amount of final the products the relevant cooking orders are also created for the different ingredients or components of the assembly order.

The production order will go through various departments in the company. The raw materials (ingredients) are received by the logistics department. The ingredients are then cooked by the cooking department. The next day the different cooked ingredients are packaged by the packaging department into the required quantity of finished, complete, products. These are then handed back to the logistics department who take care of the further transport of the products.

1.3. Problem statement

The earlier mentioned trends in the food processing industry are also noticed by Culivers: the customers demand shorter lead times and a bigger assortment of both products and packaging sizes. This is having a negative effect on the productivity of the factory and therefore the set Key Performance Indicators (KPI’s) are not at the desired level. Culivers is wondering what measures can be taken to improve the performance. The KPI’s that Culivers
uses are the productivity per man hour for various production departments and the factory as a whole.

Via an unstructured interview with the person responsible for the factory planning and his supervisor the cause-and-effect tree as can be seen in Appendix A was created. Three main causes were identified, as can be seen in Appendix A, why the earlier mentioned KPI’s are not always met. One main cause being that the production planning is sub-optimal.

Given the viewpoint of the company and the ones responsible for this project, the scope was chosen to be on the sub-optimal scheduling of production orders rather than a process redesign. Therefore it is decided to primarily research the effect of having intermediate stock of intermediate goods and the effect of information sharing within the supply chain, thereby enabling bigger production batches and thus a different production schedule. The company would like to know what the impact of having a different production schedule is, related to their KPI’s and costs. Since the relevant KPI in this case is the productivity per man hour and the total quantity of food produced does not change, this means that lower costs mean an improved KPI and higher costs a deteriorated KPI, for the same quantity of food.

Therefore, in cooperation with the company responsible, the following company questions are included within the redesign of the production schedule and will be answered by the use of a simulation model:

1. What is the effect of information sharing with a select number of partners on relevant costs and therefore KPI’s?
2. What is the effect of having intermediate stock on relevant costs and therefore KPI’s?

1.4. Scope of the project
There is a range of techniques that can possibly be used to answer, or at least provide insight to, the problems as stated by the company. The usability of these techniques depends, for example, on which assumptions are made or what the exact question is that one wants an answer to. For this project the company questions will be answered using Business Entity Lifecycle (BEL) modelling and simulation. Since this is a relatively new technique there are also various academic insights that can be gained from answering the company questions. The use of BEL modelling should provide more flexibility in modelling and understanding for the business user. In chapter 2 this technique and the existing advantages according to the literature will be discussed more thoroughly.

Within Culivers various departments and production steps can be identified, that can be allocated to four main parts of the company:

- Logistics
- Cooking
- Assembly
- Overhead
For this study only the effect of the redesigns on the cooking and assembly stages are considered. Since these are the departments that will encounter the biggest changes with a different schedule. The overhead is independent from the chosen schedules. While the influence on the logistics department is limited, since all the incoming and outgoing goods still need to be processed. In chapter 3 these choices will be elaborated further.

1.5. Research questions
Combining the company wishes with the academic relevant themes, as will be discussed in chapter 2, leads to the following research question.

Main research question: How can business entity lifecycle modelling be used to measure factory performance in a simulation aided process analysis?

This research question can be answered via several sub-questions as will be elaborated in the methodology paragraph on the following pages of this document.

The sub questions are;
1. How can the current company situation be modelled using business entity lifecycle modelling?
2. How can the business entity lifecycle model be used to create a simulation model?
3. What are the simulation results and are they valid?

1.6. Methodology
The research questions are addressed using an established methodology, as will be presented in this section.

The main research methodology used is the nested problem solving approach as described by Wieringa (2009). As this methodology is created for situations where there is both a practical and a knowledge problem to answer. Therefore it relates closely to this research, since the company problems are practical problems that are answered by also gaining insight into knowledge problems. Wieringa (2009) identifies two kinds of problems in design science that are mutually nested: Practical problems and knowledge problems. To solve practical problems a change of the world is required to better agree with stakeholder goals. While to solve knowledge problems, the world doesn’t need to be changed but the knowledge there is about the world changes.

In this report the company questions can be seen as practical problems, while the academic research questions pose a knowledge problem. He suggests using the regulative cycle that will also be discussed in this paragraph as the framework for the practical problems. Wieringa (2009) suggests to use the design research guidelines of Hevner et al. (2004) for solving the knowledge problems.

According to Wieringa (2009) the top-level question is always a practical question. However in solving practical problems it might be necessary to first solve the knowledge problems. Furthermore the (re)design validation is always a knowledge question, namely if it brings the stakeholders closer to their goal. Therefore knowledge problems are nested in practical
questions and further levels of nesting can occur. Thus while being different problems they are closely related to each other and one type of question cannot be answered without answering the order type of question. To use this methodology it is required that both the regulative cycle (van Strien, 1986) and the design guidelines as described by Hevner et al. (2004) are followed.

**The regulative cycle**
The regulative cycle by van Strien (1986) can be seen in Figure 1. This focusses mainly on solving the practical company questions.

![Regulative cycle](image)

*Figure 1. Regulative cycle (van Strien, 1986)*

Within the regulative cycle of van Strien (1986) five distinct phases can be identified. Each of these phases will be discussed.

**Problem definition & diagnosis**
The problem definition together with the diagnosis is similar to the earlier mentioned problem statement. This is the starting point of the cycle and from here on it is possible to move to the next stages. Here the relevant company problem, which is a practical problem, is defined and the causes are diagnosed. In this case the problem definition was aided by a cause-and-effect tree. Furthermore a diagnosis is made of the current situation. Also the relevant knowledge problems are established here in the form of research questions. This diagnosis of the current situation is performed in research question 1 of this research.

**(Re)design**
Two possible redesigns regarding a different schedule strategy are determined in cooperation with company responsibles. Especially this step also has a knowledge value next to a practical value as the creation of a BEL simulation model also answers research question 2. So within this step, while a part of the regulative cycle, also part of the research questions get answered using the guidelines as described by Hevner et al. (2004).

**Intervention**
There will not be an intervention in the real world since this outside the scope of this project. The resources for a real world intervention are not available, therefore this project aims to provide insight into the consequences of the redesigns. The redesigns are implemented in the simulation model and the influence, is then determined. This enables an efficient and more cost-effective way to determine the effect of certain changes. A disadvantage is that the results are less reliable then the results of a real life intervention but it provides guidance on
whether a further implementation or a real life intervention should be considered. The advantage is that this simulation of the intervention requires significantly less resources.

**Evaluation**

The simulation results of the redesign and intervention will be evaluated to draw valuable conclusions for the company. Apart from analyzing the results of the simulation with respect to their concrete results and values it also has to be determined if the gathered simulation results are reliable. This step provides answers to research question 3.

**Design research guidelines**

In order to ensure the academic relevance, the seven design research guidelines of Hevner et al. (2004) are used that can be seen in Table 1. These guidelines need to be kept in mind for the answering of the knowledge questions that are nested in the practical problems.

**Table 1. Design-Science Research Guidelines (Hevner et al., 2004)**

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideline 1: Design as an Artifact</td>
<td>Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.</td>
</tr>
<tr>
<td>Guideline 2: Problem Relevance</td>
<td>The objective of design-science research is to develop technology-based solutions to important and relevant business problems.</td>
</tr>
<tr>
<td>Guideline 3: Design Evaluation</td>
<td>The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.</td>
</tr>
<tr>
<td>Guideline 4: Research Contributions</td>
<td>Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.</td>
</tr>
<tr>
<td>Guideline 5: Research Rigor</td>
<td>Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.</td>
</tr>
<tr>
<td>Guideline 6: Design as a Search Process</td>
<td>The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.</td>
</tr>
<tr>
<td>Guideline 7: Communication of Research</td>
<td>Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.</td>
</tr>
</tbody>
</table>

In order to answer both the company and research questions a case study with explorative research will be conducted. This proposal should therefore, at least to a certain extent, confirm to these guidelines.

- **Guideline 1**: The artifacts are the resulting answers to the research questions.
- **Guideline 2**: Since the research is executed within the business environment and also answers questions posed by the company it is certainly relevant for the business.
- **Guideline 3**: Since the resulting simulation method will be executed in an exploratory case study this is also the way the design will be evaluated. Furthermore the redesign will be judged by looking at the impact of redesign heuristics and on which factors to

- **Guideline 4:** This research makes various contributions to the literature. It does so in the field of simulating business entity based process models, cost-aware business process modelling and the combination of both. The academic area of research is discussed in chapter 2.

- **Guideline 5:** This research makes use of existing knowledge and frameworks as far as feasible. However, it should be noted that since a lot of new elements are included and it is performed as an exploratory case study, it is not as rigorous as some other studies. This is also partly due to the fact that the research has to be relevant as well.

- **Guideline 6:** By generating and evaluating different alternative solutions, both to the research questions as well as to the company problems, there is a search process.

- **Guideline 7:** Since this is case study research, it answers both academic and company (management-oriented) questions. Therefore the communication will also be both effective for technology-oriented and management-oriented audiences.

1.7. Contents of the master thesis

This chapter, chapter 1, elaborates on the research questions and provides an introduction to the remainder of the report. In chapter 2 the current state of the art regarding business entity lifecycle modelling and the food industry will be discussed. After which the three research questions will be discussed and answered in chapters 3 to 5 respectively. Chapter 6 will conclude this report.
2. State of the art

This chapter discusses the current state of the art in academic literature with regards to topics that are relevant for this thesis. First the general concept of business process modelling will be introduced, after which more recent methods such as business entity lifecycle modelling will be elaborated.

2.1. Business process management

Business Process Management (BPM) is a collection of methods to model, manage and gain insight to business processes. Traditionally this mainly focusses on modelling tasks, i.e. what activities employees perform. (Dumas, La Rosa, Mendling, & Reijers, 2013)

Even though the importance of modelling business processes was acknowledged over half a century ago by Levitt (1960) it only started to get momentum since the past two decades. Its importance is underlined by Davenport (1993), Hammer (1990) and Harrington (1991). This led and leads to a rapid increase in methodologies, techniques and tools to support this. All these techniques build or continue on the classic Business Process Management (BPM) framework and add new elements. The entire process from creating a business process model through implementation and finally monitoring using BPM is called the BPM lifecycle.

Different techniques can be used for different situations since, for example, one technique might focus more on describing the system of the organization while a different technique focusses more on a system that controls the process. One of the methods that can assist to manage businesses is business process modelling. This entails the creation of an abstract model of the business with all the relevant processes, in order to be able to analyse and/or improve it. It assists management in managing the business since it provides a better insight into the company processes.

Business processes are structured activities or tasks with ordering constraints that have a specific result or goal. These business processes can be modelled on different levels of granularity; the required level of granularity depends mainly on the level of detail that is needed in order to analyse or support the processes that are relevant to the company.

2.2. Simulation of business processes

Simulation can be used to gain further insight into business processes, by making the earlier modelled business processes executable and simulating the process over time. This execution usually happens by the means of a computer and discrete-event system simulation. Which means the state variables of the simulation only change at discrete points in time. (Banks, Carson II, Nelson, & Nicol, 2010)

In the case of a simulation of a company process this means that a greater level of detail is needed for a simulation model compared to the input that is required for a process model. Since a simulation also needs information on arrivals, processing times etc., in order to correctly depict the operations.

In simulating business process models, usually a task has a given probability distribution of processing times. Cases that have to be processed such as customers or customer orders are then also generated based on a probability distribution and flow through the system.
Besides the use of probability distributions to generate cases or processing times also historical data can be used.

2.3. Cost aware BPM

Wynn et al. (2013) discuss the latest in cost-aware business process management. BPM usually focusses on investigating indicators as time and resource utilization, so mostly on KPI’s, that are not directly monetary related, instead of directly on costs, even though that is what can be most relevant for most companies. Implementing these costs of business operations within the business process management lifecycle can lead to benefits. But since this is a new field of research there are still a lot of hurdles to overcome and investigate in order to answer the question how cost information can be associated with business processes. In the best case, cost measures would be available at three times in the process:

- At design time (to make design choices)
- At runtime (selecting a cheaper material or resource)
- At post-execution time (for reporting and analysis)

There are different techniques to include costs in a process model, such as the ones discussed by Jansen-Vullers et al. (2007) or Wynn et al. (2013). These different techniques have both differences and commonalities. One of these commonalities is that both Wynn et al. (2013) and Jansen-Vullers et al. (2007) break down the costs in different categories. While these categories are not identical, the costs as categorized by Jansen-Vullers et al. (2007) can be largely related to the costs as categorized by Wynn et al. (2013) as can be seen in Table 2. This means that each of the cost types identified by Jansen-Vullers et al. (2007) consist of one or more costs type that were identified by Wynn et al. (2013). However this is not valid the other way round, i.e. administration costs are mostly fixed costs but not all fixed costs are administration costs. Where the cost types identified by Jansen-Vullers et al. (2007) mainly relate to type of costs from a process view, the cost types identified by Wynn et al. (2013) can be related to various occurrences in BPM.

