Infected by Chicken Meat?

A System Dynamics Perspective on the Occurence of Campylobacter in the Chicken Meat Production Chain

Master Thesis

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by

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Preface

Dear reader,

Thank you for taking the time to read this preface of my thesis. Below you see a picture of three children holding baby chickens. The girl on the left is me. I grew up on a farm. We grow potatoes, onions, sugar beets and wheat. We also have two broiler houses where we have approximately 50,000 conventional chickens.

During my time in Delft, it sometimes felt like I lived in two separate worlds. One world can be considered a world of "sustainability", in which eating meat often is seen as a bad thing. In contrast, there is the farmers' world, in which various arguments are advertised to eat chicken meat that originates from the Netherlands, instead of, for example, eating avocados grown in South-America. The collision of these two worlds in my personal sphere has given me a lot of different insights and perspectives into animal welfare and sustainability. However, most people forget about a factor which is maybe even more important: food safety and quality.

My personal interest in this subject has led me to meet Els. She let me think about the topic of the Campylobacter in chicken meat. Els then introduced me to Andrijana, who is a postdoctoral researcher at Wageningen University. When she told me that she was interested in modelling the Campylobacter problem using System Dynamics, a perfect match was made. I want to thank Andrijana for always being optimistic and the funny conversations we had about the corona situation and me losing my smell and taste. I will never forget the moment she told me "Edien I know you do not taste food, but just treat yourself with something sweet. You should celebrate every milestone in the process".

I want to thank Jan Anne for being critical and always enthusiastic during the various meetings. And I want to thank Els for being such an involved mentor to me. During our weekly skype calls, she would always emphasize that I could always call her if I had any problems. Her exceptional commitment to this project and to me, made me feel really comfortable during the process of writing my thesis.

Lastly, I want to thank all the enthusiastic interviewees I spoke to. Every interview was special, and I will never forget these open-hearted conversations. And of course, I would like to thank my family and friends who were always willing to listen to my chicken stories!

Edien Rommens
Rotterdam, September 2020

Summary

The foodborne illness called Campylobacteriosis is a serious public health concern. Most cases are caused by raw chicken, consisting of Campylobacter (White et al., 1997). In the Netherlands, the incidence of Campylobacteriosis is estimated to be 80.000 cases per year (Doorduyn et al., 2010). Even though the symptoms of Campylobacteriosis are mild, foodborne infection creates major health and economic problems for the human population (Authority et al., 2014). The European Food Safety Authority (EFSA) estimated that the cost of Campylobacteriosis to public health systems and lost productivity in the European Union (EU) is around EUR 2.4 billion euros per year (Gölz et al., 2014). The consumption of Campylobacter infected chicken meat causes most cases. Therefore, it is essential to reduce the percentage of infected chicken meat. This research will focus on the Campylobacter problem in the Netherlands. Figure 3.4 displays the chicken meat process from farmer to fork in the Netherlands.

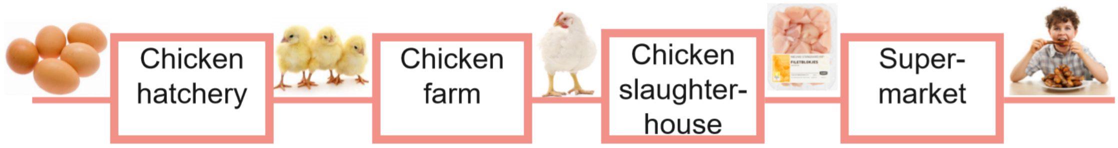


Figure 1: Chicken Supply Chain at an aggregated level

Several stages in the chicken meat production and processing chain have a significant risk for the transmission of Campylobacter. These stages are the primary production at broiler farms, transport to slaughter, the slaughter process, and processing of chicken meat products stages. Conventional chickens stay in the broiler house for six weeks . A selection of the chickens is depopulated in week five to reduce the stocking density. This process, called thinning, is regarded as a high-risk factor for Campylobacter infection of the residual birds (Rasschaert et al., 2020). According to Allen et al. (2008), there is a probability that the Campylobacters come from the boots, clothing, and hands of the so-called catching team, the transport crates, or forklift trucks. Numerous other sources of contamination, which can differ among farms and seasons, are identified. Broiler houses are indirectly infected by transporting organisms from the external environment into the houses. These transmissions are driven by the defecation of wild birds or farm animals, which is spread by flies or human activities (Broom, 2010; Nichols, 2005). Figure 4.3 shows an overview of the different transmission routes from vermin to human. Among other factors, colonization during the on-farm and thinning process plays a crucial role for slaughter flocks to become Campylobacter positive (Skarp et al., 2016). The skin of poultry carcasses and cuts is in direct contact with air and equipment surfaces and is therefore easily contaminated with Campylobacter (Rouger et al., 2017).

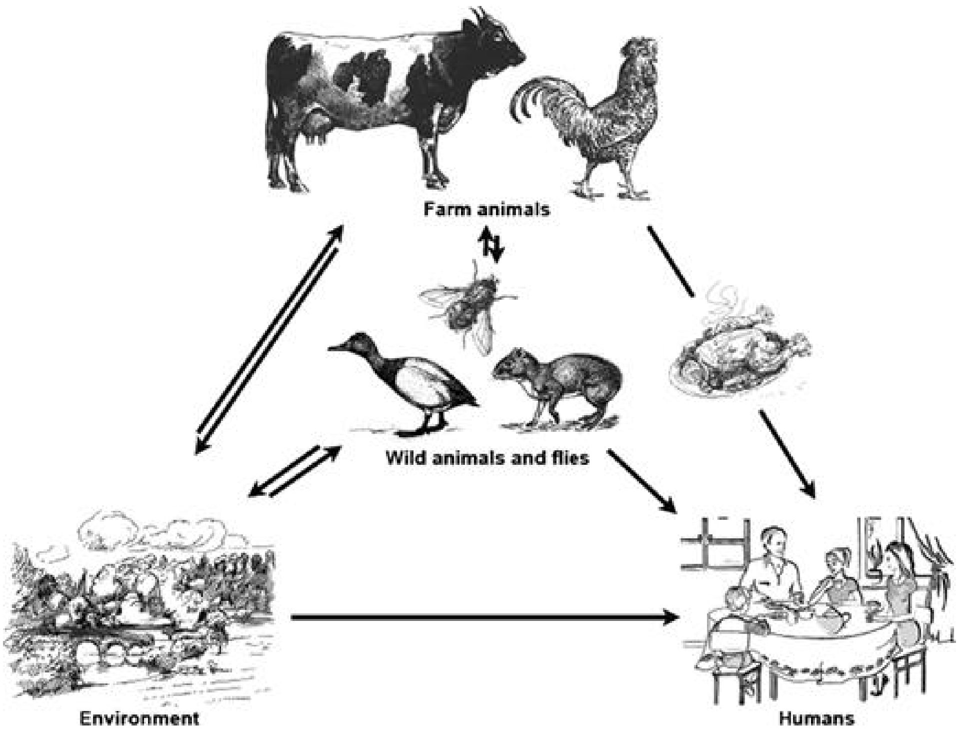


Figure 2: Global overview of the transmission routes for Campylobacter jejuni (Bronowski et al., 2014)

Knowledge about the transmission routes and the survival of Campylobacter during the entire chicken meat production process is lacking. Previous studies have solely focused on one or two stages of the production process. An overview of the entire production process is necessary to investigate the real effectiveness the current reduction measures of Campylobacter infections. Insights into the transmission of Campylobacter in the production process help to provide measures to reduce the introduction of Campylobacter in chicken meat in the Netherlands. In this research, a model is developed, which shows the effects of different measures on the percentage of infected chicken meat over time.

This research combines a multi-actor qualitative approach and a quantitative approach to turn qualitative information into quantitative model input. With this, instead of precise predictions, the focus lies on identifying trends of the amount infected chicken meat over time, which is a continuous process. System dynamics (SD) is used to quantify the problem. An SD model is constructed to analyze the chicken meat production process and the introduction of Campylobacter during this process. The moments of Campylobacter infection will become clear and various measures implemented in these infection moments can be tested. The identified stages of Campylobacter introduction are in the broiler houses, after the thinning process, during transportation, and in slaughterhouses. Submodels were created for each of these Campylobacter infection probabilities. These models rely on the information obtained from literature and interviews. Semi-structured interviews held with different actors, such as farmers, veterinarians, and the ministry of agriculture provided the necessary information for these models. The obtained qualitative information was used as input for the model, which identifies the trend of the percentage of infected chicken meat of time in the Netherlands. The underlying mathematical structure of the SD model is essential to visualize the sharp seasonality peak of Campylobacter, which is present during summer and autumn. The model shows various infection probabilities which are based on equations that depend on variables such as the temperature. When the temperature increases, more wild domestic animals and insects surround farmhouses. Furthermore, the farmer visits the broiler house more often to check if the chickens are feeling well. Farmers or insects can get infected with Campylobacter through waters or mud which contain defecation of Campylobacter infected wild animals. Hence, the infection probability in the broiler houses increases.

Model validation and verification tests are conducted to determine whether the model is useful for representing the Campylobacter transmission problem. From face- and historical data validation can be concluded that the model structure and variables are comparable with the real-life situation. However, the uncertainty range of various input parameters is significant. Based on the sensitivity analysis of the infection probabilities, it is evident that the farm is the preliminary site of Campylobacter entering into the chicken chain production process. Therefore, the primary intervention strategies should be targeted at farm level.

When implementing on-farm biosecurity policies such as limited visitors or a stricter hygiene protocol, the percentage of infected chicken meat decreases over time. The graphs still shows a seasonality peak around summer, which is caused by a higher number of insects and vermin on the farm. However, implementing these measures reduces the peak. Based on the model outcomes it can be concluded that a high contribution of the Campylobacter infections is caused by the so-called "Thinning process". Removal of this process shows the most significant effect on the Campylobacter infected chickens over time.