Table 2. Cost category comparison

<table>
<thead>
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<tbody>
<tr>
<td>Running costs</td>
<td>Usage-based costs, time-based costs, invocation-based costs</td>
</tr>
<tr>
<td>Labor costs</td>
<td>Time-based costs</td>
</tr>
<tr>
<td>Machinery costs</td>
<td>Usage-based costs, fixed costs</td>
</tr>
<tr>
<td>Training costs</td>
<td>Time-based costs</td>
</tr>
<tr>
<td>Inventory costs</td>
<td>Time-based costs</td>
</tr>
<tr>
<td>Transport costs</td>
<td>Measurement-based costs</td>
</tr>
<tr>
<td>Administrative costs</td>
<td>Fixed costs</td>
</tr>
<tr>
<td>Resource utilization</td>
<td>Usage-based costs</td>
</tr>
</tbody>
</table>

2.4. Business process redesign

An overview and qualitative analysis of Business Process Redesign (BPR) heuristics was written by Reijers & Mansar (2005). Where a heuristic in this paper is a short qualitative rule on how to improve the process. They noted the problem that most of the literature mainly focusses on the before and after situation while the critical part of the redesign itself did not
receive a lot of attention. Therefore, resulting from an extensive literature review, a framework is proposed to help practitioners as shown in Figure 2 and is based on the WCA framework of Alter (1999). In this framework six linked elements can be seen. For the various elements or components mentioned in the framework, universal best practices are then described.

![BPR framework by Reijers & Mansar (2005)](image)

**Figure 2. BPR framework by Reijers & Mansar (2005)**

Jansen-Vullers et al. (2007) look at the impact of redesign heuristics and on which factors to judge redesigns. They suggest judging the result of redesigns on the four dimensions on the Devil’s quadrangle: Time, costs, quality, and flexibility, as illustrated in Figure 3 (Brand & Van der Kolk, 1995). Also Reijers & Mansar (2005) suggest the devil’s quadrangle as evaluation framework for their redesign heuristics. The devil’s quadrangle has got this name since it indicates the (devil’s) dilemma in redesigns. Changing one of the four measures on the quadrangle is having an impact on one or more of the other dimensions, necessitating to judge the results of a redesign on all four criteria.

![Devil’s quadrangle, (Brand & Van der Kolk, 1995)](image)

**Figure 3. Devil’s quadrangle, (Brand & Van der Kolk, 1995)**

The four dimensions of the devil’s quadrangle can be interpreted in the following way: The quality of the workflow can be measured for two different angles, both external and internal quality. External quality involves if the customer is satisfied with the product. Internal quality is about the quality of the workflow from the workers perspective, i.e. if the worker
has a high-level of autonomy and requires different skills. This concerns monitoring both the quality of the output and the quality of the process.

The time dimension considers the various times and durations that exist in the process, such as the lead, throughput and processing times.

The cost dimension measures the financial impact of the redesign, for example through changes in running and inventory costs.

The final dimension in evaluating redesigns is flexibility. Flexibility can be identified for individual resources, individual tasks and for the workflow as a whole. These different flexibility types are:

- Mix flexibility: The ability to process a variety of cases.
- Labour flexibility: The ability of the resources to perform different tasks.
- Routing flexibility: The ability to handle a case through different routes within the company.
- Volume flexibility: The ability to handle different volumes over time.
- Process modification flexibility: The ability to easily modify the process.

2.5. **Business Entity Lifecycle modelling**

One of the new techniques of modelling business processes is Business Entity Lifecycle modelling (BEL modelling). It was introduced by Nigam & Caswell (2003) who designed the Operational Specification (OpS) technique to model BEL’s. They developed the concept of business entities “in the context of a technique for constructing formal yet intuitive operational descriptions of a business” (Nigam & Caswell, 2003, p. 428). The aim of OpS is to have an operational modelling technique that is not only useful for business people and intuitive for business communication. But that is also based on a formal structure to be of use in rigorous design and design analysis.

The big difference between the classic way of modelling business processes and BEL modelling is that, while the classic way of modelling focusses on processes and activities, BEL modelling focusses on the transformation of a data entity. It is stressed that in modelling with business entities, the key operation is to recognize the business entities rather than classifying them. Business entities are taken to be the only explicit information that is contained within the business. That means they are the set of business records that represent the information contents of the business.

The main advantage of BEL modelling is that it is more flexible in representation then the classic way of BPM, this makes it more intuitive for business users to use, as it has been found that business entities can be naturally identified by managers and other process owners.

An example of a common business entity is customer order. The modelling then focusses on what kind of transformations are done on the data that is included within the customer order.

Traditional process models focus on actions taken by the company to achieve a certain goal, i.e. they are called verb-centric. Whereas modelling based on business entities focusses on
what is acted upon, i.e. it’s noun-centric. A business entity is defined as: “an identifiable, self-describing unit-of-information through which business stakeholders add value to the business” (Liu et al, 2007, p. 327). Furthermore an operational model represents the business operations at a granularity level that is detailed enough for validating and managing the progress towards goals and also to clarify the dependencies that exist between goals. Therefore the biggest difference between the classical way of BPM and BEL is that the focus changes from process-oriented towards data-oriented modelling.

2.6. Guard-Stage-Milestone
Over the past decade various improvements, additions and variations have been made to the original BEL modelling concept as described by Nigam & Caswell (2003). One of these variations is the Guard-Stage-Milestone (GSM) method (Hull, et al., 2011). This method allows the specification of when certain elements (stages) in the model become either active or inactive. The (de-)activation of this stages happens through the guards and milestones that can be triggered by the external world, another BEL instance or by milestone and stages changing their status. Therefore the GSM approach offers an addition to the OpS method in the sense of having opening and closing guards and therefore it will also be used in this thesis. This technique will be applied in paragraph 3.3 of this thesis including an example of its application.

2.7. Food processing industry
The food processing industry is different from other processing industries. The most important difference is the fact that food is perishable. Not only the final product is perishable but also the intermediate products and most of the stock is perishable. This limits the process flexibility with regards to the amount of inventory that can be held which also effects other parts of the business such as the production department.

Van Donk (2001) describes some of the trends in food processing industry that are still present today. One of these trends is that consumers preferences seem to change more often, which causes an increase is packaging sizes, the amount of products as well as the quantity of new products introduced. Furthermore there is pressure from the retailers, mainly supermarkets, which demand faster replenishment, shorter lead times and lower prices. In some cases lead times have already reduced from five to two days and further reductions could become a reality.

A different trend within the manufacturing industry, which the food industry is a part of, is a further integration of supply chains. For example sharing production scheduling or inventory information. This creates a feed forward flow of information according to Van der Vorst et al. (1998). Which is one of the ways of coping with the uncertainties that are common in supply chains. These uncertainties are for example caused by unpredictable customer demand in various stages of the supply chain and quality variations. Another way of coping with this is providing excess capacity or inventories within the supply chain, however this is regarded as both costly and inefficient. The problem of demand variance is exacerbated upstream in the supply chain; this effect, of variance amplification, is called the bullwhip effect and has serious cost implications. (Chen, Drezner, Ryan, & Simchi-Levi, 1999)
When modelling supply chains it is important to take all the relevant factors into account. For example to not only consider inventory and transportation but also other costs, such as order processing, handling and transportation. Also other interaction effects are very relevant, for example, within food processing, cost of cooking, packaging etc. per batch. Also it should be noted that a part of the variance and uncertainty is uncertainty in demand, process and supply. This uncertainty exists in all supply chains and while it can be reduced it can never be completely eliminated.

Food supply chains (FSCs) are even more complicated than usual supply chains since there is a focus on food quality and perishability, on top of that there is a sustainability discussion that focuses on the reduction of product waste, this is the amount of food that is thrown away because the quality is not up to standards anymore. Usually because the product is past the best-before-date. In many cases, since these FSCs are complex instances, an analytic evaluation is not possible and discrete event simulation is a logical approach. Therefore one should ideally use discrete event simulation to simulate these processes, as it quantifies results and can also take uncertainties into account. A different reason that FSCs are complex systems is due to the presence of multiple organizations, functions and people that all operate in the boundaries of a dynamic environment. (van der Vorst, Tromp, & van der Zee, 2009)

Furthermore there are several objectives that can facilitate the redesign process for a joint supply chain. Of which the most important is to create information transparency throughout the FSC. However this can be difficult since companies might have the feeling that they lose bargaining power. But this should be less of a problem for companies within the same group. One of the shortcomings of traditional modelling is that decision makers, control rules and the interactions are mostly hidden. This is surprising since control structures are essential to supply chains. Furthermore the fact that most of this is hidden is not good for the realism of the model, nor for the flexibility and modularity. This shortcomings can be overcome by the use of three key concepts: Agents, jobs and flows, where flow items are the same as business entities. (van der Vorst, Tromp, & van der Zee, 2009)

The benefit of modelling the food environment using BEL models instead of traditional process models lies in the earlier mentioned advantages such as more flexibility and a better understanding and visibility to the business users.

2.8. Conclusion
Since business entity lifecycle modelling promises greater flexibility and understanding in modelling this is an interesting area of research, to gain insight into how it can answer the practical problems posed in chapter 1. Partly to judge if the results and methods used in past case-studies can also be used for this project to create BEL models and gain more insight into the company and its relevant processes. However, even more interesting is the use of BEL models for simulation of the business processes. Since using a BEL model as the basis for a simulation has not yet been explored, we can gain insight into the advantages and disadvantages for using a BEL model as the basis of the simulation and also simulating the business entities and therefore answer the knowledge questions. This will mean for example that processing times are not determined on the server but that it is stored on the business
entity. A more detailed description of the process of generating a simulation model from a BEL model will be given in chapter 4.

The four earlier mentioned extensions to the classic theory in BPM are described in the literature including their added value and are indicated by the arrows numbered 1 to 4 in Figure 4. However the way in which these extensions together can be combined into a new BEL model is not well-described in the literature, the dotted lines, numbered 5 and 6 indicate a relationship that is not well described and will be discussed in this report. Furthermore the line number 7 shows a well-described relationship. Therefore, as mentioned before, it would be very interesting to research the question if and how these different elements can be combined and for the cost-aware based modelling also what the value is of this individual technique.

\[ \text{Figure 4. Overview of relevant BPM techniques} \]
3. Business entity lifecycle modelling

The findings related to the first research question will be discussed in this chapter. The research question is: **How can the current company situation be modelled using business entity lifecycle modelling?**

Given the use of the business entity lifecycle (BEL) modelling techniques to create a simulation model, the methods described in the academic literature will be the starting point. However since every practical problem is unique, the knowledge problems encountered while solving these practical problems will also be discussed. Therefore this chapter starts with elaborating on the company processes to give an insight into the company and the associated. These processes are then more formally and conceptually described through the use of both OpS and GSM modelling after which the data aspect is discussed followed by the cost aspect.

3.1. Processes within the company

In general terms more information regarding the company is presented in this paragraph. In addition to this general information a more formal description of the company can be read in the upcoming paragraphs of this chapter.

Culivers, being a part of the Sligro Food Group, only receives customer orders from within their group. These customer orders can be divided into different types of orders by different internal customers that have a different process within the company and also different end users. The two order categories are either Make-To-Order (MTO) or Make-To-Stock (MTS) customers. For MTO customers, Culivers keeps no stock, while for MTS customers, Culivers does keep stock. The different internal customers are described below, an overview can be found in Table 3.

- **Sligro ZB**: Orders every week on Wednesday to replenish their inventory, and thus this is Make-To-Order (MTO) for Culivers. Products are then delivered to the nearby customer distribution centre on the end of Friday, implying a two day lead time.
- **Sligro BS**: End-users order via Sligro BS for delivery on the next day. Culivers holds the inventory for these products and delivers from their inventory. A challenge here is that a large amount of slow-movers means that sometimes products have to be made-to-order.
- **Sligro Freezer**: Comparable to Sligro ZB, however the lead time for frozen meals is two weeks.
- **Em-Té**: Comparable to Sligro ZB for products with a one month consume-by-date, however the one week meals are produced daily, based on the order from the previous week.
- **Van Hoeckel**: Comparable to Sligro BS. As is the case for Sligro BS the orders are from end-users, through Van Hoeckel, to Culivers. Also here there are a large amount of slow-movers necessitating that sometimes products have to be made-to-order.

Each customer order consists of one or more orderlines for different products (SKU) in a variety of quantities. Of most SKUs, various packaging sizes exist, for example 3 and 6 person packages.
A SKU then contains one or more recipes. It should be noted that in the company context an SKU can be raw material, intermediate products (cooked recipes) or finished goods. One can imagine that the recipe of mashed potatoes or gravy is used in many SKU’s. Therefore one (internal) cooking order can be for a recipe which is used in a variety of different SKU’s.

Table 3. Overview of Internal Customers

<table>
<thead>
<tr>
<th>Internal Customer</th>
<th>Type of product</th>
<th>MTO / MTS</th>
<th>Consume-by-date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sligro ZB</td>
<td>Meals and meal components, inventory driven by internal customer.</td>
<td>MTO</td>
<td>~1 month</td>
</tr>
<tr>
<td>Sligro BS</td>
<td>Sligro BS places their customer order 1 on 1 at Culivers, delivered from stock when available.</td>
<td>MTS</td>
<td>~1 month</td>
</tr>
<tr>
<td>Sligro Freeze</td>
<td>Frozen products, inventory driven by internal customer.</td>
<td>MTO</td>
<td>1 year</td>
</tr>
<tr>
<td>Em-Té</td>
<td>Supermarket products, inventory driven by internal customer, orders once a week.</td>
<td>MTO</td>
<td>7 days / ~1 month</td>
</tr>
<tr>
<td>Van Hoeckel</td>
<td>Meals for elderly people, Van Hoeckel places their customer order 1 on 1 at Culivers, delivered from stock when available.</td>
<td>MTS</td>
<td>~1 month</td>
</tr>
</tbody>
</table>

In the main kitchen different cooking lines can be found. In this research, line 1 to 7 and 9 are considered, while line 8 is out of scope given the small scale of that line. Some of these lines have commonalities where others don’t have any commonality. A quick overview can be found in Table 4. Taking into account the maximum capacity restrictions, products made on line 4 to 7 can be made on any of these four lines. The other lines have specific properties that do not allow the interchanging of cooking orders from one line to the other. Line 9 can be seen more as a conveyor belt where raw products are inserted at the beginning and the cooked products exit at the end. Therefore this line does not have a maximum batch capacity.

Table 4. Overview of cooking lines

<table>
<thead>
<tr>
<th>Line</th>
<th>Function</th>
<th>Maximum capacity (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooking of farinaceous dish such as pasta</td>
<td>105</td>
</tr>
<tr>
<td>2</td>
<td>Two steamers, like ovens, amongst others used for vegetables</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>Kettle used for mashed dishes mainly</td>
<td>900</td>
</tr>
<tr>
<td>4</td>
<td>Kettle for soups and sauces</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>Kettle for soups and sauces</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>Kettle for soups and sauces</td>
<td>200</td>
</tr>
<tr>
<td>7</td>
<td>Kettle for soups and sauces</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>Cooking Cooling line, used for potatoes and vegetables</td>
<td>-</td>
</tr>
</tbody>
</table>
3.2. Operational specification modelling

The operational specification (OpS) modelling technique was introduced simultaneously with the concept of business entities by Nigam & Caswell (2003). Furthermore the OpS modelling technique provides some information on how to discover business entities, which is key in business entity lifecycle modelling. Also a default question is provided on how to discover business entities, together with questions of different authors these are listed in Table 5.

<table>
<thead>
<tr>
<th>Author</th>
<th>Suggested question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigam &amp; Caswell (2003)</td>
<td>What does your unit produce?</td>
</tr>
<tr>
<td>Bhattacharya et al. (2005)</td>
<td>What do you produce? How do you produce it?</td>
</tr>
<tr>
<td>Liu et al. (2007)</td>
<td>Scoping: What is your business, what are you producing and what is the product of your process?</td>
</tr>
<tr>
<td></td>
<td>Evaluation: How do you measure that you are doing what you intend to do?</td>
</tr>
</tbody>
</table>

These questions are partly overlapping or complimentary, as all three sources suggest to ask the question: “what do you produce?”.

Information gathering

In order to create a basic conceptual model of the company, one semi-structured interview was conducted with two company stakeholders. These stakeholders being the person responsible for scheduling and his manager, who is also responsible for the procurement, since they have the best overview of the company. The interview was conducted with them together, providing them the possibility to complement each other. A semi-structured interview approach was chosen since a structured interview did not provide enough freedom for this research. An unstructured interview was deemed not rigorous enough since it was still undetermined which questions would definitely lead to the identification of business entities and provide a basis for the conceptual model. Hence the approach chosen was a semi-structured interview.

The interview started out with the overlapping question in literature of “what do you produce?” . However the answer stalled with “meals” and would not lead to the identification of business entities. Therefore the need for another question arose. According to Nigam & Caswell (2003) business entities can be seen as what kind of paper and information flows through the company. This was the basis for the next question, "what kind of paper and information flows through the company" resulting in the company stakeholders starting to recognize business entities. In some situations this question might have been to direct to identify business entities but in this case the fact that still a lot of information flows through the company physically and on paper helped conceptualizing and visualizing the idea of business entities for the company stakeholders. More time intensive workshops were used by Bhattacharya et al. (2005) to identify business entities, which might explain why their
questions were sufficient in their case contrary to this case. However such a workshop was not possible in this research due to time constraints.

The first business entity that that was discussed, was customer order, as could be expected based on the relevant literature. The lifecycle of a customer order is created based on the information gathered during the interview. Nigam & Caswell (2003) suggest the key business entity, in this case customer order, can be used to identify other business entities. Therefore the customer order lifecycle was used to let the stakeholders that were interviewed determine which other business entities interacted with or are used by the customer order. From the answers given by the stakeholders several conclusions could be made. Once a make-to-order customer order is planned by the scheduler and implemented in the production schedule the cooking- and portioningslip are created to enable the production of the order. The cookingslip calls for a recipe to be cooked and thus calls for a transformation. While the portioningslip calls for the assembly of various components that were cooked as instructed by the cookingslip. When there is a customer order for a product that is already in the inventory of the company this process can be skipped. Therefore during the interview the cooking- and portioningslip are the two next business entities that were discovered within the company. Since the company keeps track of the inventory it was also identified as a business entity. The final business entity is the schedule in which all the cooking- and portioningslips are scheduled. Including the other entities that are invoked during the lifecycles of the earlier discovered business entities. All these business entities complete the OpS model of the company which can be found in Appendix B

3.3. Guard-Stage-Milestone modelling
A more detailed technique for modelling business entity lifecycles was introduced by Hull et al. (2011). The technique is called the Guard-Stage-Milestone, abbreviated as GSM, model. The GSM model in this case especially provides more detail with respect to when certain actions are initialized and terminated which enriches the basic model as given by the OpS modelling and provides a better basis for creating the simulation model.

The design choices needed when creating the more detailed GSM model will be discussed in this paragraph. A part of the information needed for this greater level of detail is coming from the earlier mentioned interview while the rest of the information was gathered through observations during time spent at the company.

The business entities customer order and inventory were omitted compared to the OpS model. While customer order is identified as a key business entity to the company, it actually consists out of one or more orderlines for different products (SKU) in a variety of quantities. Via the schedule these orders, when they are make-to-order, are then translated into a combination of portioning slips. Since this research focuses on the production part and not on the entire order, the business entity customer order is therefore omitted.

Furthermore for the inventory, it is assumed that the raw materials stock is always available. This assumption does not lead to unrealistic results since in reality the raw materials are nearly always available and when they are not only that specific order will be delayed, so this
is not having a big ripple effect on the entire company or on other end products as could happen on an assembly line for example.

As for the inventory of products that are ready to be sold, they can be seen as a collection of portioning slips of which the production is completed. Note that a portioning slip contains an integer number of finished products after the assembly (portioning) is completed. For example when a portioning slip contains 100 pieces of products A, after 50 are sold it can be regarded that still 0,5 of that portioning slip remains.

This leads to a GSM model that is displayed in Figure 5. An enlarged version of this figure can be found in Appendix C. It is assumed that the generated events are visible for all business entities and that all events belong to one business entity.

![Figure 5. GSM model of the company](image)

The syntax of the GSM model is described hereafter. The horizontal division into three segments are the three different business entities that are identified: Schedule, cooking slip & portioning slip.

As the name GSM suggests there are three main components of a GSM model. The Guards, Stages & Milestones, where each stage consists of one or more milestones, guards and a stage body. After a guard is triggered, which can happen for example by a human actor or by invocation the associated stage opens and the business entity can be processed. Once a milestone is achieved the processing of the business entity finishes and the stage closes again.

The following icons can be observed in the model:

- **The rectangle with rounded corners**: Indicates a stage body, when there are no further rectangles inside it, it is an atomic stage. Within atomic stages tasks can be performed on the business entity. This is for example where attribute values are assigned to the business entity.
- **The diamond with a cross (◇)**: Indicates the creation of the business entity
- **The diamond (◇)**: Guard, opening of a stage.
- **The circle (○)**: Milestone, closing of a stage.

The further details in the GSM model compared to the OpS model have been achieved via semi-structured interviews with the relevant company stakeholders, being the managers of
the cooking and assembly department by asking how they processed their corresponding business entity (i.e. a cooking slip or a portioning slip). Based on these interviews, in addition to the GSM model of the company, the triggers of the guards and milestones are determined that form the GSM rules that can be found in appendix D.

In this case, looking at the cooking slip business entity we can see the following occurrences. After the initialization is triggered through the guard present at the stage Initiating cooking slip this process starts. When the milestone is achieved the stage closes again. The achieving of this milestone then triggers the next guard which opens the stage cooking process, after this stage is opened also the weigh goods stage opens. Through these kind of triggering mechanisms the whole process can be completed.

3.4. Data

Data is one of the key characteristics of business entity lifecycle modelling. As stated by Nigam & Caswell (2003) a business entity “consists of two parts: an enterprise-wide unique identity and self-describing content.” (p. 430). Therefore all data has to be contained on the business entities, or should at least be directly linked to it. Not only is it necessary to determine the data that is currently stored within the business entities. It is also important to consider which data is needed for simulation purposes. Since OpS is mainly designed to model workflows and not for simulation, and since there is more information relevant to a simulation then to workflows, there is a need for additional information. For example it is necessary to keep track of data relating to processing times and costs, while in the real world this data is not always used in the modelled process. For example, in the situation of this case study the company has no insight into processing times for the various cooking and portioning slips. There is some general knowledge relating to processing times but this is only partly documented. Specific processing times are unknown and therefore not documented and also not available on the current cooking and portioning slips. Therefore it is necessary to choose which data is relevant to model. This also depends on the scope of the project, since not all the data that exists in the real world is relevant for this research. For example data on the customer orders is not relevant as only the production process will be simulated.

UML

Since UML was used by Bhattacharya et al. (2005) in their research it is included in this research as well to structure the data. During the development of the OpS model where the business entities have been identified an UML class diagram has also been created, which includes the identified business entities but also the related data information. Such as a customer that is related to the business entity customer order. One of the advantages of making a UML diagram is that it forces the user to have deeper thoughts about the data and their relationships compared to only using the OpS model. Furthermore it provides a clearer picture of the data and the relationships between the data that does exist. This UML model of the current data structure can be seen in Figure 6. This UML class diagram can then be used again to create the information model for the GSM modelling and the simulation model. The UML diagram, which will be used for the the simulation model can be found in Figure 7.
Figure 6. The UML model belonging to the OpS model

The basis of the UML diagram used for simulation is the UML diagram of the current data structure of the company related to the identified business entities. To this data structure, the data that is relevant for simulation, such as processing times, was added and the irrelevant data was omitted. The resulting UML diagram that is used for the simulation can be seen in Figure 7. This UML diagram is then converted to the plain attributes as used in GSM and later in the simulation model.
3.5. Inclusion of costs

Since the company is also interested in the costs of the different schedule redesigns the costs also need to be included in the resulting simulation model. The inclusion of costs is also one of the measurements of a redesign on the devil’s quadrangle (Brand & Van der Kolk, 1995) because costs are only of interest in giving an impression of the effect of the redesigns the costs can be limited to the costs representing the effects of the redesign. To be exhaustive and to validate omitting other costs, all costs are briefly mentioned in this paragraph.