To conclude, it is crucial to raise awareness among the involved actors. Policies can help in expanding this awareness by setting stricter protocols, monitoring the various processes of the production chain, and offering high-quality information to all actors. Effective implementation of biosecurity measures and protocols depends on understanding the various risk factors and sources of Campylobacter. The farmers must bring the protocols to the attention of visitors of the broiler house and limit the number of visitors. In addition to the hygiene protocols of the visitors, the farmer needs to take care of a clean farm. A clean farm means no muds or water on the way to the broiler house and no vermin on the farm side. Removal of the thinning process is recommended to let the number of Campylobacter infected chickens decreases while enhancing animal welfare, because the chickens will have more space and so less stress. However, the thinning process is seen as a financial necessity. Therefore, subsidization will be needed to compensate the farmers.

For future research it is essential to see what the financial effects are of the removal of the thinning process. A second model for free-range concept chickens should be developed. Subsequently, a financial factor in the models should be inserted. Then, an exact financial comparison of a process with and without thinning can be made. Also, the uncertain parameters should be compared and filled with real data. For example, valid input data can obtained by a large-scale survey filled out by various farmers and slaughterhouses. Lastly, it is recommended to investigate the behavior of the supermarkets selling chicken meat and consumers buying and preparing chicken meat. When supermarkets are aware of the consumer behavior buying chicken meat, supermarkets could for example warn the consumers by placing an informing etiquette on the chicken meat packages. Focusing on this last part of the chicken meat consumption process can help reducing the number of Campylobacteriosis cases.

Contents

Glossary

Anaerobic: Living, active, occurring or existing in the abscence of free oxygen
Broiler industry: The broiler industry is the process by which broiler chickens are reared and prepared for meat consumption.
Flock: A group of chickens living together in one farmhouse
Litter: Material used as bedding for animals
Microaerophilic: Living, active, occurring or existing in a very low concentration of oxygen
Partial depopulation: early removal of a portion of birds from a commercial broiler flock.
Respiratory type of metabolism: system basically consists of a gas exchanging organ and a ventilatory pump.
Thinning: flock thinning applies to a situation in which a portion of the birds in a poultry house is removed for slaughter and processing, leaving the remaining birds to grow to normal clearance age
Logistical slaughtering: slaughtering in a specific order, so for example first slaughtering the Campylobacter negative chickens and then the Campylobacter positive chickens
Catch crew: a group of people who come to the farm to catch the chickens and put them on transport to the slaugtherhouses
Process Hygiene Criterion: intended to reduce human Campylobacteriosis attributed to the consumption of broiler meat

1 Introduction

Infectious diseases are currently one of the biggest global challenges (Van Der Meer, 2013). Major new threats appeared to the world like AIDS, SARS, and Corona virus, but also less threatening infections, such as infections caused by the Campylobacter bacteria. Campylobacter is a bacterium that can cause a human illness called Campylobacteriosis (Gölz et al., 2014). Campylobacteriosis is a collective name of infections caused by pathogenic Campylobacter species and is characterized by different mild symptoms such as fever, vomiting, watery or bloody diarrhea (Scallan et al., 2015). Campylobacteriosis is a global problem. The incidence of Campylobacter infections occurred in high-, middle-, and low-income countries (Hansson et al., 2018). As published by Skarp et al. (2016), human Campylobacter infections have been increasing in the past decade with poultry meat as the primary cause. Poultry encompasses chicken, turkey, duck, and laying hens (Skarp et al., 2016), of which chicken is the predominant species for meat production.

Foodborne illness is a serious public health concern and, according to White et al. (1997), raw chicken meat containing Salmonella or Campylobacter bacteria causes the largest number of foodborne illness cases. The number of cases of people getting sick of the Campylobacter is increasing (Gölz et al., 2014). In the European Union in 2009, 2,017,110 Campylobacteriosis cases were reported and this number increased to 2,147,790 cases in 2013 (Skarp et al., 2016). Consequently, public awareness of Campylobacter infections grows continuously (Gölz et al., 2014). With an incidence of approximately 55.5 cases per 100,000 population in the year 2012 (Authority et al., 2014), this disease is the most frequently reported foodborne illness in the European Union (EU). However, due to mild symptoms, most human clinical cases are not regularly published (Pezzotti et al., 2003) which leads to under-reporting. As appears from Gölz et al. (2014), it can be assumed that the actual incidences of Campylobacteriosis are eight up to 30-fold higher. Moreover, Campylobacter foodborne infection causes 8.4% of the global diarrhea cases (Igwaran and Okoh, 2019). The European Food Safety Authority (EFSA) estimated the cost of Campylobacteriosis to public health systems and lost productivity in the EU around EUR 2.4 billion per year (Gölz et al., 2014).

The EFSA estimated that poultry meat consumption accounts for approximately 50% to 80% of the Campylobacteriosis cases in the European Union (Skarp et al., 2016). Contamination of chicken by Campylobacter is widely accepted as a significant risk factor for human Campylobacteriosis (Lin, 2009). Poultry meat production and consumption are increasing globally. In 2023 the poultry meat industry is expected to be the largest meat sector by around 130.7 million tonnes of meat (Skarp et al., 2016). The Netherlands has always been a dominant force in the production and trade of poultry meat. The poultry industry is massive, efficient, and highly developed in the Netherlands making the Netherlands a country that is not only densely populated with people, but also with poultry (Leenstra et al., 2006). This creates problems with spatial planning, pollution, and it increases the risks of infectious diseases.

The control and, if possible, the prevention of Campylobacter in poultry meat is an important food safety issue, which can reduce the risk for humans to get infected (Lin, 2009). Different studies pointed out that the full elimination of Campylobacter in the chicken meat production process is hard for most countries (Gölz et al., 2014). The occurrence of the Campylobacter infections is often irregular (Blackall, 2017) and so far there is no explanation that can predict the presence of Campylobacter. This makes it difficult to understand the transmission events that result in human disease. Developing effective biosecurity measures, which are procedures used to prevent the introduction and spread of disease-causing organisms in poultry flocks, has been recognized as critical but complex (Newell et al., 2011). Numerous sources of contamination, which can differ among farms and seasons, are identified. From the article by Hansson et al. (2018), it is evident that knowledge is lacking about the transmission routes and the survival of Campylobacter during the entire chicken meat production process. Different researches are focused on only one or two stages of the production process. To investigate the real effectiveness of the application of available current measures on reduction of Campylobacter infections, an overview of the entire production process is necessary. Pasquali et al. (2011) write that more scientific research is needed to investigate the real effectiveness of the application of available measures on reduction of Campylobacter infections. Proposed changes to industry practices on broiler houses or in slaughterhouses should be supported by robust research evidence to be acceptable (Newell et al., 2011). Also, earlier research on the Campylobacter problem is either qualitative or does not include dynamics over time (Bearth et al., 2014; Nauta et al., 2007; on Biological Hazards , BIOHAZ).

Different assumptions and boundaries are set to specify the scope of this research. In this research, the focus point will be the chicken meat production process. According to Nauta et al. (2007), the broiler chickens are generally regarded as one of the primary sources of the Campylobacteriosis. Therefore, control and prevention should aim at reducing Campylobacter infection at all stages of the chicken meat production process (Butzler, 2004). The Campylobacter case is a global problem, but in this research, the focus will be on the Netherlands. In the Netherlands, the incidence of Campylobacteriosis is estimated to be 80.000 cases per year (Doorduyn et al., 2010) and it is estimated that Campylobacter species infections represent at least one-third of the disease burden of all intestinal infections (Ruiz-Palacios, 2007). This represents around 5 percent of the total Dutch inhabitants. While the number of cases of Salmonella infections decreased the past decade, the number of Campylobacteriosis confirmed cases in the Netherlands remained at a constant level (Van de Giessen et al., 2006). According to Luangtongkum et al. (2006), it is evident that Campylobacter is highly prevalent in organic, free-range, and conventional poultry production processes. However, according to Newell and Fearnley (2003), the percentage of infected flocks is generally higher in organic and free-range flocks compared to the conventional flocks of chickens, because of both environmental exposure and the age of the birds at slaughter. These risks are not applicable to conventional chickens. Therefore, this research focuses on the conventional chicken meat production process.

The objective of this research is to understand the chicken meat production process and its uncertainties in the sources and transmission routes of Campylobacter. In order to do so, this research develops a model of the chicken meat production process from farmer to slaughterhouse. In this model, the most critical uncertainties are analyzed and different policies are introduced to show to what extent these may contribute to reducing the occurrence of Campylobacter in chicken meat. Therefore, the following research question is formulated:
What are the effects of biosecurity measures that can be introduced to reduce the introduction of Campylobacter in chicken meat in the Netherlands?

Based on the objective of this research and the set boundaries, the following sub-questions are formulated:

1. *By which mechanisms do Campylobacter bacteria invade the chicken?*

2. *What biosecurity measures exist to prevent Campylobacter transmission in different parts of the chicken supply chain?*
3. *What does the chicken meat production chain look like as a qualitative model?*
4. *How may the fractions of Campylobacter positive and negative chicken meat develop over time in the absence of measures to prevent contamination?*
5. *To what extent does the developed system dynamics model represent the Campylobacter problem?*
6. *What are the effects of current biosecurity measures to prevent Campylobacter transmission under different uncertainties?*
7. *What policy recommendations can be made to control and prevent Campylobacter transmission in the chicken meat production process?*

To answer the questions, the research is defined in five different phases which are: problem identification, model conceptualization, model formulation, model testing and model use (Forrester, 1968). A system dynamics model is developed to understand the contamination routes of Campylobacter and to understand the causal mechanisms of the seasonality of Campylobacter contamination. The chickens staying in broiler houses and slaughterhouses can be modeled as stocks by using system dynamics. Both for the broiler house residence moment and for the slaughterhouse residence moment, a Campylobacter positive and negative stock are modelled. If the chickens get infected, they will flow to the positive stocks. To build this model, a multi-actor qualitative approach is combined with a quantitative approach to turn qualitative information into quantitative input data. The information is obtained from literature and semi-structured interviews with involved actors. System dynamics is useful in quantifying this problem because it is not about precise predictions but about identifying trends of the percentage of infected chicken meat over time.

The following chapter explains the research approach and used methods in detail. The main methods for this research are system dynamics and semi-structured interviewing. This chapter is followed by the problem identification, in which not only the system but also the different actors and their intentions become clear. Chapter 4 starts with an actor analysis which is based on the semi structured-interviews. Using this actor analysis and the literature, the conceptual model is built and explained. The model conceptualization is followed by the formalization part, in which the equations and parameters are explained. Chapter 5 summarizes the validation and verification tests which are conducted to see if the model is representing the real-world situation. Chapter 6 shows the results of the various policies implemented in different uncertain scenarios. In chapter 7, the answer to the main research question is given, followed by recommendations for policies and practice. Finally, chapter 8 reflects on the research by describing the limitations and providing recommendations for future research.