As mentioned in Chapter 2 Wynn et al. (2013) determines three moments during which cost information should be available:

- At design time (to make design choices)
- At runtime (selecting a cheaper material or resource)
- At post-execution time (for reporting and analysis)

To determine if during these three moments the costs are available it should first be determined which costs are relevant. Therefore the inclusion starts out at the design time phase with determining which costs are considered relevant. Due to time constraints, for this
case study determining which costs are relevant becomes a trade-off between available or easy to obtain cost data and the effect of the costs on the end result.

The scheduled redesigns are aimed at reducing the amount of labour hours and wages spent on the products, so this is the primary cost consideration. However to decide on labour hours and the associated costs different measurements are possible, so although considered relevant, which measurement to use has to be determined. The hours spent on a product by an operator can be measured and used as a driver for labour costs. But the operator also incurs waiting times that are paid by the company which are not directly related to a specific product. Therefore the second measurement possibility is including this waiting time by taking the total time spent every day until the last product of a specific operator leaves the system as a measure of total labour costs. This is the best measurement since it includes the costs of waiting that are paid by the company.

Another cost that is influenced by the redesigns is the inventory cost. One of the drivers of inventory cost is the Weighted Average Cost of Capital (WACC) combined with the value and staying time of the inventory. In the ideal case other costs driving the inventory costs that should be considered are the storage costs and the handling costs associated with storage. Since there is ample storage space and the storage and handling costs are difficult to determine, these costs are considered out of scope for this research. Therefore the inventory costs can easily be determined on a business entity level by multiplying their staying time in the inventory with their value and the cost of capital and hence are written to the business entity.

Although in the ideal case the overhead or transport costs should be taken into consideration in this case study these costs are not taken into account. The overhead or transport costs are not considered to be relevant mainly because the redesign has very little influence on them. Overhead costs will remain constant and the transport costs are not included in the scope of this research. So concluding, in this case the costs considered relevant for the cost measurement are the labour costs and the WACC. The company is interested in the general picture instead of in a product specific cost measurement. This means that an aggregate of the individual business entity timings can be collected and processed in order to determine the value for relevant costs.

As mentioned before ideally other costs would also be included in the cost measurement, including but not limited to, running costs, machinery costs, overhead costs & administrative costs.

The costs that were determined relevant earlier should now be included at runtime according to Wynn et al. (2013). This does reveal a shortcoming in business entity lifecycle modelling however. It is impossible to assign the labour costs of waiting time of an operator to a specific case and therefore to a specific business entity, since the operator can actually be waiting for multiple business entities. This stresses the difficulties in trying to pinpoint specific costs or times to specific business entities, it turns out to be impossible. This problem shows that
sometimes the fine level of granularity provided by business entity lifecycle modelling unnecessary. The fine level creates unnecessary complexity in this case, as it might also do in similar cases. This complexity might make it impossible to assign values such as costs, to a specific business entity. When possible all information is and should be stored on the business entities, however for more general figures of the simulation this is more complex than the classic way of storing information.

When it is possible to allocate the costs immediately to the business entity this is done. Although the indirect values of the costs are available, the inventory and labour costs should still be computed from these values. This means that not all the costs are directly available at run time on the business entity since they cannot always be allocated directly to a single business entity.

During post-execution time all the costs measures are available again. This requires that costs that are incurred are stored on some kind of cost entity next to the regular business entities. This cost entity then contains measurement values, for example the total labour costs, that cannot be allocated directly to individual business entities, but can be mapped to them. Again when possible costs are allocated directly to the business entities, such as inventory costs, but when finished these costs are processed to create a general overview instead of costs at a business entity level.

3.6. Conclusion
The main topic of this chapter was to answer the first research question:

*How can the current company situation be modelled using business entity lifecycle modelling?*

Within this chapter various techniques were discussed to answer this research question from different viewpoints. The company situation was first modelled on a high level using the OpS model, which showed that getting to the concept of business entities is not always as straightforward as the literature might suggest. This OpS model then formed the basis for creating the GSM model including the GSM rules. The inclusion of costs proved challenging since the available cost information was limited. Furthermore it showed that costs cannot always be directly related to business entities. Finally the data was discussed including the use of UML diagrams which showed that UML is well suited for displaying the relevant data and that some changes to the UML model had to be made to make it more suitable for simulation.
4. Creation of the simulation model and schedule redesigns

While the creation of business entity lifecycle models is described in literature, for example by Nigam & Caswell (2003) and Bhattacharya et al. (2005), creating a simulation model from business entity lifecycles is not. Therefore this is a very interesting theme to gain further insight into the potentials of this technique and necessary to answer the company questions. Compared to the classic way of simulation modelling the biggest difference is that information related to the process is explicitly represented by the business entity. Also for realizing the simulation model the difference between the traditional way of modelling and the modelling used in this case study will have an effect. Therefore the main topic of this chapter is to answer the second research question: How can the business entity lifecycle model be used to create a simulation model?

4.1. Simulation software

Liu et al. (2007) discussed verifying operational business entity lifecycle models using CPN tools. With the use of a petri-net reachability graph important properties of business entities such as persistence, no split and reachability can be verified. Liu et al. (2007) also consider a token in a petri-net comparable to a business entity from a business entity lifecycle model. It is rightfully mentioned by them that CPN tools can also be used to simulate these kind of models, however there were various reasons not to do so in this research. The primary consideration is that CPN tools can only read data as name-value pairs and does not support tables or a comparable structure to store data. Since a lot of data will be used in the simulation it is essential that the software is easy to work with when handling relatively large amounts of data. Therefore the large amount of data that is present in the process would be very cumbersome to import into CPN tools. The same is then true for exporting the results of the simulation. Alternative simulation software that was also financially feasible were therefore explored and Incontrol Enterprise Dynamics was used for creating the simulation.

Enterprise Dynamics

Since Incontrol Enterprise Dynamics is selected as the most feasible simulation software for this research the most important information will be discussed here for a general understanding.

The basic elements in an Enterprise Dynamics simulation model are:

- Atom: These are the items that flow through the simulation and represent the concept of business entities.
- Source: Here the Atoms are generated.
- Queue: Here the atoms can be stored, comparable to an inventory or repository.
- Server: Processes an atom, using service times that can be read from the atom; a server could be for instance ‘filling kettle’ or ‘cooking’. A real life machine can have different, separate, processes and this can therefore be modelled as multiple sequential servers. A server can be seen as a task that requires a machine or as a task that does not require a machine.
- Operator: There are not only machines in the factory but also humans. These operators can be called by a server and the process will only start if the requested operator is present. Note that not all processes require an operator as some processes are automated.
An example of a simple Enterprise Dynamics model including the basic elements, except for the operator, can be seen in Figure 8. On the far left the atoms can be seen which from there on can flow through the system over the arcs (lines). When more than one arc leaves an atom there are multiple ways to define over which arc the atom should flow.

![Figure 8. Example of a simple Enterprise Dynamics model](image)

The implementation of so called labels containing the data related to an atom in Enterprise Dynamics closely resembles the concepts of business entity lifecycle modelling. The biggest difference might even be the terminology, as business entities can be considered the same as atoms in Enterprise Dynamics since it is the same concept. All data that is stored on an atom is written on the label and has a name and a value.

One of the most important arguments to select Enterprise Dynamics over other simulation software such as CPN tools was the easy link with Microsoft Excel, given the large amount of data that needs to be processed. Before the start of each simulation the relevant data, in this case the cooking- and portioningslips are imported from Microsoft Excel intro Enterprise Dynamics, where this data is then written to the corresponding Atoms. When an Atom leaves the simulation, the data such as processing and throughput times that was stored on it is written to a table and exported to Microsoft Excel at the end of the simulation. This intervention with reading and writing to Excel files could only be done manually for each simulation run. This limitation impeded the possibility to effectively perform multiple runs, as it disabled the possibility to have multiple runs through the built-in software tools where data is usually stored implicit within the program and only the results are shown.

4.2. Mapping the GSM model to Enterprise Dynamics

The start of creating a simulation model will be the GSM model described in the previous chapter and shown in Figure 5.

The as-is schedule that is used in the simulation is the historical production schedule from Culivers. This data is the basis for the redesigns of the production schedules, for which the production schedule will be modified. This modification is discussed in paragraph 4.6.
The GSM model has four main characteristics that need to be mapped into the *Enterprise Dynamics* model. These are: *guard, stage, milestone* and *business entity*. However there is key information that is not present in the GSM model but is essential for the *Enterprise Dynamics* model to be run properly. This mapping is indicated in Table 6 will be discussed after which the items that did not exist in the GSM model will follow. Note that when terminology from *Enterprise Dynamics* is used this refers to the modelling in *Enterprise Dynamics*, while when GSM terminology is used this describes the conceptual GSM model elements.

Table 6. Mapping Table of GSM to Enterprise Dynamics

<table>
<thead>
<tr>
<th>GSM</th>
<th>Enterprise Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>Server</td>
</tr>
<tr>
<td>Guard</td>
<td>Implicit, 4D script</td>
</tr>
<tr>
<td>Milestone</td>
<td>Implicit, 4D script</td>
</tr>
<tr>
<td>Business entity</td>
<td>Atom with label</td>
</tr>
<tr>
<td>-</td>
<td>Operator, arcs</td>
</tr>
</tbody>
</table>

Central in the GSM model is the *stage*, a stage can contain one or more tasks that are not necessarily explicitly mentioned in the GSM model. For each task of a *stage* in the GSM model a *server* is created in the *Enterprise Dynamics* model. This entails that there can be far more *servers* than stages in the GSM model, even more so since certain *Atomic* stages can be executed in parallel. Except for the *stage* were a *business entity* is initialized. That *stage* is represented in the *Enterprise Dynamics* model as a *source* followed by a *server* with zero processing times where the values are written to the *atom label*.

The next two important characteristics of GSM models are the opening and closing of stages through *Guards* and *Milestones*. This opening and closing of stages can also be modelled in *Enterprise Dynamics*. It is modelled such that the *server* only opens again for a new *atom* when the previous *atom* has left all the servers that relate to the same *stage*. Therefore an atomic stage from the GSM model can consist of multiple servers in *Enterprise Dynamics*, that represent the various tasks performed within the atomic stage. But within this collection of servers for tasks, only one server can be busy at a time since the *server* is closed after one *atom* enters the first server of a specific stage. This also means there is no need for inventory points between the servers in the same atomic stage since there can be no other business entities present so the atoms can always move to the next server.

Once the *atom* leaves the last server that is related to the associated *atomic stage* the first *server* of that *stage* opens again. This is comparable to the achievement of a *Milestone* in GSM. Therefore it is assumed that leaving the last related *server* in *Enterprise Dynamics* means that the *milestone* is achieved. The opening and closing of *servers* in *Enterprise Dynamics* can be implemented through the use of the in *Enterprise Dynamics* incorporated 4DScript. For example in the GSM model the atomic stage cooking can become open based on the milestone of a business entity. However an atomic stage can consist out of one or more tasks (Hull, et al., 2011) and therefore multiple tasks that need to be simulated differently. E.g.
filling of kettle, cooking, emptying kettle. When an atom enters the first server of this stage the input to that server closes and only opens again when the business entity leaves the last server of that stage. After which the next cooking order, which was waiting in the queue, on that line can be processed. This can be compared to a business entity, in this case cooking slip, triggering the opening of a stage and the respective closing after all the tasks are completed. Therefore this behaviour is mimicking the GSM behaviour.

Table 6 clearly shows that the information contained in the GSM model is not directly suited for simulation with Enterprise Dynamics. While the GSM model can be used as a basis for the simulation, more details have to be filled in. This can be done by observing what happens exactly to the business entities in such a stage. For example operators are not explicitly modelled in the GSM model. While operators are crucial to most factories and other businesses they do not have an explicit place in GSM models, however operators can perform tasks within the stages. Therefore information on the operators has to be gathered separately in order to be able to include them in the simulation model as this information is not necessary for the creation of the GSM model it was not gathered in that phase.

Another necessity in Enterprise Dynamics is the concept of arcs, these arcs are necessary for atoms to move from one element in the model to the next. Since the business entity flow is modelled by the rules of the GSM model instead of arcs a direct mapping is not possible. The method used in this situation was to once again observe the reality to see the possible flows of business entities. Although direct mapping is not possible one rule can be made, within an atomic stage of a GSM model, the associated servers in the Enterprise Dynamics model are connected by exactly one arc, and within an atomic stage no split or merge is possible.