2
Research Methodology

To answer the research question "*What are the effects of the biosecurity measures that can be introduced to reduce the introduction of Campylobacter in chicken meat?*", it is essential to understand the chicken meat production process and its uncertainties in the sources and transmission routes of Campylobacter. Therefore, first, a better insight into the current situation is necessary. A model should be developed to get a better idea of the chicken meat production process and the transmission routes of Campylobacter in this process. This semi-structured model will be based on both information obtained from literature and different expert interviews. Based on the semi-structured model, a quantitative system dynamics model will be developed to find out what fraction of chicken meat over time is contaminated by Campylobacter. This system dynamics model will be tested and will be used to test different current and new policy measures under different uncertain scenarios. In this chapter, firstly, the research approach will be explained, and thereafter, the used methods will be elucidated.

2.1 Research Approach

The answers to the different sub-questions are needed to answer the main research question. In the following figure an overview of the different sub-questions divided into three separate chapters is given. In the following chapter a description of the system based on information from literature will be given. The current situation with the developments over time will be elucidated in chapter 4. In chapter 5, the model will be verified and validated. Finally, the quantitative System Dynamics model will be used to show the impact of various implemented policy measures in different uncertain situations, which are shown in chapter 6. Mixed current and new policies are implemented in the model and simulated in various scenarios. The result of simulation runs will show what effect the different policy measures have on the total amount of Campylobacter infected chickens over time. In the following part of the chapter, it is explained what the used methods include and how they will contribute to answering the different sub-questions. In the following figure 2.1, an overview of the chapters answering the different sub-questions is given. A quantitative system dynamics model will be developed based on information obtained from literature and semi-structured interviewing.

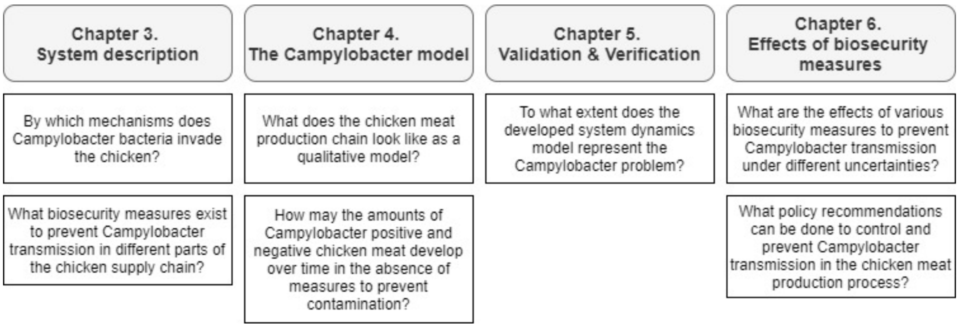


Figure 2.1: Sub-questions divided per chapter

The modeling process which is used for this research is summarized in figure 2.2 and a more in-depth explanation is given, using the following steps (Forrester, 1968):

1. Problem identification: this first phase of the process of this research is called the problem identification. By identifying the boundaries, an overview of the problem is obtained. Literature and some unstructured interviews are used to identify the problem.
2. Model conceptualization: in the model conceptualization part the identified problem was conceptualized as a system dynamics semi-structured model, which was created in the program Vensim. Using system dynamics, the dynamics of chickens getting colonized in different phases of the production chain is made explicit. Different actors are interviewed to get a total overview of the problem and to develop a semi-structured model of the transmission routes of Campylobacter in the chicken production chain. In this part the problem is split into different parts of the chicken production chain. For every specific part a semi-structured sub model will be developed based on literature and interviews.
3. Model formulation: in this phase the qualitative model will be updated to a so-called quantitative model. Assumptions based on literature and the interviews will be made to find values which can be used for the different model parameters in the main model and the different submodels of the different parts of the chicken meat production process. Different equations based on relations between variables are built and implemented in the model.
4. Model testing: the model testing part is important to see if the model shows, what it should show. For this research the model should show the effects of Campylobacter on the chicken meat production process. A validation and verification part will help to create a useful and reliable model. Using system dynamics, a sensitivity analysis and extreme value test will be conducted. The extreme value test is performed to further test the structure of the model. Various parameters are set to extreme conditions to evaluate if the model behaves the way it is expected in such conditions. The sensitivity analysis will show the most sensitive parameters or variables. These most sensitive parameters and variables will be used for the part of the process in which the model is used, because they have the most effect on the percentage infected chicken meat. Face validation will be used by walking through the model with two Campylobacter experts. In this way the model can be compared with the real situation. Also the model outcomes are compared with historical data which can be retrieved from Nepluvi. The conceptualization, formalization and testing part will all three be iterative processes. Multiple rounds of revision and evaluation are necessary to build a well developed system dynamics model (Homer, 1996).
5. Model use: based on the most sensitive parameters and variables, policies will be developed which can be implemented in the model. Although, first an uncertainty analysis will be conducted to have an overview of the influence of the different uncertain parameters on the model output. After this

uncertainty analysis, different policy measures will be tested on the model using different uncertain parameters. In this way the influence of different measures implemented on the Campylobacter problem will become visible. The different outputs will show in what parts of the chicken chain the influence is the largest.

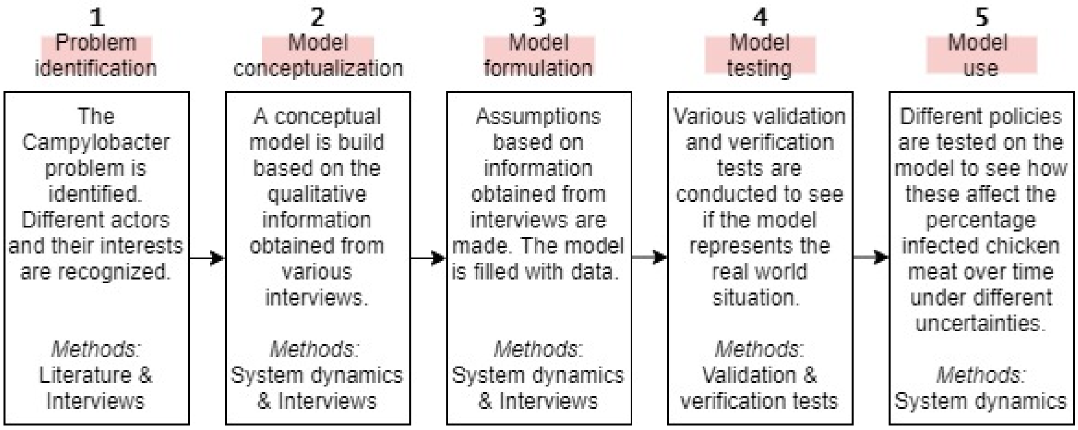


Figure 2.2: Overview of the research modeling process

2.2 Methods

As can be read in the modeling process, the two main techniques that are used for this research are System Dynamics and Interviewing. In this section these two techniques and their purposes are explained in more detail.

2.2.1 *System Dynamics*

System Dynamics (SD) is a method to model dynamically complex systems with nonlinear behaviour generated by feedback and accumulation effects (Forrester, 1995). SD models are built with information obtained from different stakeholders, and they serve as visual tools for communication about complex problems with different stakeholders and their interests. In the history of SD, different types of diagrams are used as, the Stock-Flow Diagram [SFD] and the Causal-Loop diagram [CLD] (Lane, 1999). For this research first, a combined semi-structured SFD-CLD model of the chicken meat production process will be developed, which will show by what mechanisms chickens are infected with Campylobacter. Using this semi-structured model, a quantitative System Dynamics model will be created, which will be based on data obtained from literature and different interviews with actors. Using system dynamics it is possible to simulate the model behaviour, with feedback loops, stock-flow structures, table functions and time delays (Kwakkel et al., 2013; Sterman, 2002a; Forrester, 1968). This can help to understand the contamination routes of Campylobacter and the underlying causal mechanisms of seasonality of Campylobacter contamination.

At the system dynamics conference, a model about the foodborne mechanisms for Norovirus was shown by David Lane (Lane et al., 2019). The Norovirus model is complete but so-called "parameter hungry". However, the model forms a framework for the research agenda in the future. The Campylobacter problem has various overlapping characteristics with the Norovirus problem. Both problems are about infections due to foodborne diseases. Using system dynamics for the Campylobacter problem can help creating a framework for the research agenda in the future. So despite various uncertain parameters, a complete model can be created when using system dynamics. Also, system dynamics is a method to show how things can change through time (Forrester, 1995). This is important for showing the sharp seasonality peak of Campylobacter visible in the summer and fall period, which is shown in figure 3.2. Different factors, which are changing over time, will contribute to this seasonality peak. An SD model can explain the dynamic behaviour of the system over time and provide insight in possible ways to influence the system behaviour of the transmission of Campylobacter in the chicken chain (Pruyt, 2013). The quantitative System Dynamics model will be able to show the total Campylobacter positive and negative chickens over time. Different current and new biosecurity measures can be implemented in the model for different scenarios. The output "total Campylobacter positive chickens" will show the influence of the various biosecurity measures on the complex situation.

In figure 2.3 a small visualization of a stock-flow diagram is given. In the model, stocks will be used to visualize the Campylobacter positive and negative chickens in specific places of the chicken meat production process, such as broiler houses or slaughterhouses. The flows between the stocks show the transportation of the chickens from one location, such as a farmhouse, to another location, such as a slaughterhouse. The stocks can be seen as integral equations of the flows, flows are equations of other variables or constants, and constants assume constant values over a simulation run (Pruyt, 2013). Besides the stock-flow structure, feedback loops are essential to visualize the Campylobacter occurrence in the chicken meat production process. In this complicated situation, feedback loops can be used to show the infection of the chickens on different moments in the chicken meat production process (Pruyt, 2013). For example, can the infection rate in farmhouses be based on a causal loop of human-chicken contact, which influences the number of sick chickens, which affects the total visits of the veterinarians. This increase in total visits will lead to a higher probability of infection due to human activities in the broiler house.