The fact that not everything can be mapped directly is a challenge when trying to simulate GSM models. For further research this problem can be approached from two directions at the same time. The conceptual model can become richer as to better match the simulation model and the simulation model could also become more like the conceptual model. An optimum is probably somewhere between those two approaches.

4.3. Assumptions
Assumptions are essential to any simulation since a simulation is the creation of a simplified version of reality to get insight into the complex real world. Therefore, as in any other simulation, assumptions were necessary in this case study. The assumptions made will be discussed briefly.

- **The production of products always succeeds.**
  In reality the production can sometimes fail because of problems with the ingredients, the cooking process or various other reasons. However this rarely happens (<1%) and does not disturb the process. The product then has to be produced again only slightly increasing the workload.
- The schedule is followed exactly.
  Personnel can decide to deviate from the scheduled sequence for a variety of reasons. However in the simulation the schedule is always followed exactly.

- There is always enough stock of raw material.
  Since in reality the raw materials are nearly always available and when they are not only one production order will be delayed so this is not having a big ripple effect on the entire company as could happen on a factory with an assembly line for example.

- There is one operator assigned for each of the following lines: Line 1, 2, 3, Line 4, 5, Line 6, 7 & Line 9.
  This is usually the case in the company. However based on the mix of production orders the head of the cooking department can decide for a different allocation of operators to lines. Since there are no decision making rules for this, the default situation is assumed to always happen. This can have a slight impact on the time different lines finish.

- Operators do not perform tasks at different lines then the assigned line.
  Sometimes operators help each other out with small tasks. However this is a rare practice and since it happens irregularly without decision making rules it is also hard to model. This will not have a significant effect on the simulation.

- Operators are present 24 hours.
  Eight hour shifts are used within the company. However since one shift is directly followed by the next they can also be considered as one longer shift. A regular production day is 16 working hours, or 2 shifts, but operators are present in the model for 24 hours to allow for overtime.

- Jobs enter the system at hour 0 of the scheduled day.
  As in reality, cooking and production orders (jobs) are released at the beginning of each working day. Hour 0 is considered the start of the first working day within the simulation.

- If the same product is produced in sequence no cleaning is necessary.
  As in reality cleaning is only necessary if different products are made subsequently. If the same product is produced on the line no cleaning is necessary. The reason this situation occurs is usually caused by a capacity restriction of the kettle.

- No breakdowns
  It is assumed that machines do not break down. Of course in reality this does happen from occasionally but the absence of reliable data about breakdowns made this infeasible to incorporate. The effect will be that all the results will be slightly more optimistic than in real life. However since also in the as-is model no breakdowns are assumed this influence is minimal.

### 4.4. Time measurements

For running a simulation it is essential to know the relevant processing times, furthermore these times are also relevant cost drivers. Culivers produces over a thousand different intermediate and final products. Therefore it is impractical and nearly impossible to determine the different processing times for the different stages and actions of each product. A method had to be derived to be able to make reasonable estimates for the processing times
of each SKU. Therefore time measurements were taken on a low-level, partly based on product details, that could then be extrapolated to a product level.

The cooking line that is used plays an important role in the time that is used to process the cooking orders. In general procedures and activities vary from line to line. Therefore, for each cooking line within the scope of this research, line 1 to 7 and 9 the processing times for various steps and their time drivers were determined separately.

On each cooking line different time drivers were identified for different activities, namely:

- The weight of the production order (weight)
- The number of ingredients in the recipe (ingredients)
- A constant, this can be the same value for one or multiple lines

What time measurements apply to each cooking line can be seen in Table 7. For each column the same colour indicates that the same action is performed on all these lines and that therefore the times have the same probability distribution. All the columns are independent.

It should be noted that some time measurements are related to operators performing actions while other actions are performed by machines. Most notably the time in kettle, for both cooking and cooling only consumes machine time, the same applies for CIP. CIP is an abbreviation of cleaning in place and is the automated cleaning of the kettle. Apart from this automated handling on some kettles, on other kettles cleaning still needs to be done manually. On top of that there is, also when using CIP, an additional manual component.

<table>
<thead>
<tr>
<th>Line</th>
<th>Getting ingredients</th>
<th>Filling kettle</th>
<th>Time in kettle</th>
<th>Pumping to cooler</th>
<th>Getting carts</th>
<th>Empty kettle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>N/A</td>
<td>Constant</td>
<td>Weight</td>
</tr>
<tr>
<td>2</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>N/A</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>3</td>
<td>Constant + Ingredients</td>
<td>Constant</td>
<td>Constant</td>
<td>N/A</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>4</td>
<td>Constant + Weight</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>5</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Weight</td>
</tr>
<tr>
<td>6</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>7</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>N/A</td>
<td>Constant</td>
<td>Weight</td>
</tr>
<tr>
<td>9</td>
<td>N/A</td>
<td>N/A</td>
<td>Weight</td>
<td>N/A</td>
<td>Constant</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Even when using the simplified schedule presented in Table 7 it can be seen that a total of 29 different times needed to be measured. Because the total sum of all the different coloured cells for each individual column is 29, i.e. there are seven different processing times for cleaning while administration only has one processing time due to the fact that this process is the same for all lines.
Using the results of the measurements it is possible for each production order it is then possible to determine the expected processing times of the various steps, based on the number of ingredients of the recipe, the weight of the production order and the cooking line. For time measurements regarding ingredients this was done by determining the processing time per ingredient for that step. The processing times that are related to weight are measured separately to properly distinguish them. If a specific cell in Table 7, has more than one time driver e.g. constant and weight then the separate actions that drive both times were measured separately. Together with the time measurements, the number of ingredients, weight and cooking line were recorded for determining the time measurements.

Of the measurements a uniform distribution was determined using the upper and lower bounds of the measured processing times. When there were not enough measurements to determine an upper and lower bound a non-stochastic value was determined by using the average value of the relevant measurements. The processing times do not take into account factors such as experience of the operator etc. as this is out of scope for this research.

The determined processing times as displayed in Table 8 were determined based on the earlier discussed time measurements conducted at Culivers. However due to time constraints it was not always possible to have enough measurements for a statistically reliable measurements. Therefore the determined processing times as displayed in Table 8 are based on the time measurements but are not always 100% accurate. The only processing times the company did have information on, were the processing times for line 9. Since the line and operator follow a pair, the operator and the line can be seen independent from the other lines. Therefore a distribution could be plotted since there were enough measurements available already, this is also the reason that line 9 has normal distribution.

**Assembly**

The assembly line process is less organized than the cooking process and therefore very hard to simulate. While the steps that a product goes through are clear, the steps that the employees take are complicated and hard to depict in reality. These assembly steps consist out of but are not limited to, getting the goods from the intermediate cooling, man the pump on the assembly line, putting the various ingredients in the packages, cleaning the line but also setting-up the line for the next product which is a complex procedure with many steps. Due to the complexity of the steps employees take it is assumed that the by the company currently used times in the scheduling process are the actual processing times. Since these assumed times are currently used to make the assembly schedule and assembly personnel scheduling and this works to all the stakeholders their satisfaction. It can be assumed that the estimated times are accurate. These timings include 10 minutes set-up time for lines 1,2,3 and 15 minutes for the other lines. The packaging time per product is 4 seconds on lines 1,2,3, 9,6 seconds on line 4 and 4,8 seconds on line 5.
4.5. The enterprise dynamics model

The information discussed in this chapter and chapter 3 was used to create the resulting Enterprise Dynamics model. A part of this model, depicting the cooking process, can be seen in Figure 9. The blue blocks indicate a queue while the other blocks resemble servers. The little persons that can be seen resemble operators and the red lines that can be seen are the arcs through which the labels can flow. Since Figure 9 shows a part of the process after the goods were distributed over the respective cooking lines, this split cannot be seen here and is already to the left. Atoms are sent to the right cooking line by a label value that is attached to it based on the schedule. Contrary to most classical simulation models where the processing times would be stored on the server in this case, the processing times are stored on the atoms. In
this simulation model all processing times are read from the label values that are attached to the atoms. The opening and closing of the server inputs as described earlier is done using the 4DScript of Enterprise Dynamics and cannot be seen in the attached figure.

Figure 9. Part of the model created in Enterprise Dynamics

In table 9 the biggest differences of this model compared to how the model in Enterprise Dynamics would have been if typical classical simulation techniques were used can be seen.

Table 9. Comparison to classic simulation modelling

<table>
<thead>
<tr>
<th>Current BEL simulation modelling</th>
<th>Classic simulation modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrivals are read from the historical orders</td>
<td>Arrivals are based on a stochastic arrival rate</td>
</tr>
<tr>
<td>Processing times are read from the atom label</td>
<td>Processing times are determined per server</td>
</tr>
<tr>
<td>The routing of the atom is read from the atom label</td>
<td>The routing of the atom is determined by a stochastic distribution</td>
</tr>
<tr>
<td>Information relating to the results of the simulation is written to the atoms</td>
<td>Information relating to the results of the simulation is recorded separately.</td>
</tr>
</tbody>
</table>

This is not to say that this comparison is true in all cases. Especially in classic simulation there are many different options to depict the reality. For example processing times can also be made dependent on the product and not necessarily to the server, however this is not common. The same goes for the arrivals, while a stochastic arrival rate is common (Dumas, La Rosa, Mendling, & Reijers, 2013), historical deterministic arrivals can also be used in classic simulation.

4.6. Schedule redesigns

For this scenario two different schedule redesigns are considered based on the company questions as discussed in chapter 1. Given these company questions two different redesigns can be established.

For all the redesigns the original historical schedule is used as the basis for the redesign. Since this schedule is not created by a clear set of rules but by best-judgement of the planner it is
not feasible to generate an entire new schedule based on historical orders. Therefore only the parts relevant for the redesign will be changed on the historical schedule. These changes will be discussed in this paragraph and paragraph 4.7. These changes of the historical schedule might lead to some situations that might not occur in reality such as very busy and very quiet days. Therefore it is advised to have a look at the average values of the results since this will show a more realistic picture then results on a day level.

**Company question 1**  
*What is the effect of information sharing with a select number of partners on relevant costs and KPI’s?*

The information sharing with a partner allows Vendor Managed Inventory (VMI) to take place. Then the vendor, in this case Culivers, can determine when and how much of a product they want to ship to the, in this case internal, customer. Because, in general food products have a short consume-by date, the company decided to use VMI only for frozen goods. These goods have consume-by date of at least one year in the future there is a lot of freedom with regards to production scheduling and inventory. For other goods the consume-by dates are significantly shorter and therefore there is less to gain with VMI.

This selection of relevant goods results in a list of a little over 100 products that can be used for VMI. In cooking weight these VMI products entail 13,2% of the total sales. Also they make up 3,7% of the total assembly orders. Furthermore the customer decided that they want a maximum of 3 months’ worth of sales of product in stock. This maximum of 3 months is common policy for VMI throughout the Sligro Food Group. Because of limitations with the forecasting system used. This forms the basis of redesign 1.

**Company question 2**  
*What is the effect of having intermediate stock on relevant costs and KPI’s?*

There is a possibility to have intermediate stock: between the cooking and packaging, products can be left here for two additional days in a cooled environment. This means production orders to a maximum of three days can be combined. This is valid for all the products made, so not only for the frozen products mentioned in company question 1.

Therefore two production orders might be combined if possible. Doing this with historical productions orders is not completely realistic, since short-lead times are guaranteed, it can be that a product is ordered daily, however these orders were not known the day before while in this schedule they are. Therefore in real life it is to be expected that this effect of batching is less pronounced. Furthermore it is not possible to do this for all products since there is a limited cooled space to store the intermediate products. Therefore this redesign will only be applied to the twenty products that are produced in the largest quantities. The redesign will be evaluated in two different cases. One redesign entails combining cooking orders over a maximum of two days while the second redesign will combine cooking orders over a maximum of three days.
Since there is no effect on the assembly in this specific redesign this is, contrary to redesign 1, left untouched in this redesign.

4.7. Practical execution of the schedule redesign

Company question 1

What is the effect of information sharing with a select number of partners on relevant costs and KPI’s?

The original assembly and cooking schedules were the basis of this redesign. The VMI products were identified within the assembly schedule and combined with orders that were at most 90 days in the future from the first occurrence of a specific product, therefore there is a rolling horizon. However this combining of production orders stops when it would cause the combined assembly order to go over 1800 kilograms. Note that if an order is scheduled later then an order that would lead to exceeding the 1800 kilograms, this order can still be combined with the earlier scheduled combined order. This occurs when this new combination does not lead to a weight higher than 1800 kilograms.