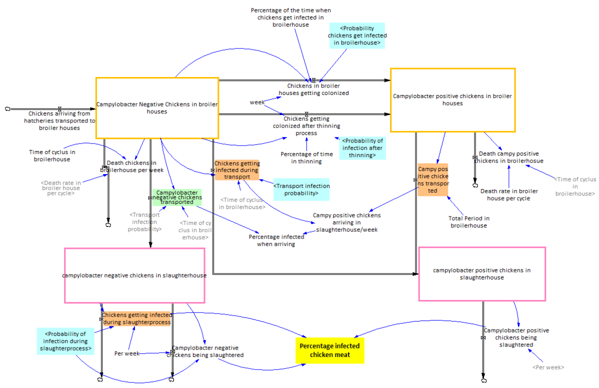


Figure 2.3: Example of a stock flow structure

2.2.2 *Semi-structured Interviewing*

For developing a quantitative model, model boundaries, mechanisms and interrelations among the variables should be identified. Therefore it is needed to first understand the real-world situation. All of these details will be as well obtained from literature, as well from interviews with different actors. The technique that is used for the interviews is called "semi-structured Interviewing". Semi-structured interviewing is a technique that is used to gain information from different stakeholders. The researcher is explicitly seeking to gain access to the knowledge, experience and perspectives of research subjects (Kelly et al., 2010). The term semi-structured interviewing will provide qualitative data, which can be used for building a qualitative model (Cohen and Crabtree, 2006). This interviewing technique is most useful when insights must be gained into the world of others.

For this research, it is essential to get a detailed picture of the chicken meat production process and the transmission routes of Campylobacter during this process. Therefore it is crucial to gain insights into the worlds of the different actors. It is important to first understand the general Campylobacter problem. Some qualitative interviews are done to obtain general information with a Campylobacter expert and some farmers. These general interviews help to start building a simple model, which can be elaborated by using information from specific actors for specific parts of the model. The interviews were conducted as conversations, as can be read in the summary of the interview with a Campylobacter expert [Interview B.2.1].

Various actors have a direct influence on the chicken meat production process, which are the farmers, poultry catch group, transporters, slaughterhouses and veterinarians. These actors will first be interviewed to get a detailed picture of what details should be taken into account when modelling the chicken meat production process and the transmission routes of Campylobacter occurring in this chain. Before the actors are interviewed, they are asked to fill in the informed consent which is shown in appendix B. In appendix B, the different interview questions specific for every actor and the purposes of the interviews are shown. The first questions asked, will be specialized in the chicken chain itself to know which specific events are happening in and around the farmhouses, slaughterhouses and the transport in between. Various farmers are interviewed to recognize the differences between the organic, free-range and conventional chicken farmers. Also, it is important to obtain detailed information about the actions and environment on and around the farm. Therefore eight different farmers are interviewed. Two different slaughterhouses will be interviewed to find out what the slaughterprocess looks like. Besides, detailed information about the processes on farm, on transport and in slaughterhouses, various questions will be asked about their opinion on the Camoylobacter problem. So, the second part will be more particularly about the occurrence of Campylobacter bacteria, current measures and the view of the actor on the Campylobacter problem. For some actors, it is chosen to interview two or more to get a more objective view. As can be seen in table B.1 six different farmers are interviewed. In this way a clear and fair overview of the process happening on farm can be generated. Besides the "direct actors", the indirect actors also influence the Campylobacter problem, by for example making different rules or regulations. Therefore the two ministries will be interviewed as well. An overview of the interview questions is shown in appendix B. In the table 2.1 below a list of the interviewed actors is displayed together with the purpose of the interviews. Before the interview starts, the interviewee is sent a consent form, which should be signed. After the interview, the interviewee will receive a summary of the interview, which he or she can comment on.

Table 2.1: Different interviewees and the purposes of the interviews

Actor	**Purpose of the interview**
Conventional chicken farmer	Understand the details of the conventional chicken meat production process and see what current measures to reduce Campylobacter infected meat are introduced.
Organic chicken farmer	Understand the details of the organic chicken meat production process and see what current measures to reduce Campylobacter infected meat are introduced.
Free range chicken farmer	Understand the details of the free range chicken meat production process and see what current measures to reduce Campylobacter infected meat are introduced.
Veterinarian	Obtain information about the introduction and transmission of Campylobacter in chickens.
Slaughter-house	Understand the processes happening in the slaughterhouse and recognize how these influence the occurrence of Campylobacter in chicken meat.
Ministry of Health, Welfare and Sport	Understand the rules and regulations and the general view of the government on the Campylobacter problem.
Ministry of Agriculture, Nature and Food Quality	Understand the rules and regulations and the general view of the government on the Campylobacter problem.
Transport company	Understand the process between the farm houses and the slaughterhouses
Poultry Catch Group	Understand the catch process in the farmhouses.

3

System description

In the following chapter, information is given about the Campylobacter bacteria, the Chicken Chain in the Netherlands, the introduction of Campylobacter in the chicken chain, and the current measures to reduce the introduction of Campylobacter in the chicken chain.

3.1 Campylobacter bacteria

Campylobacter species are gram-negative spiral, rod-shaped or curved bacteria and have a size of approximately 0.2 to 5 µm (Kaakoush et al., 2015). Most of the Campylobacter species grow under *microaerophilic conditions* and have a *respiratory type of metabolism* (Kaakoush et al., 2015). Several species require hydrogen, and some species prefer anaerobic conditions for growth (Kaakoush et al., 2015). In the factsheet (EFSA, 2014) the Campylobacter is defined as *"a bacterium that can cause an illness called Campylobacteriosis in humans"*. Campylobacteriosis is a type of gastroenteritis (Galanis, 2007). It is proved that the species Campylobacter (c.) jejuni and Campylobacter (c.) coli are responsible for most Campylobacteriosis cases (Gölz et al., 2014). Most human infections (approximately 90%) are associated with Campylobacter jejune, and about 10% are caused by Campylobacter coli (Bronowski et al., 2014). "*Characteristics of Campylobacter jejuni include anaerobic/microaerophilic growth conditions, optimum growth at 42–43°C, and the inability to grow below 30°C* " (Levin, 2007).

Human Campylobacteriosis occurs world-wide (Gölz et al., 2014). In Europe, Campylobacter bacteria are reported as the most common bacterial diarrhoea pathogens. Kaakoush et al. (2015) suggests a rise in the global occurrence of Campylobacteriosis in the past decade. The numbers of cases of Campylobacteriosis have increased in North America, Europe, and Australia. The risk of Campylobacteriosis is linked to the consumption of animal products, particularly the consumption of poultry meat, such as chicken meat. Epidemiological studies indicate that between 50-80 percent of all human Campylobacter infections are related to poultry (Kaakoush et al., 2015). Also, contact with different animals, drinking of raw or improperly pasteurized milk, and different environmental sources are also considered as risks for humans (Gölz et al., 2014). The transmission of Campylobacter to animals and humans interact in complex ways (Bronowski et al., 2014). These transmissions are driven by the defecation of wild birds or farm animals, water flow due to climatic conditions, spread by flies, and other complex ecological parameters (Broom, 2010; Nichols, 2005). In figure 3.1 an overview of the different transmission routes from vermin to human are shown.

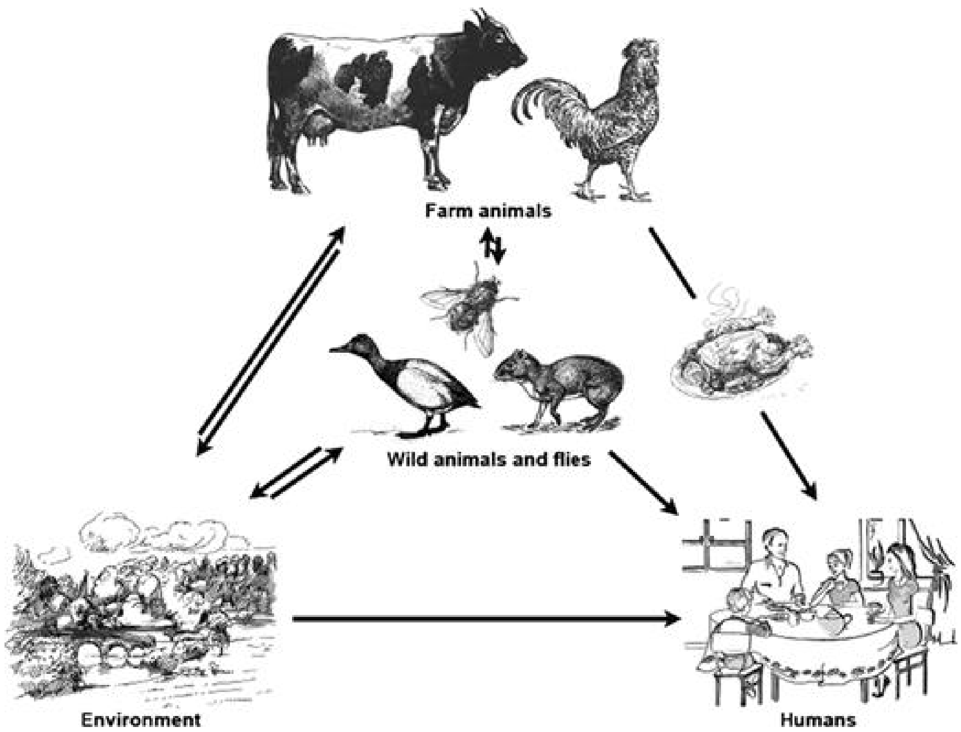
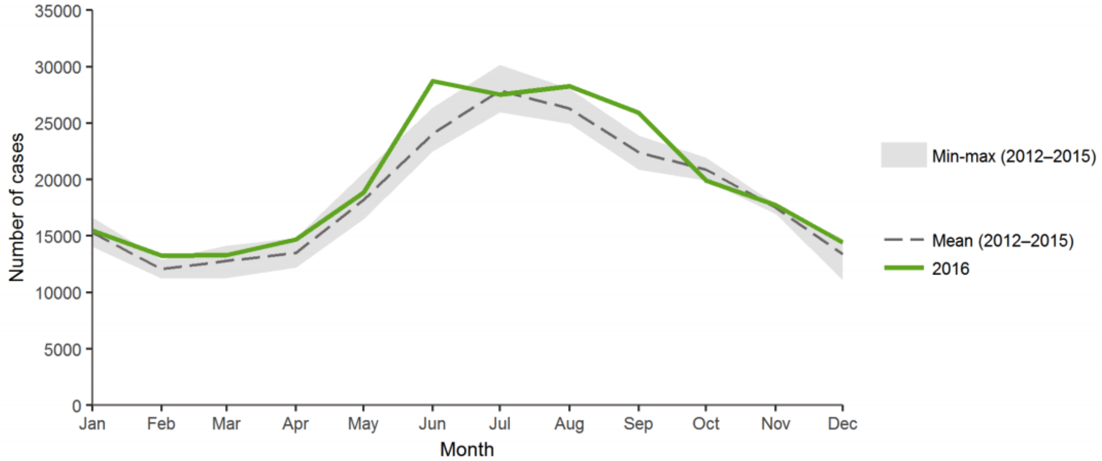


Figure 3.1: Global overview of the transmission routes for Campylobacter jejuni (Bronowski et al., 2014)

According to (Skarp et al., 2016), the symptoms of the Campylobacter infection typically occur 1 to 5 days after exposure. Campylobacteriosis is generally associated with mild illness, of which the symptoms are diarrhoea, abdominal pain, fever, and rarely vomiting (Ruiz-Palacios, 2007). The illness normally resolves within 2 to 5 days, but it can last up to several weeks (Galanis, 2007). Also, Campylobacteriosis can cause the post-infectious syndrome, called Guillain-Barré (Skarp et al., 2016), which is the most common and most severe acute paralytic neuropathy (Willison et al., 2016). Campylobacteriosis is usually self-limiting and therefore, antimicrobial treatment is not needed, except in severe cases when patients have a compromised immune state (Skarp et al., 2016). In the article of Igwaran and Okoh (2019) and the research executed by Kovats et al. (2005) it is reported that a sharp seasonality peak of Campylobacter is visible in the summer and fall period. Figure 3.2 shows the sharp peaks for cases in the different European countries for the years 2012-2015 and 2016. Countries with milder winters have their peaks of infections earlier in the year (Kovats et al., 2005).



Source: Country reports from Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Romania, Slovakia, Slovenia, Spain, Sweden and UK.

Figure 3.2: Distribution of confirmed Campylobacteriosis cases by month (EU/EEA, 2012–2015 and 2016)

3.2 Chicken industry in the Netherlands

Since April 1995, Campylobacter has been included in the monitoring network for gastroenteric pathogens in the Netherlands (Friesema et al., 2012). In 2003 an outbreak of avian influenza in poultry resulted in an extensive removal of chicken flocks. After this outbreak, the cases of Campylobacteriosis reduced with 30%. This observation, acquired by Friesema et al. (2012), showed the relation between the consumption of poultry or direct contact with poultry and Campylobacter infections among humans. Various studies claim that about 50–70% of human Campylobacteriosis can be attributed to the consumption of poultry and poultry products (Umaraw et al., 2017).

Worldwide poultry meat production and consumption are increasing. Poultry meat is expected to be the largest meat sector by around 130.7 million tonnes in 2023 (Skarp et al., 2016). In the Netherlands, people eat about 20 kg of chicken meat per person per year (Center, 2017). The Netherlands has always been a dominant force in world production and trade of poultry meat within specific chickens meat. It is shown in figure 3.3 in the year 2000 the Netherlands counted 1094 poultry companies (Wageningen-University, 2020). In the year 2019, this number was reduced to 629 companies. On average, 76437 chickens live on each farm, which indicates a total of 48 million broiler chickens living in the Netherlands. The chicken industry is significant, efficient and highly developed in the Netherlands (Warren, 1972). The Dutch poultry meat production imports and exports a considerable amount of chicken meat (Mangen et al., 2004). The domestic production of chicken meat is mainly used for export (Mulder and Zomer, 2017), which implies that the contamination of chicken meat with Campylobacter, not only affect the health risks of Dutch consumers but also affect consumers in countries that import Dutch chicken meat. The total on average annual export of chicken meat in the Netherlands is 1.4 million tonnes per year (Center, 2017).

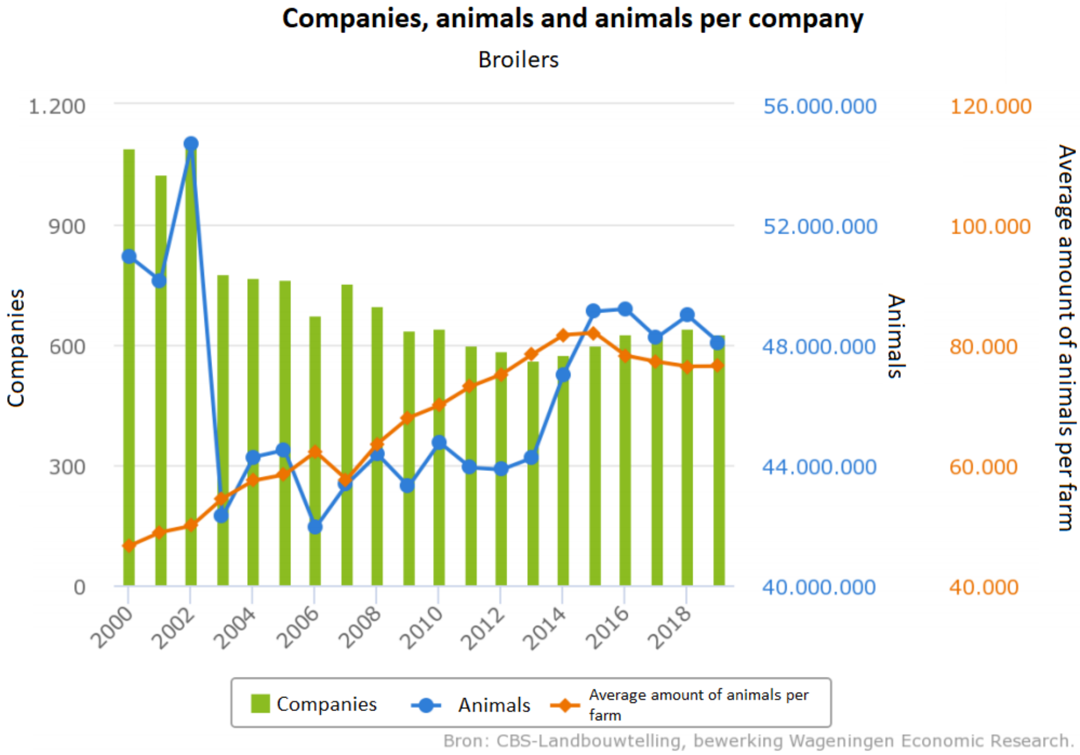


Figure 3.3: Companies, animals and animals per farm in the Netherlands (Wageningen-University, 2020)

Chicken is an affordable product for everyone in the Netherlands (Hin et al., 2013). Consumers buy a lot of chicken meat, but they do not want to know how this chicken filet is produced. The welfare of animals on farms is a heavily debated topic (Mulder and Zomer, 2017). The conventional broiler chicken industry has been under criticism for decades (Saatkamp et al., 2019). Therefore new initiatives to improve the broiler animal welfare are undertaken by introducing so-called middle segment broiler production systems, which would lie in between the conventional and organic chicken meat systems. The Dutch Animal Protection organization introduced the Beter-Leven 1-2-3 star system to brand animal welfare products. Then, around 2012, a breakthrough at the entire Dutch chicken market in the Netherlands, occurred. Several large Dutch retailers decided to replace the conventional broiler meat, for new broiler meat products with higher animal welfare. Each of these retailers came up with a name for their new concept chicken meat, such as "De Nieuwe Standaard Kip" (Saatkamp et al., 2019). Many different new "concepts" have been developed for chicken meat. An overview of the main differences between the conventional, middle (Free-range chickens) and the organic chicken industry is shown in table 3.1. According to Newell and Fearnley (2003), the prevalence of Campylobacter positive flocks is also dependent on flock size and the type of production system. The amount of Campylobacter positive flocks is generally higher in organic and free-range flocks compared to the conventional flocks of chickens, because of both environmental exposure and the age of the birds at slaughter (Ellen et al., 2012). There are around 15 slaughterhouses in the Netherlands, which exceed 10.000 tons of chicken meat being slaughtered on an annual basis (Ellen et al., 2012).

Table 3.1: Main characteristics of the different chicken industry productions (Ellen et al., 2012)

	Conventional	**Free-range**	**Free-Range outside**	**Farmers free range**	**Farmers free range outside**	**Biological**
Minimum slaughter age	42 days	56 days	56 days	81 days	81 days	>70 days
Occupancy rate per square meter	33 kg	25 kg	27.5 kg	25 kg	25 kg	21 kg
Free air occupancy rate [m2/animal]	NA	NA	1	2	2	4
Availability entrance free air	NA	NA	50% of the day	After 6 weeks	Constantly	8 houres/day
Size of the flock (per broiler house)	No Requirements	No Requirements	No Requirements	Maximum of 4800 chickens	Maximum of 4800 chickens	Maximum of 4800 chickens

3.3 The introduction of Campylobacter in the chicken meat production process

In europe up to 70 % of the chicken flocks is contaminated with Campylobacter (Meunier et al., 2016). According to Skarp et al. (2016), all of the stages in the chicken meat production and processing chain have a role in the transmission of Campylobacter. These stages are the following: primary production at rearing farms, transport to slaughter, the slaughter process and processing of chicken meat products, selling products at the retail level and finally, handling and consumption of chicken meat products at home and in public places (Skarp et al., 2016). A summary of the most important stages of the production process is presented in figure 3.4. A more detailed representation and explanation of the chicken meat production process is shown in the Appendix A in figure A.1. Recognition of both vertical and horizontal transmission routes of infection is crucial to investigate (Newell et al., 2011). In horizontal transmission, the Campylobacter bacteria are transmitted among chickens living in the same flock, while vertical transmission occurs from mother chickens to their offspring (Chen et al., 2006). Broiler chickens are free of Campylobacter on the day of hatching (Wagenaar et al., 2006), so each cycle of broilers starts with a flock of Campylobacter negative chickens. Jacobs-Reitsma et al. (1995) discusses that the Campylobacter species were frequently found in the broiler flocks but never before the birds were two weeks old. This phase of 2 weeks is called the lag phase (Wagenaar et al., 2006). This so-called "lag phase" in the detection of Campylobacter colonization in chickens, suggests that vertical transmission of this organism is uncommon (Newell et al., 2011). From the research executed by Callicott et al. (2006), no evidence was found for vertical transmission of Campylobacter. In this research is assumed that if vertical transmission happens, it is not a significant source for the contamination of chicken flocks with Campylobacter. Therefore the most pragmatic approach is to focus first on the horizontal transmission routes of Campylobacter.