This 1800 kilogram maximum weight is four times the capacity of the biggest regular kettle. This strategy leads to a slightly higher portion of the VMI products being made in the beginning of the simulation period. A more realistic implementation would therefore lead to a more even spread of VMI products throughout the period. However due to the complexity this was not implemented.

Based on this new assembly schedule also a new cooking schedule can and has been determined. For each VMI product the associated recipes were extracted from the company’s database and their production quantity on the relevant days was also shifted in the same fashion as the assembly. When an assembly order is brought forward, the ingredients that need to be cooked for this assembly order need to be brought forward to the same date, else the ingredients are not ready to be assembled. The implementation of this redesign required extensive data manipulation since the link between assembly orders and cooking orders was very implicit within the companies database.

Another item is that the combination of different cooking orders sometimes exceeds the maximum capacity of the kettle. The company has kettles in different sizes and for different types of product. If the combination of cooking orders surpasses the kettle capacity it is first moved to a bigger kettle, when the capacity of the largest suitable kettle is also exceeded, the cooking order is then split into multiple equal batches that do fit in the kettle. The advantage is that this eliminates the need for cleaning between two cooking orders of the same batch and thus even in this case time is saved.

Company question 2

What is the effect of having intermediate stock on relevant costs and KPI’s?

The original assembly and cooking schedule is the basis of this redesign. The twenty recipes that are produced in the biggest quantity are considered for this redesign to be kept as
intermediate stock. Since the cooled stored space is limited and the achieved effect is the highest for products that are made more often and in bigger quantities.

As mentioned earlier two different cases of this redesign are considered, one were two days of production are combined and one where three days of production are combined, for the same twenty recipes. The way this redesign was created is similar to the redesign of company question 1. In the historical cooking schedule, if it was possible to combine the production orders for two or three days this was done with a rolling horizon. Once again if this lead to the situation were maximum kettle capacity is exceeded the production order is moved to a bigger kettle, when also this capacity is exceeded the order is split into multiple equal size batches, once again eliminating the need for cleaning.

4.8. Challenges in using Enterprise Dynamics
While using Enterprise dynamics gave the possibility to simulate the business processes in the way BEL modelling is designed, by defining all the data on the business entities, it had both advantages and disadvantages. Despite the facts that it is possible the program was never intended to be used in this way, which created significant inefficiencies when running the simulation, especially regarding loading the values from the schedule into the simulation model and onto the atoms and writing the results from the simulation model back to Microsoft Excel. This used a lot of computer time but required little effort by the user. Also due to this inefficiencies it was infeasible to have multiple runs and create a confidence interval through those regular means. While the experience of using business entities lifecycle modelling as a start of the simulation was positive in terms of understandability and clarity. It would be beneficial if there was simulation software that properly supports this.

4.9. Conclusion
To answer the main question of this chapter various choices had to be made, firstly the selection of simulation software to be used in this research, Enterprise Dynamics was chosen for this. Furthermore there is a discussion how the GSM model can be used as the basis for a simulation. It is found that part of the GSM model can be used for the simulation but it does not include all the information necessary. Therefore the available information is extended by gathering extra information on, for example, process times. To give an impression of the created simulation model the Enterprise dynamics model is discussed shortly. This model is compared to the classical way of modelling to emphasize the differences and the need for extra information. In general it can be concluded that a simulation model can be based on a business entity lifecycle model, however it presents technical challenges for the simulation software. In further research it could be investigated if other simulation software is more suited for this type of simulations. Furthermore the mapping of the conceptual models towards a simulation model is not rigorous yet, which also requires further research.
5. Results and validity
This chapter will discuss the results of the simulations that were executed by using the earlier described simulation model. The evaluation of the redesigns will partly be based on the four factors of the Devil’s Quadrangle model by Brand & Van der Kolk (1995) as earlier elaborated in chapter 2. Please note that all the numbers relating to costs are scaled to ensure confidentiality for the company.

5.1. Introduction to the simulation
To model the current and future situations, the historic production orders are retrieved from the companies ERP system for a whole year. From the 2nd of January 2013 until the end of December 2013. A period of one year is chosen since there are distinct seasonal influences. Most profoundly a summer cycle, a winter cycle and the Christmas period. Therefore a whole year treats all these periods equally. In this period there were 262 production days. The company operates on weekdays and not in weekends or during holidays, except for the Christmas season. Depending on the actual days of Christmas and boxing day it might be that the company operates on the Saturday before or after Christmas.

In this period, over 30.000 cooking orders (cookingslips) were fulfilled totalling 1100 different recipes. Furthermore over 17.500 assembly orders (portioningslips) were produced of which 1503 unique products were assembled. This shows the complexity of the company and the simulation. Therefore, as discussed in the previous chapter, assumptions had to be made with regards to processing times etc. It is unavoidable that this is having its effect on how close the as-is situation gets to the reality.

5.2. Results of the as-is situation simulation
The results for this simulation run and the other simulation runs will be split in two parts. The results of the simulation of the cooking stage and the results of the simulation of the assembly stage. This is done since the second redesign does not have an effect on the assembly department. As only the cooking orders are moved forward in that redesign, thus creating some inventory between the two departments but it does not change anything to the assembly department. Different parameters and results from the simulation will be reviewed.

Cooking
All products that have to be produced on a given day enter the simulation on time 0 of that day. In the real world most products finish within this day. In real life products are rarely shifted to the next day; unfortunately, the company data did not show on which days this did happen. In Figure 10 the hours that elapsed between the start of the day and the finishing time of the last products on the respective cooking lines can be seen. Also called hours until last product finished in the relevant tables, it indicates how many hours after entering the cooking department the last product of that day for the specified lines leaves the system. This is also the time at which the operator can end the working day.
Another metric that can be used is how much time the operators spent on average on performing tasks per working day and can be seen in Table 10. There is a large difference between the time an operator spends and the time the last products leaves the system. Partly this is also true in real life. When the operator has completed all his tasks and the meals are cooking on all lines there is nothing he can do. Furthermore it is also a partial weakness of the simulation, for example there are a number of tasks that do not need to be invoked at a specific time in the process. However in the simulation all tasks are invoked in a specified sequence and the operator get that tasks added to his task list in a First-In First-Out way. An example of this is the task of administration. The simulation invokes it during the ‘getting ingredients’ process but in reality it can also be done a few minutes later, when the operator could have been be idle anyhow.
Table 10. Time operators are busy and associated costs on an average daily level for the as-is situation.

<table>
<thead>
<tr>
<th>Operator for line</th>
<th>Hours busy per working day</th>
<th>Hours till last product finished</th>
<th>Idle time (%) of total time</th>
<th>Costs of busy hours</th>
<th>Total cost of idle time</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>9,14</td>
<td>14,04</td>
<td>35%</td>
<td>€ 85,94</td>
<td>€ 46,11</td>
<td>€ 132,05</td>
</tr>
<tr>
<td>4,5</td>
<td>6,71</td>
<td>10,94</td>
<td>39%</td>
<td>€ 63,07</td>
<td>€ 39,83</td>
<td>€ 102,90</td>
</tr>
<tr>
<td>6,7</td>
<td>7,89</td>
<td>10,88</td>
<td>28%</td>
<td>€ 74,17</td>
<td>€ 28,16</td>
<td>€ 102,34</td>
</tr>
<tr>
<td>9</td>
<td>4,77</td>
<td>5,53</td>
<td>14%</td>
<td>€ 44,90</td>
<td>€ 7,11</td>
<td>€ 52,01</td>
</tr>
</tbody>
</table>

Daily cost: € 268,09 | € 121,21 | € 389,30
Yearly cost: € 68,881,80 | € 31,118,20 | € 100,000,00

Assembly

For the assembly department the scope is on the packaging lines. Once again since this process is rather chaotic in real life, some assumptions had to be made, this entails that we assume there are always four persons working on a packaging line. In reality also always four persons are scheduled per line, if one or more of them are not needed for the assembly of a specific product they already start working on other production orders. In Figure 11 the maximum throughput time per day of all the different packaging orders can be seen. Some outliers exist for very big orders.

In total during the 364 days of simulation 31246 working hours were spent in the packaging department. Leading to baseline costs of €1,126,04 per day and € 293,895,62 for the entire year. These costs will be used to compare the influence of the scheduled redesigns on the assembly department. These costs are thus higher than the costs for the cooking department. However the cooking department has more variables with regards to kettle fill rates etc. and is therefore considered the focus point of this research.
Validity
With shifts of 8 hours and usually 2 shifts per working day, you would expect that operators are finished on average within 16 hours. While this holds for most operators in the simulation model it does not hold for the operator of line 1,2,3. There are multiple explanations for this.

That the operator of line 1,2,3 is more busy than the others can be explained by the fact that the operator of line 8 can help at line 1,2,3. Furthermore it could also be due to a rather large error in the time measurements, especially for the operator of line 1,2,3. Since there is a big amount of different tasks these timings were difficult to determine within the limited time available. Furthermore lines 1,2 and 3 are all very different, between them and also compared to the rest of the factory which meant a relatively small number of measurements was available per task. However since these lines are handled by the same operator they are considered together. Line 1,2 and 3 process around 25% of all the considered cooking orders.

These results will be used as the basis for the analysis on the impact of possible schedule redesigns. So the effect that is probably primarily caused by incorrect time measurements should be limited and the general impact trend of the redesigns can still be determined, i.e. whether the redesigns have a positive or negative impact. However it does have a negative effect on the accuracy, also due to the absence of confidence intervals caused by limitations within Enterprise Dynamics when using it as a simulator of BEL models.

5.3. Results of the VMI redesign simulation
From Figure 12 it is immediately clear that this redesign, as it is discussed in chapter 4, causes some minor spikes in the cooking behaviour compared to the as-is situation. This is expected as orders are combined. In total 2219 production rows were eliminated out of 30,000 in total using the redesign implementation as discussed in chapter 4. It is standing out that the production hours of line 4,5 are much higher than in the as-is situation. This can be attributed to the fact that line 4 contains the biggest regular kettle. Therefore the batching of production orders leads to the fact that smaller production orders from smaller kettles are combined into bigger production orders that have to be produced on line 4, making that line very busy.
Looking at the costs in Table 11, it can be seen that the total costs are higher than in the as-is situation. While the cost of busy hours are slightly lower, the costs for idle time are higher. If it is possible to reduce the idle time through more efficient scheduling this redesign can be beneficial. Also the higher idle times on line 4,5 can be explained by the batching of production orders in line 4. Since a lot of orders move to line 4 this line is busy and the operator is waiting for this line to finish while 5 is already finished. In reality the schedule could then move one or more cooking orders of line 4 to different lines to reduce the idle time of the operator. However such advanced scheduling decisions were not considered in these redesigns, but in order to get a more complete and thorough understanding of the impact of using VMI a better schedule should be created which takes into account that there is an equal workload over the different lines.

Table 11. Time operators are busy and associated costs on an average daily level for the VMI redesign situation.

<table>
<thead>
<tr>
<th>Operator for line</th>
<th>Hours busy per working day</th>
<th>Hours till last product finished</th>
<th>Idle time (%) of total time</th>
<th>Costs of busy hours</th>
<th>Total cost idle time</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>8,36</td>
<td>12,96</td>
<td>35%</td>
<td>€ 78,68</td>
<td>€ 43,22</td>
<td>€ 121,90</td>
</tr>
<tr>
<td>4,5</td>
<td>7,35</td>
<td>12,81</td>
<td>43%</td>
<td>€ 69,16</td>
<td>€ 51,33</td>
<td>€ 120,49</td>
</tr>
<tr>
<td>6,7</td>
<td>7,55</td>
<td>11,25</td>
<td>33%</td>
<td>€ 71,01</td>
<td>€ 34,81</td>
<td>€ 105,82</td>
</tr>
<tr>
<td>9</td>
<td>4,72</td>
<td>5,45</td>
<td>13%</td>
<td>€ 44,39</td>
<td>€ 6,87</td>
<td>€ 51,26</td>
</tr>
</tbody>
</table>

Daily cost: € 263,23 € 136,23 € 399,46
Yearly cost: € 67,986,16 € 35,124,22 € 103,110,38

Assembly
The redesign caused the assembly orders to reduce with 237 in total. This leads to a decrease in the number of setups and therefore the total assembly costs are reduced by € 1,111,40
In Figure 13 it can be seen that the impact for the assembly department is minimal. Since their total processing times are so dependent on set-up times and their throughput of different products is quite high this can be also be expect. The loss of 237 set-ups on a total of over 17,000 does not create a significant change.