Horizontal transmission of the Campylobacter appears to be the normal route of the infection (Newell et al., 2011). At commercial production systems, flocks consist of approximately 10.000 to 30.000 birds per house, with several houses present at a farm. This houses can be considered as closed environments, but Campylobacters are appearing everywhere in the environment in and around the chicken broiler houses (Newell et al., 2011). According to Newell et al. (2011), broiler houses are indirectly infected by transporting organisms from the external environment into the houses by human activities, or by the entrance of domestic or wild animals. It is evident that low numbers of infected birds affect rapid transmission to Campylobacter-free chickens (Shanker et al., 1990). Most farms have similar levels of environmental contamination (Newell and Fearnley, 2003). The research of Wagenaar et al. (2006) concludes that contamination with Campylobacter of flocks increases with the age of the animal, the number of broiler houses on a farm and the presence of other animals on the farm or in the direct vicinity. The main factors associated with the Campylobacter flock infection on-farm, which are all related to each other, include the following (Newell and Fearnley, 2003):

- Wild and domestic animals and insects: Different mammals and birds are considered as possible hosts for Campylobacter (Newell et al., 2011). The faecal material from all mammals and birds on or close to a chicken farm is considered as a high risk to the chicken flocks.
- Water: Several studies investigated the relationship between the water source and flock Campylobacter positivity. Standing waters, such as puddles or ponds, are on-farm sites which Campylobacters can be recovered. The Campylobacters survive well in water. However, most studies found that the water source is a low-risk factor. Therefore in this research the factor water will not be taken into account.
- Broiler house cleansing and disinfection: an obvious potential source is a carryover of the Campylobacter infection from a positive old flock to a new flock in the same broiler house, because of used litter is left out in broiler houses. However, in the Netherlands and most other European countries, the used litter is removed, and the broiler houses are cleaned every time a new flock of chickens arrives. Therefore this factor does not apply to the Netherlands.
- Atmosphere: the location of ventilation fans and the use of air conditioning increases the risks of flock becoming Campylobacter positive. However, the exact role of aerosols is not clear, and the air in broiler houses is impossible to control (Newell and Fearnley, 2003).
- Human traffic and activities: Human traffic is one of the most important transmission routes for the Campylobacters entering the broiler houses. Farm staff, who are in contact with other livestock, increases the risk of positive flocks. Besides this, the number of staff members and the number of visits they undertake is related to that risk (Newell and Fearnley, 2003). One of the moments that human traffic is a significant tranmission route, is during the thinning process.

As can be seen in figure A.1, after some weeks, the chickens are caught to be transported to the slaughterhouses. For conventional chickens, the practice of thinning or partial depopulation is used to reduce the stocking density in the house (Rasschaert et al., 2020). According to Allen et al. (2008) "*thinning is early removal of a portion of birds from a commercial broiler flock*". The thinning process, which happens when the conventional chickens are around five weeks old, is regarded as a high-risk factor for Campylobacter infection of the residual birds (Rasschaert et al., 2020). The research of Herman et al. (2003) indicates that other contamination of Campylobacter occurs during the broiler chickens' transport to the slaughterhouse. In the study executed by Herman et al. (2003), insufficient cleaning and disinfection of the containers are indicated to cause other contamination of Campylobacter.

Besides colonization during the on-farm, thinning and transport process, different crucial factors for slaughter flocks to become Campylobacter positive are recognized (Skarp et al., 2016). These factors are slaughter in the summer, increasing bird age at slaughter, the official health status of the flock. During slaughter, mechanical evisceration can cause intestinal rupture or leakage, which is followed by the discharge of gut contents (Posch et al., 2006). Direct contact between carcasses and contact of bodies with contaminated equipment surfaces can lead to horizontal transmission of faecal bacteria originating from the gut contents (Posch et al., 2006). Several studies confirm the importance of hygiene during slaughter Herman et al. (2003); Posch et al. (2006). A second route in the slaughterhouses can be the transmission during slaughter through the air (Posch et al., 2006). To clean the chicken meat along the slaughter line, a system of water sprays is used. This use of water produces a lot of aerosols in the air, which provide an excellent vector for transmission (Posch et al., 2006). However few data is currently available about this second route.

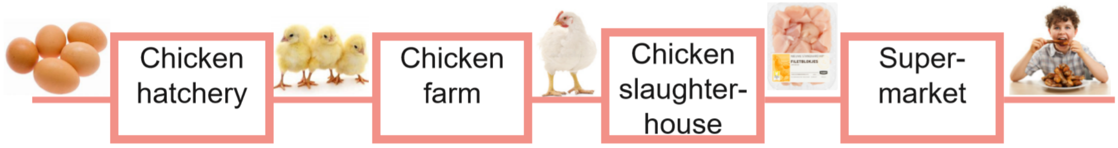


Figure 3.4: Chicken Supply Chain at an aggregated level

3.4 Current Rules and regulations

In the Netherlands two departments that are mainly involved in food safety issues (including Campylobacteriosis), namely the Ministry of Health, Welfare, and Sports and the Ministry of Agriculture, Nature, and Food Quality (Bogaardt et al., 2004), are responsible for the Campylobacter problem. The NVWA is part of the Ministry of Agriculture, Nature, and Food Quality and is the monitoring organization. The EFSA, which is the European Food Safety Authority, estimates that a public health risk reduction from the consumption of broiler meat of more than 50% could be achieved if carcasses are allowed to only have a limit of 1000 cfu/g (on Biological Hazards , BIOHAZ), which means less than 1000 Campylobacters on 1 gram of chicken meat. Various interventions to reduce flock prevalence and prevent products with high concentrations of Campylobacter entering the market should be facilitated. There is an increasing demand for the setting of risk-based food safety standards for Campylobacter (Nauta et al., 2012). According to on Biological Hazards (BIOHAZ), two different types of criteria can be defined: food safety criteria and process hygiene criteria. The Food safety criteria are set for products placed on the market and determine the acceptability of an individual batch of food products. If the requirements are not met, the product/batch has to be withdrawn from the market. Process hygiene criteria give guidance on and are an indicator of, the acceptable functioning of Hazard Analysis and Critical Control Points-based (HACCP) manufacturing, handling and distribution processes (on Biological Hazards , BIOHAZ). The process hygiene criterion is a criterion indicating the satisfactory operation of the production process (Nauta et al., 2012). These criteria set an indicative contamination value above which corrective actions are required to maintain the hygiene of the process in compliance with food law. The purpose of PHC is not to achieve an immediate effect on the Campylobacter status in meat, but to stimulate food producers to improve the Campylobacter status of their chicken meat (Nauta et al., 2012).

Since the first of January 2018, the European Process Hygiene Criterium has been implemented for Campylobacter. This Hygiene criterium will be monitored in the Netherlands by the NVWA. Weekly a slaughterhouse is obliged to take five scruff samples. Over a period of 10 weeks, 50 samples are analyzed. When 20 out of the 50 samples have a higher value than the allowed amount of 1000 cfu/g, the PHC is exceeded (NEPLUVI, 2018). Every few years, the criterium will become stricter. In 2020 only 15 out of 50 samples are chosen as a minimum, and in 2025 this will be only ten (NEPLUVI, 2018). When a flock of chickens is contaminated with less than 1000 cfu/g, the flock will be called Campylobacter negative. When a flock is infected with more than 1000 cfu/g, the flock is called Campylobacter positive (NEPLUVI, 2018). This research will talk in terms of positive and negative. The numbers of the exact amount of cfu/g will not be used.

3.5 Current strategies to prevent the introduction of Campylobacter

Several risk assessments for Campylobacter in poultry meat have been conducted to control and prevent the presence of these bacteria throughout the chicken meat production process (Hermans et al., 2011). In various countries interventions are required to reduce the levels of Campylobacter in poultry meat (Newell et al., 2011). Nevertheless, according to Hermans et al. (2011) after all efforts during the past decade, there still is no valid, reliable, and practical intervention measure available to prevent or reduce Campylobacter colonization in poultry meat.

As the primary source of Campylobacteriosis is chicken, prevention should aim at reducing Campylobacter infection at all different stages of the chicken meat production process (Butzler, 2004). Campylobacter spreads rapidly throughout the flock, mostly by horizontal transmission. Thus, it is the crucial goal to prevent colonization of the first bird (Newell et al., 2011; Shanker et al., 1990). According to Skarp et al. (2016), the reduction of Campylobacter-positive chicken flocks, which means decreasing prevalence and bacterial counts on chicken meat, will be the most relevant strategy to reduce the number of Campylobacteriosis infections. The farm is the preliminary spot where Campylobacters enter into the chicken chain. Therefore the major intervention strategies should be implemented at farm level (Skarp et al., 2016).

Biosecurity measures should be improved, which prevent Campylobacter transfer from the outside environment entering the various broiler houses. Skarp et al. (2016) describes that better education of farmers, awareness and management of these biosecurity procedures, are desired. Existing biosecurity protocols are generally perceived to be adequate, but the consistency with which they are applied by the famers and visitors can be variable (Newell et al., 2011). For example, routine procedures such as the effective use of hygiene barriers, hand washing, and boot disinfection can easily be performed under normal conditions. However, during emergencies, such as when a fan fails in a broiler house, these implemented procedures will be ignored by the farmer. Well-designed and well-located farms, the development of appropriate standard operating procedures to minimize risk factors, staff education, and incentives to maintain biosecurity at the highest level would all contribute to the reduction of the number of Campylobacter positive chickens. Strict biosecurity measures at farm level are crucial (Rasschaert et al., 2020). However the thinning, transport and slaughter process should not be forgotten. For these processes, it is recommended to improve materials, the cleaning and disinfection process, and container design to make them easier to clean (Rasschaert et al., 2020).