Figure 13. Processing times assembly in the VMI redesign situation.

**Inventory**

In assembly the implementation of the VMI redesign meant moving forward 4,495,799 kilogram days, this is the product of the weight and days that a products was moved forward. Sligro books their inventory to sales value and the average sales value of Culivers products is €2.04/kilogram. Therefore using the discount rate of Sligro of 7.9% it is possible to calculate the extra inventory costs. (Sligro Food Group N.V., 2013). This does not take into account the costs of the (cooled) storage itself since this is not a constraint at the moment. Therefore the extra inventory costs are €1983.70.

**Validity**

Based on the results of this redesign it is impossible to conclude if there is a significant difference compared to the as-is situation. Logic implies there should be a cost saving, and with regards to the cost of busy hours and the costs of assembly a slight cost saving is also observed.

**Conclusion**

The introduction of VMI only influences a small amount of orders, therefore no big changes should be expected. The extra inventory costs are determined to be with €1983.70. There also is a gain of €1,111,40 in the assembly department. However the extra gains in the cooking department are harder to quantify. A benefit can be seen in the busy time costs reduction by €895,63. However the waiting time increases, but this could be tackled by better scheduling. Another advantage of using VMI however is, that the company has more scheduling freedom, something that is not explicitly taken into account in this simulation, but is certainly positive regarding the flexibility dimension on the devil’s quadrangle. This leads to
a better ability to counter variance in direct customer orders with VMI products that can be planned by the company. Leading to a smaller difference in throughput between different working days. The external quality of the products is only influenced by a shorter due-date though this should not be too much of a concern since there will still be at least 9 months left.

5.4. Results of the 2 days intermediate stock redesign simulation
For the intermediate stock redesign there is no change in the assembly process. The assembly process is the same as in the as-is situation since there is only batching at the cooking level.

Of the 2536 cooking orders that concerned articles considered in this redesign, after combining a maximum of two days of production into one day this lead to a reduction of 896 cooking orders so that 1640 cooking orders remained. Therefore reducing the amount of cooking orders for the twenty most produced products with about one-third. The redesign implementation is discussed in chapter 4.

Cooking
Looking at Figure 14, it can be seen that as in the VMI redesign again there are some outliers where production orders are combined. In a real world schedule these kind of excesses should be tackled. As in the VMI redesign it is standing out that the production hours of line 4,5 are much higher than in the as-is situation, this can again be attributed to the order batching. Looking at the more general picture of costs involved as displayed in Table 12 it can be seen that the total costs of busy hours are slightly higher on a year base by €246,51, while there are fewer cooking orders and thus set-ups this could be due to the fact that bigger kettles have higher processing times and thus higher labour costs. Also the idle times are slightly higher. This can once again be attributed to the schedule anomalies that were created in the schedule by combining the orders.

![Figure 14. Hours necessary to complete product after start of day in the two days intermediate stock situation.](image-url)
### Table 12. Time operators are busy and associated costs on an average daily level for the two days intermediate stock situation

<table>
<thead>
<tr>
<th>Operator for line</th>
<th>Hours busy per working day</th>
<th>Hours till last product finished</th>
<th>Idle time (%) of total time</th>
<th>Costs of busy hours</th>
<th>Total cost of idle time</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>8,26</td>
<td>12,75</td>
<td>35%</td>
<td>€ 77,73</td>
<td>€ 42,20</td>
<td>€ 119,93</td>
</tr>
<tr>
<td>4,5</td>
<td>7,67</td>
<td>13,42</td>
<td>43%</td>
<td>€ 72,13</td>
<td>€ 54,09</td>
<td>€ 126,22</td>
</tr>
<tr>
<td>6,7</td>
<td>7,78</td>
<td>11,54</td>
<td>33%</td>
<td>€ 73,22</td>
<td>€ 35,32</td>
<td>€ 108,54</td>
</tr>
<tr>
<td>9</td>
<td>4,74</td>
<td>5,49</td>
<td>14%</td>
<td>€ 44,61</td>
<td>€ 7,03</td>
<td>€ 51,64</td>
</tr>
</tbody>
</table>

| Daily cost       | € 267,68                   | € 138,64                        | € 406,33                   |
| Yearly cost      | € 69.128,30                | € 35.744,24                     | € 104.872,55              |

**Inventory**

There is an effect on the inventory. Using a similar calculation as for the VMI redesign a total of 339590 of day kilograms were taken forward creating an inventory cost of €149,84.

**Validity**

On a general level compared to the as-is situation the effect is minimal. If the schedule would be fine-tuned a positive effect would be expected.

**Conclusion**

The negative effect on the inventory is €150 and the increase in labour costs is €4873. Important is to keep in mind that good scheduling is key for a successful implementation. As a different use of operators and their idle time could probably reduce the labour costs. Furthermore this redesign reduces flexibility since there are fewer production options to create certain ingredients (not daily anymore) and also the external quality may suffer a bit from having a longer time between cooking and packaging. There is no change to the internal quality.

### 5.5. Results of the 3 days intermediate stock redesign simulation

Of the 2536 cooking orders that concerned articles considered in this redesign, after combining a maximum of three days of production into one day this lead to a further reduction of 225 cooking orders compared to the first variant of this redesign so that 1415 cooking orders remained. This means that a little under half of the cooking orders for the associated products are now combined. Once again the implementation of this redesign is discussed in chapter 4.

**Cooking**

The results that can be seen in Figure 15 and Table 13 show, as can be expected, a similar image to that in the previous paragraph where one day is combined. However all the associated cooking costs are slightly lower. Some processing times are a bit higher than in the previous variant.
Figure 15. Hours necessary to complete product after start of day in the three days intermediate stock situation

Table 13. Time operators are busy and associated costs on an average daily level for the three days intermediate stock situation

<table>
<thead>
<tr>
<th>Operator for line</th>
<th>Hours busy per working day</th>
<th>Hours till last product finished</th>
<th>Idle time (%) of total time</th>
<th>Costs of busy hours</th>
<th>Total cost of idle time</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>7,95</td>
<td>12,35</td>
<td>36%</td>
<td>€ 74,81</td>
<td>€ 41,35</td>
<td>€ 116,16</td>
</tr>
<tr>
<td>4,5</td>
<td>7,66</td>
<td>13,4</td>
<td>43%</td>
<td>€ 72,03</td>
<td>€ 54,00</td>
<td>€ 126,04</td>
</tr>
<tr>
<td>6,7</td>
<td>7,76</td>
<td>11,53</td>
<td>33%</td>
<td>€ 73,02</td>
<td>€ 35,42</td>
<td>€ 108,45</td>
</tr>
<tr>
<td>9</td>
<td>4,70</td>
<td>5,45</td>
<td>14%</td>
<td>€ 44,23</td>
<td>€ 7,03</td>
<td>€ 51,26</td>
</tr>
<tr>
<td>Daily cost</td>
<td></td>
<td></td>
<td></td>
<td>€ 264,10</td>
<td>€ 137,81</td>
<td>€ 401,91</td>
</tr>
<tr>
<td>Yearly cost</td>
<td></td>
<td></td>
<td></td>
<td>€ 68.199,80</td>
<td>€ 35.527,59</td>
<td>€ 103.727,40</td>
</tr>
</tbody>
</table>

Inventory
There is an effect on the inventory. Using a similar calculation as for the VMI redesign a total of 605020 of day kilograms were taken forward creating an inventory cost of €266,96 compared to the as-is situation.

Validity
The picture is very similar to the two day intermediate stock redesign which is what can be expected.
Conclusion
Compared to the earlier mentioned variant of this redesign this 3 days intermediate stock variant delivers slightly better results in terms of costs, the labour costs are €2691 lower while the inventory costs are €267 higher on a yearly basis, thus leading to a positive financial result of €2424. This can be attributed to even fewer set-ups then in the variant with 2 days of intermediate stock. Once again, important is to keep in mind that good scheduling is key for a successful implementation. This solution is a bit less flexible than the other alternative of this redesign, since there are even fewer cooking days for some products. Furthermore also the external quality may suffer a bit more, while there is no change to internal quality.
6. Conclusions
This chapter will answer both the main research questions as well as the company specific
questions. Furthermore recommendations will be made towards Culvers, both for the results
gathered in this research and possible directions for further research.

6.1. General conclusions
To answer the main research question several sub-questions were defined of which the
answers will be discussed here.

Sub-question 1
How can the current company situation be modelled using business entity lifecycle modelling?
As discussed in chapter 3 existing techniques such as the Operational Specification model
(Nigam & Caswell, 2003) and the Guard-Stage-Milestone approach (Hull, et al., 2011) were
used as the starting point to answering this research question. The approaches and methods
described by them certainly helped in creating the conceptual models that would form the
foundation for the remainder of this document. However some of the strategies mentioned
in the literature to identify business entities needed some extra attention to make them work
in this case.

Additions to the current techniques involved the inclusion of costs on a basic level. In this case
the personnel and inventory costs were considered relevant to take into account for the
research. However these not all of these costs be included directly on the business entities,
since some costs, such as waiting costs for the operator cannot be directly allocated to a single
business entity.

Another addition was a more explicit modelling of the data involved in the Business Entity
Lifecycle model. This was done using the UML modelling notation and certainly supported
getting more insight into the relevant data. This is especially useful since data is central to
BEL-modelling.

Sub-question 2
How can the business entity lifecycle model be used to create a simulation model?
This sub-question is central in the research. After creating the models as described in
literature with some extensions they were used to create a simulation model.
It was decided to use Incontrol Enterprise Dynamics as the simulation software of choice for
this project. Since the simulation software had to, at least, support business entity modelling
where all the data is stored on the business entity, options for the choice of software were
limited. Mapping the GSM-model into an enterprise dynamics model created a few rules that
can be followed in the future.
Atomic stages of the GSM model can contain one or multiple servers in the Enterprise
Dynamics model where the server is closed upon the atom entering the first server and only
opened again when it leaves the last server of that stage. This is a translation of the opening and closing of stages as described by the GSM model.

The GSM model lacks additional details that are also needed for the simulation model in *Enterprise Dynamics*. Therefore it is necessary to gather more information besides the GSM model, such as which servers or actions form a stage and what the tasks of operators are since these are not considered in GSM.

But not only the simulation model had to be made, even more important is, and certainly in BEL modelling, the data. Simulation usually creates a need for more data then what is necessary in the modelling process. For example processing times have to be established, which proved to be a challenge given the vast amounts of different products Culivers produces. Therefore process times were estimated for each SKU based on characterises such as number of ingredients or the weight. Also production schedule redesigns had to be created for the different situations that were modelled.

It can be concluded that the earlier mentioned rules can be used as a starting point to create a business entity lifecycle based simulation model. However also additional information is necessary that does not currently exist in the conceptual models that are commonly used for business entity lifecycle modelling.

**Sub-question 3**

*What are the simulation results and are they valid?*

The simulation results also provide a direction of answer towards the company questions. However first the academic impact will be discussed here.

One of the greatest challenges in using the simulation was that *Enterprise Dynamics* isn’t really made to simulate BEL models. Therefore it was a time consuming challenge to get the simulations up and running and it was virtually impossible to replicate runs. Of course this also hurts the validity together with the fact that precise time measurements were not possible with the more than 1000 SKU’s that are produced. However the research did show that it is certainly possible to use BEL modelling as the basis for simulation and also provided benefits in this complex situation. Since there were so many unique products and production orders, the possibility to conveniently gather this complexity was very welcome. Having the data where it actually should be, on the business entity, makes for an easy understandable model that also offers more flexibility since for example processing times and routing can be altered by adjusting the data while there is no need to change anything in the model.

The results will be discussed together with the answers to the company questions.

**Main research question**

*How can business entity lifecycle modelling be used to measure factory performance in a simulation aided process analysis?*
By using the existing frameworks for creating BEL models a basis is made from which a simulation model can be made that can be run and analysed. Challenges exist in the step from a BEL model to a simulation model and the limited support of current simulation software towards implementing BEL models as the basis of simulation.

Based on this research it seems that both the classic and business entity lifecycle modelling simulation techniques are suitable for business process management and simulation. The advantage that business entities are easier to recognize by the business owners seems to hold, as at least in this research they were easily identified. The flexibility of using business entities did not fully show because of rigorous software limitations providing little flexibility, however this could be overcome by better software. Currently the marginal support by the software, at least by Enterprise Dynamics was a disadvantage in using this technique. However this does not mean it doesn’t have potential, far from it, but it needs to be intrinsically supported.

6.2. Conclusions related to the company questions
Culivers was wondering what the effect was of using information sharing and having intermediate stock within their production processes.

Company question 1
What is the effect of information sharing with a select number of partners on relevant costs and therefore KPI’s?
As the redesign is currently modelled this leads to more larger and fewer smaller orders, especially at the beginning of periods. A clear cost advantage could not be established from the simulation as the extra inventory costs negated the gains made in the production process, though this might also have to do with the earlier mentioned limit of not being able to perform multiple runs. Furthermore this redesign gives more scheduling freedom and thus provides more flexibility. Especially a closer look to a better schedule while using information sharing could create more cost gains. Once again the flexibility is not quantified here but there is a definite advantage in having more freedom to schedule the orders.

Company question 2
What is the effect of having intermediate stock on relevant costs and therefore KPI’s?
For the intermediate stock redesign, two variants were researched, one variant which combined two days of production orders and the other variant combining three days of production orders. This was done for the 20 products that are made in the biggest quantity. Once again it can be seen that the batching of cooking orders sometimes leads to high workloads on specific days. Off course this can be offset by scheduling smarter and avoiding these kind of increases. For having two days of intermediate stock no financial benefit could be derived from the simulation, however for both the three days of intermediate stock there is a financial benefit of €2424,- in total. This shows again that these redesigns might and can be beneficial but that they have to be scheduled well. In terms of flexibility this redesign reduces flexibility as some products cannot, or at least are not scheduled to be made daily.

Company advice
Related to the proposed redesigns. The introduction of VMI is definitely something to consider as the increased flexibility is big advantage but no financial miracles should be
expected. The introduction of intermediate stock might help reduce costs but it also increases complexity. Furthermore the food safety and quality aspects have to be investigated. The most important result however is that more attention should be spend on making a very good schedule for the redesigns as this might show a bigger impact. Unfortunately a thorough and detailed schedule redesign was outside the scope of this project.

6.3. Research Limitations
Since this research also partly entailed discovering new fields with respect to simulating business entities there are various limitations.

The biggest limitation is caused by the fact that Enterprise Dynamics only has limited support for business entity simulation that is not naturally embedded in the program. This made it impossible to get confidence intervals on the results thereby reducing the power of the simulation results. However it showed the tendencies and more important the possibility of simulating business entities.

Another limitation is caused by the inability to perform precise and enough process time measurements. Due to the big number of products and different actions performed by the employees. Therefore the processing times, while measured, also have limited statistical power and should be seen more as a rough indication than as an exact science.

6.4. Recommendations and directions for further research

*Detailed time study at Culivers*
Currently there is only a limited insight at Culivers what their exact processes consist of and what the associated processing times are. For Culivers to get more insight in the production process it would be good to conclude a thorough time study, though this might be a rather lengthy process. But this is the only way to get insight how long processes take exactly and would also help in allocating and determining the right costs for products. This would also help the employee in charge for scheduling to get a better insight into the situation.

*Further exploration of relevant associated costs*
In this research only the costs for personnel and inventory were taken into account. However there are more costs that could be associated to the business entities. Such as the costs of potential inventory that goes out-of-date or the costs for cooled storage once capacity becomes an issue and investments have to be made.

*Development of simulation software supporting business entity lifecycle models*
One of the major obstacles during this project was the lack of software that was really designed to handle BEL models. While the first experiences during this project seem positive, it is not possible to say something definitive about this without software that fully supports this new technique of modelling and simulation. Therefore the development of simulation software that supports this way of modelling could help gaining further insight into the advantages and disadvantages of this way of modelling for simulation purposes.
Bibliography


Appendices
A. Cause-and-effect tree

Here the cause and effect tree of the encountered company problems is displayed.
B. OpS model of the company
C. GSM Model

Schedule
- Create schedule
  - Scheduled

Cookingslip
- Initializing Cooking Slip
  - Initialized Cooking Slip

Cooking process
- Weigh goods
  - Weighed
- Cooking
  - Cooking Finished
- Improperly Cooked

ReWeighing
- ReCooking
- Cooked

Portioningslip
- Initializing Portioning Slip
  - Initialized Portioning Slip
- Intermediate Cooling
  - Sequenced

Packaging Process
- Packaging
  - Packaging finished
- Conserving
  - Conserved
- Sleevings
  - Sleevings finished
- Improperly Packed
- Packed

RePackagingProcess
- Logistics
  - Delivered
### D. GSM rules

#### Table 14. GSM rules for schedule artifact

<table>
<thead>
<tr>
<th>Stages</th>
<th>Guards (Opening sentries)</th>
<th>Terminating sentries</th>
</tr>
</thead>
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<td>Create schedule</td>
<td>( r_1: \text{on +StartScheduling} )</td>
<td>( r_2: \text{on +Scheduled} )</td>
</tr>
<tr>
<td>Initializing Cookingslip</td>
<td>( r_3: \text{on +Scheduled} )</td>
<td>( r_4: \text{on InitializedCookingslip} )</td>
</tr>
<tr>
<td>Initializaling Portioningslip</td>
<td>( r_{13}: \text{on +Scheduled} )</td>
<td>( r_{14}: \text{on +Initialized} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Achieving sentries</th>
<th>Invalidating sentries</th>
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</thead>
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<td>( r_{31}: \text{on C:CreateSchedule} )</td>
<td>( r_{32}: \text{on +CreateSchedule} )</td>
</tr>
<tr>
<td>Initialized Portioningslip</td>
<td>( r_{50}: \text{on C:CreateSchedule} )</td>
<td>( r_{51}: \text{on +CreateSchedule} )</td>
</tr>
</tbody>
</table>

#### Table 15. GSM rules for cookingslip artifact

<table>
<thead>
<tr>
<th>Stages</th>
<th>Guards (Opening sentries)</th>
<th>Terminating sentries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initializing Cookingslip</td>
<td>( r_5: \text{on InitializedCookingslip} )</td>
<td>( r_6: \text{on +Cooked} )</td>
</tr>
<tr>
<td>Cooking process</td>
<td>( r_7: \text{on +CookingProcess} )</td>
<td>( r_8: \text{on +Weighed} )</td>
</tr>
<tr>
<td>Weigh goods</td>
<td>( r_9: \text{if Weighed} \land \text{CookingProcess} )</td>
<td>( r_{10}: \text{on +CookingFinished} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Achieving sentries</th>
<th>Invalidating sentries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initialized Cookingslip</td>
<td>( r_{33}: \text{on C:Initializing-CookingSlip} )</td>
<td>( r_{34}: \text{on +InitializingCookingSlip} )</td>
</tr>
<tr>
<td>Weighed</td>
<td>( r_{35}: \text{on C:WeighGoods} )</td>
<td>( r_{36}: \text{on +WeighGoods} )</td>
</tr>
<tr>
<td></td>
<td>( \text{if CookingProcess} )</td>
<td>( r_{37}: \text{if ReWeighing} \land \text{ReCooking} )</td>
</tr>
<tr>
<td>CookingFinished</td>
<td>( r_{38}: \text{on C:Cooking} )</td>
<td>( r_{39}: \text{on +Cooking} )</td>
</tr>
<tr>
<td></td>
<td>( \text{if CookingProcess} )</td>
<td>( r_{40}: \text{if ReCooking} )</td>
</tr>
<tr>
<td>ReWeighing</td>
<td>( r_{41}: \text{on E:WeighedWrong} )</td>
<td>( r_{42}: \text{on +Weighed} )</td>
</tr>
<tr>
<td></td>
<td>( \text{if CookingProcess} )</td>
<td></td>
</tr>
<tr>
<td>ReCooking</td>
<td>( r_{43}: \text{on E:CookedWrong} )</td>
<td>( r_{44}: \text{on +Cooking} )</td>
</tr>
<tr>
<td></td>
<td>( \text{if CookingProcess} )</td>
<td></td>
</tr>
<tr>
<td>Cooked</td>
<td>( r_{45}: \text{on C:Cooking} )</td>
<td>( r_{46}: \text{on +WeighGoods} )</td>
</tr>
<tr>
<td></td>
<td>( \text{if WeighGoods} \land \text{CookingProcess} )</td>
<td>( r_{47}: \text{if ReWeighing} \land \text{ReCooking} )</td>
</tr>
<tr>
<td>Improperly Cooked</td>
<td>( r_{48}: \text{on C:IntermediateCooling} )</td>
<td>( r_{49}: \text{on +IntermediateCooling} )</td>
</tr>
<tr>
<td>Sequenced</td>
<td>( r_{52}: \text{on C:IntermediateCooling} )</td>
<td>( r_{53}: \text{on +IntermediateCooling} )</td>
</tr>
<tr>
<td>Packed</td>
<td>( r_{65}: \text{on C:Packaging} \land \text{C:Freezer} \land \text{C:Sleeving} )</td>
<td>( r_{66}: \text{on +RePackagingProcess} )</td>
</tr>
</tbody>
</table>
### Table 16: GSM rules for portioningslip artifact

<table>
<thead>
<tr>
<th>Stages</th>
<th>Guards (Opening sentries)</th>
<th>Terminating sentries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initializing Portioningslip</td>
<td>( r_{13}: \text{on} + \text{Scheduled} )</td>
<td>( r_{14}: \text{on} + \text{Initialized} )</td>
</tr>
<tr>
<td>Intermediate cooling</td>
<td>( r_{15}: \text{if} \text{Scheduled} ^ \land \text{Initialized} )</td>
<td>( r_{16}: \text{on} + \text{Sequenced} )</td>
</tr>
<tr>
<td>Packaging process</td>
<td>( r_{17}: \text{on} + \text{Sequenced} )</td>
<td>( r_{18}: \text{on} + \text{Packed} )</td>
</tr>
<tr>
<td>Packaging</td>
<td>( r_{19}: \text{on} + \text{PackagingProcess} )</td>
<td>( r_{20}: \text{on} + \text{PackagingFinished} )</td>
</tr>
<tr>
<td>Conservating</td>
<td>( r_{21}: \text{if} \text{PackagingFinished} \land \text{PackagingProcess} )</td>
<td>( r_{22}: \text{on} + \text{Conservated} )</td>
</tr>
<tr>
<td>Sleeving</td>
<td>( r_{23}: \text{if} \text{SterifowFinished} \land \text{PackagingProcess} )</td>
<td>( r_{24}: \text{on} + \text{SleevingFinished} )</td>
</tr>
<tr>
<td>Logistics</td>
<td>( r_{28}: \text{on} + \text{Packed} )</td>
<td>( r_{29}: \text{on} + \text{Delivered} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Achieving sentries</th>
<th>Invalidating sentries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initialized Portioningslip</td>
<td>( r_{50}: \text{on C:CreateSchedule} )</td>
<td>( r_{51}: \text{on} + \text{CreateSchedule} )</td>
</tr>
<tr>
<td>Sequenced</td>
<td>( r_{52}: \text{on C:IntermediateCooling} )</td>
<td>( r_{53}: \text{on} + \text{IntermediateCooling} )</td>
</tr>
<tr>
<td>Packaging finished</td>
<td>( r_{54}: \text{on C:IntermediateCooling} )</td>
<td>( r_{55}: \text{on} + \text{Packaging} )</td>
</tr>
<tr>
<td>Conservated</td>
<td>( r_{57}: \text{on C:Conservating} )</td>
<td>( r_{58}: \text{on} + \text{Packaging} )</td>
</tr>
<tr>
<td>Sleeving finished</td>
<td>( r_{60}: \text{on C:Sleeving} )</td>
<td>( r_{61}: \text{on} + \text{Packaging} )</td>
</tr>
<tr>
<td>RePackagingProcess</td>
<td>( r_{63}: \text{on} + \text{ImproperlyPacked} )</td>
<td>( r_{64}: \text{on} + \text{Packed} )</td>
</tr>
<tr>
<td>Packed</td>
<td>( r_{65}: \text{on C:Packaging} \land C:Freezer )</td>
<td>( r_{66}: \text{on} + \text{RePackagingProcess} )</td>
</tr>
<tr>
<td>Improperly Packed</td>
<td>( r_{67}: \text{on} + \text{RePackagingProcess} )</td>
<td>( r_{68}: \text{on} \text{PackagingProcess} )</td>
</tr>
<tr>
<td>Delivered</td>
<td>( r_{69}: \text{on} + \text{Packed} )</td>
<td>( r_{70}: \text{on} \text{Logistics} )</td>
</tr>
</tbody>
</table>