Slaughterhouses are experiencing pressure to deliver carcasses with low Campylobacter contamination even when they receive and slaughter Campylobacter colonized flocks (Rasschaert et al., 2020). Therefore it is also essential to have a more in-depth look into the process happening from transportation of chickens to arrival in the slaughterhouses to the actual slaughtering of chickens. According to Posch et al. (2006) the process should be changed. It should be improved with a reduction of faecal contamination of carcasses and the mechanical equipment in slaughterhouses to stop the occurrence of the Campylobacter colonization during the transport or slaughter process. For the present, it could be a possibility to slaughter Campylobacter-negative flocks before positive flocks to reduce cross-contamination. Intervention procedures against horizontal transmission and their effectiveness have to be studied further during the whole chicken meat production period (Jacobs-Reitsma et al., 1995). However, the proposed changes to industry practices on broiler-houses or in slaughterhouses, to be acceptable, should be supported by robust research evidence, especially if they involve extra costs (Newell et al., 2011).

3.6 Summary

Chicken is an affordable product for everyone in the Netherlands (Hin et al., 2013). Consumers buy a lot of chicken meat. Around summer almost 70 per cent of the chicken meat is infected with Campylobacter, which can cause Campylobacteriosis. Campylobacteriosis is a type of gastroenteritis. Campylobacters invade the chickens mostly at the primary production level. Horizontal transmission of the Campylobacter appears to be the normal route of the infection. Campylobacters are appearing everywhere in the environment in and around the chicken broiler houses (Newell et al., 2011). According to Newell et al. (2011), broiler houses are indirectly infected by transporting organisms from the external environment into the houses either by human activities, or by the entrance of domestic or wild animals. Low numbers of infected birds affect rapid transmission to Campylobacter-free chickens (Shanker et al., 1990). Interventions at the first part of the production level, which is the on farm side, to reduce Campylobacteriosis are preferable. However, it is also important to reduce the introduction of Campylobacter in other parts of the chicken production chain (Rasschaert et al., 2020). For the thinning, transport and slaughter processes it is recommended to improve materials, the cleaning and disinfection process, and container design to make them easier clean (Rasschaert et al., 2020).

4

The Campylobacter transmission model

In this chapter, the model conceptualization and model formalization are shown. Before these phases are introduced, an overview of the current situation is drawn of the problem based on the information obtained from the different interviews and from literature. The model conceptualization section is divided into various subsections to understand the different parts of the chicken meat production process model. In the formalization section, the details of the variables and equations used in the model are explained.

4.1 The actors and their interests

Campylobacteriosis is an emerging foodborne illness of high relevance for public health in the Netherlands. Campylobacteriosis is often associated with the consumption of not well prepared chicken (Bearth et al., 2014). The chicken meat production process, which is happening on the farms and in the chicken slaughterhouses, is monitored by the NVWA, which can be seen in figure A.4. In the slaughterhouses, people of the NVWA are always present. The chicken meat is tested on Campylobacter by the slaughterhouses their selves and they have to send their results to the NVWA. If this result exceeds the minimum allowed amount of Campylobacter bacteria on chicken meat, the NVWA will warn the slaughterhouse. The minimum allowed amount of Campylobacter bacteria is a requirement which is posed by the EFSA (Authority et al., 2018), which is a limit of less than 1,000 CFU/g. This criterion, which is in force since 1 January 2018, aims to control and prevent Campylobacter in chicken carcasses. In this way, the number of human Campylobacteriosis cases linked to the consumption of chicken should reduce (Authority et al., 2018). The European Commission introduced the process hygiene criterion for Campylobacter on poultry carcases in slaughterhouses (on Biological Hazards , BIOHAZ). If this criterion is not recognized by the various slaughterhouse, corrective measures should be taken to improve both slaughter hygiene and on-farm biosecurity. The different authorities of the various European countries must verify the implementation of the process hygiene criterion by the operator. For the Netherlands, the Ministry of Agriculture and Fishery and the Ministry of health, welfare and sport are the two ministries, who challenge the Campylobacter problem. The NVWA functions under the responsibility of these two ministries. In the Interview B.2.3 appears that if a slaughterhouse exceeds the hygiene criterion, they will have to discuss with the NVWA about their new prevention strategies to reduce the amount of Campylobacter in chicken meat. This limit will become stricter over the years (every five years, a new criterion is set) [Interview B.2.8]. The slaughterhouses will also communicate to the farmers, and they will impose requirements on farmers, such as taking care of more hygiene measures on farm [Interview B.2.8]. The NVWA, ministries and EFSA are called the "monitoring actors", which will not be used in the model, as they only impose rules and regulations, but not have a direct influence. The farmers, poultry catch group, slaughterhouses and veterinarians, are actors who can influence the problem directly. In appendix A, the formal chart is given to show an overview of the informal and official relations between the different actors (Enserink et al., 2010). The various actors have different desired situations, which are visualized in table A.1. Interviews and literature are used to get a clear overview of the current situation, the influences of the actors on the problem and the relations between these actors. In the following section the results of the interviews, which summaries can be read in appendix B, are presented.

4.2 Results of the interviews

In the following section the most important conclusion of the different interviews are summarized. As is shown in chapter 3, different farmers can be distinguished. For this research, conventional chicken, free-range chicken and organic chicken farmers were interviewed to get a good overview of the entire chicken farm industry in the Netherlands. Nevertheless, for the model only details of the conventional chicken farmer are used.

The Conventional chicken farmer [Interview B.2.5]:

- "A clear, hygienic protocol is important in the farmhouses. Switching clothing is an easy way to keep any bacteria out of the chicken farmhouses. Every six weeks, when new flocks of chickens arrive, the farmhouses are made sterile."
- "The farmer himself should have a look in the mirror. Most of the time, they are especially strict on other people entering the farmhouse."
- "After five weeks, the cath group arrives to start thinning. According to the farmers, before the thinning process starts, it would be a perfect moment to check if the chickens are Campylobacter positive or not. The conventional chicken farmer does not understand why this bacteria is not monitored anymore."

The Free-range chicken farmer [Interview B.2.6]:

- "As well for the free-range chicken farmer, the hygienic protocol is from great importance. But he also emphasizes the fact that farmers should have a look in the mirror to see if they "always" follow their own protocol."
- "According to them, it would be an idea if slaughterhouses always start slaughtering the Campylobacter free flocks. I do not understand why the information about Campylobacter is not given to the farmers anymore."

The Organic chicken farmer [Interviews B.2.7]:

- Geert is convinced the chickens get more resistant to infections in an environment which is not cleaned every few weeks. According to him, Campylobacter and salmonella only enter a bacteria-free chicken house.
- He is allowed to slaughter a maximum of 200 chickens per week and 2000 per year. When he exceeds this minimum amount, the NVWA will come around to control the slaughtering process.

From the interviews with the farmers can be concluded that in specific between the organic farmers and the conventional or free-range farmers is a big gap in over-viewing the Campylobacter problem. The organic farmer assumes that hygienic measures are not working for reducing the level of Campylobacter in broiler houses. In contrast, the conventional and free-range chicken farmers claim that the hygiene level on a farm is essential to reduce the level of Campylobacter. This conclusion is discussed with other actors such as veterinarians and people from the ministries, as can be read in the different interviews B.2.3, B.2.1, B.2.2. The flock Campylobacter positivity is generally higher in organic and free-range flocks compared to the conventional flocks of chickens, because of both environmental exposure and the age of the birds at slaughter (Ellen et al., 2012). So changing the environmental exposure and the age of the birds at slaughter would already reduce the level of Campylobacter in organic and free-range chickens. The level of Campylobacter is the smalles in conventional chickens and therefore in this research details of the conventional chickens are used in the model. Another important conclusion is that conventional chicken farmers imply that they do not have the information about Campylobacter, which they would like to receive. They do not know what measures they can implement to reduce the amount of Campylobacter positive chickens, and their chickens are not tested on Campylobacter in the broiler houses.

The conventional chickens are being caught and transported at different points in time. The first moment is after around five weeks and is called the "thinning" process. The thinning process, which happens when the chickens are about 5 weeks old, is a high-risk factor for infection with Campylobacter for the chickens leftover in the broiler house (Rasschaert et al., 2020). Thinning of a chicken flock may lead to Campylobacter infections, but the exact sources of the organisms and how they are introduced remain unclear (Allen et al., 2008). There is a probability that the Campylobacters originate from the catching team and equipment they use. Therefore the actor who will in this research be called the "catch crew" plays an essential role in the Campylobacter transmission problem. An interview with the catch crew has been conducted, and some important conclusions of this Interview are the following:

The catching crew [Interview B.2.9]:

- "It can happen that the catch crew visits more than one farm in 1 night.
- "At every farm, are such different biosecurity measures, which we follow up. Some farmers are really strict on changing all clothing and shoes for every separate broiler house, but others do not mind. The catch group listens to what the farmer wants from them."

Besides to colonization during the on-farm, thinning and transport process, different important factors for flocks during the slaughter-process to become Campylobacter positive are recognized (Skarp et al., 2016). Therefore two different slaughterhouses are interviewed, which had different opinions on the problem. The fist slaughterhouse [Interview B.2.10], emphasized the importance of receiving Campylobacter negative chickens. If a slaughterhouse receives positive chickens, they can not be changed into Campylobacter negative chickens. The second slaughterhouse [Interview B.2.8] agreed with this, but also explained that Campylobacter is only located in the blind gut of the chickens so that when the chickens are slaughtered really precisely, there is a small chance of finally having Campylobacter negative chicken meat. But he actively notices that this probability is super low and that this will rarely happen in slaughterhouses. However, he confirms that slaughterhouses can introduce different mitigation measures to reduce the amount of Campylobacter positive chicken meat. One of the biggest problems is the cross-contamination problem in slaughterhouses. When a positive flock is firstly slaughtered, the slaughter-lines can be colonized by Campylobacter. A new flock can easily get infected by these colonized slaughter-lines. Based on the last Interview in combination with literature (Rasschaert et al., 2020), two main conclusions can be drawn:

The slaughterhouse [Interview B.2.8]:

- The chickens are not tested on Campylobacter when they are in the broiler houses. The slaughter order depends on the salmonella status. So first the negative salmonella flocks are slaughtered, followed by the salmonella positive flocks. For the salmonella positive flocks, a difference is made in the magnitude of the danger of the salmonella bacteria.
- After every ride, the transport cars and crated are cleaned and disinfected. They are not in contact

with the poultry catch group, but the farmer is. In less than 8 hours, the chickens always have to be slaughtered after being thinned.

- The slaughterhouses can contribute to the reduction of Campylobacter positive meat by slaughtering hygienic. This can be done by using more hot water on the pickers and a tighter adjustment of equipment. The Campylobacter bacteria are settled in the cecum of the chicken.

Based on the different interviews of actors working in the chicken meat production process, can be concluded that they all think the problem is more significant in another part of the chain than in their part. For this research, it is essential to create first a clear overview of the production chain process and to make the transmission routes of Campylobacter in the chicken chain as transparent as possible. In the following section 4.3, a general overview and specific sub-models for the different parts of the chain are given.

4.3 Model conceptualization

According to Zeigler et al. (2000) "*Conceptual modelling is the abstraction of a model from a real or proposed system, which involves some level of simplification of reality* ". According to Pruyt (2013) "*model conceptualization is developing a causal theory about the issue*". A purpose of the model, the model boundaries and the most important variables should be defined. Based on these factors, a qualitative conceptual model can be developed. In the following section first, a global description of the set up of the qualitative model is given. Then various subsections will show an overview of the sub-models which show different parts of the chicken meat production process.

The qualitative model is based on the chicken meat production process, which is shown in the figure 4.1 below and which is shown in detail in appendix A in figure A.1. For this research, the model boundaries are set from the moment that the chickens are arriving in the broiler houses, until the moment that the chicken meat is produced in the slaughterhouses. These boundaries are chosen to cover all the different moments that Campylobacter bacteria can enter the chicken or chicken meat. The purpose of the developed model is to firstly get a more detailed overview of the chicken meat production process in the Netherlands and secondly to find out by using and testing different measures placed in different scenario's of the chain, what actions have the most significant impact and are recommended to reduce the amount of Campylobacter positive chicken meat.

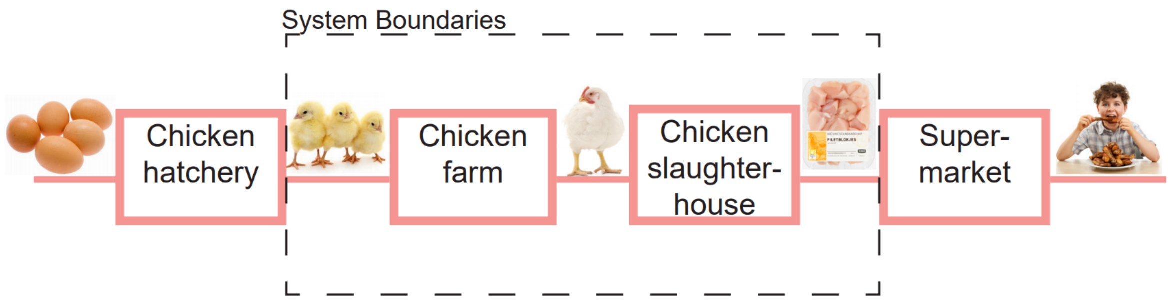


Figure 4.1: System Boundary of the chicken meat production process

In Vensim, which is simulation software for system dynamics models, a qualitative model is created based on the chicken meat production process. Figure 4.2 shows the main stock-flow diagram of the model. The model starts with an incoming flow called *Chickens arriving from hatcheries transported to broiler houses*, which are chickens arriving in the broiler houses from the hatcheries when the chickens are around one day old. This flows end up to a stock which is called *Campylobacter negative chickens in broiler houses*. The chickens in the broiler houses can get colonized by Campylobacter. The part of the chickens that will be colonized over time, is controlled by the *infection rate in broiler house* and the *infection rate after thinning*. This part of the chickens will flow to the other stock on the right side of the model, which is called *Campylobacter positive chickens in broiler houses*, whereby the chickens are infected by Campylobacter in the broiler house. If the chickens are on the "right hand" side of the model, they can not flow back. If they are infected, they will stay Campylobacter positive. The *Infection rate on farmhouses* and the *infection rate after thinning* are based on various other factors, which will be explained in subsections 4.3.1 and 4.3.2.

The duration of Campylobacter colonization in chickens has not been fully determined. Though, it is broadly acknowledged that colonization in chickens continues at least for the life span of a chicken (Newell and Fearnley, 2003). The life span of conventional chickens is less than 47 days. Based on different interviews [interview B.2.11] and according to Cawthraw et al. (1996), the Campylobacter infection spreads rapidly between the chickens. Within three days, up to 20.000 birds will become infected. Once Campylobacters have entered into the broiler houses, it is recognized that all chickens become colonized within a few days (Rasschaert et al., 2007). In this model, the colonization between chickens staying in one broiler house is not developed. The model is developed for the total amount of chickens in the Netherlands.

After five weeks, a part of the regular chicken flock will be caught by a catch crew [Interview B.2.5], which is called "flock thinning". The term flock thinning applies to a situation in which a portion of chickens in a broiler house is removed for slaughter and processing, leaving the remaining birds to grow to average clearance age (Allen et al., 2008). The Campylobacter positive and Campylobacter negative chickens that are caught during the process are placed on transport, which can be seen in figure 4.2. During the catching or so-called "thinning" process, the so-called "left-over chickens" can become infected by the infection probability called *Probability of infection after thinning*. When the chickens become infected after this process, they will flow to the "Campylobacter positive" right part of the model. At the end of the rearing process, which is for the conventional chicken six weeks, all "left-over chickens" of the flock are placed on transport.

On transport, there also is probability that the chickens get infected. This infection flow is based on the probability called *Transport infection probability*. In section 4.3.3, a more in-depth explanation of this infection probability is given. Finally, the chicken flocks arrive in the slaughterhouses. From the stock called *Campylobacter negative chickens in slaughterhouse*, the chickens can flow into *chickens getting infected during slaughter process* and *Campylobacter negative chickens being slaughtered*. According to the [Interview B.2.10], the chicken flocks are being slaughtered in the order of how the chicken flocks arrive in the slaughterhouse. This means that when a positive flock of chickens arrive first in the slaughterhouse, they will first be slaughtered.

According to on Biological Hazards (BIOHAZ) different steps of the chicken meat production process, which are primary production, after thinning, during transport, during slaughter and processing, offer options to control Campylobacter. Therefore the infection rates in these different processes are modelled and explained in more detail in the following subsections.

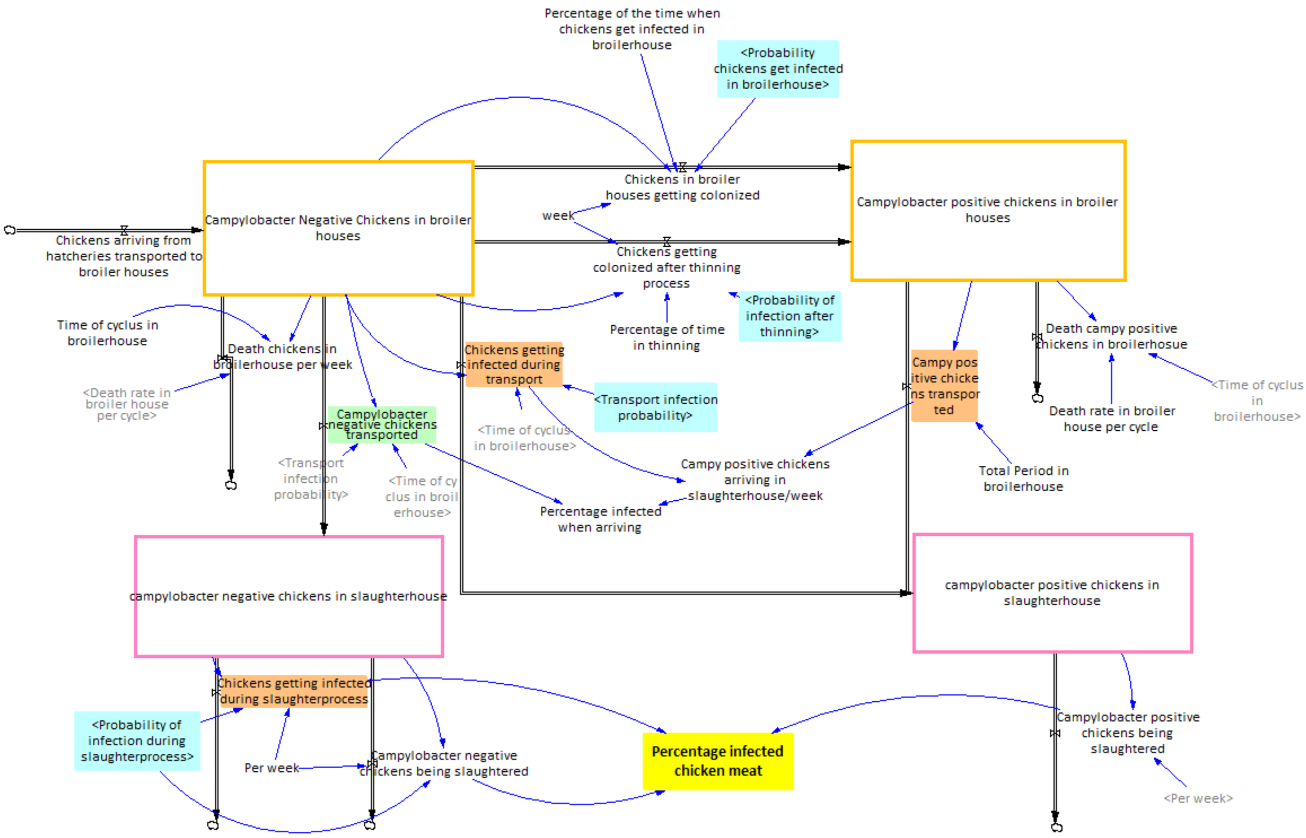


Figure 4.2: Conceptual stock flow structure (bigger image: figure C.3 in Appendix C)

4.3.1 *Conceptualization submodel 1: Primary production on farm*

From the process described above it can be concluded that there are multiple sources and transmission routes for Campylobacter during the production process. Based on literature combined with the interviews, the main risk factors are identified in the primary production process. In figure 4.3 an overview of the transmission routes for Campylobacter on farm level are shown.

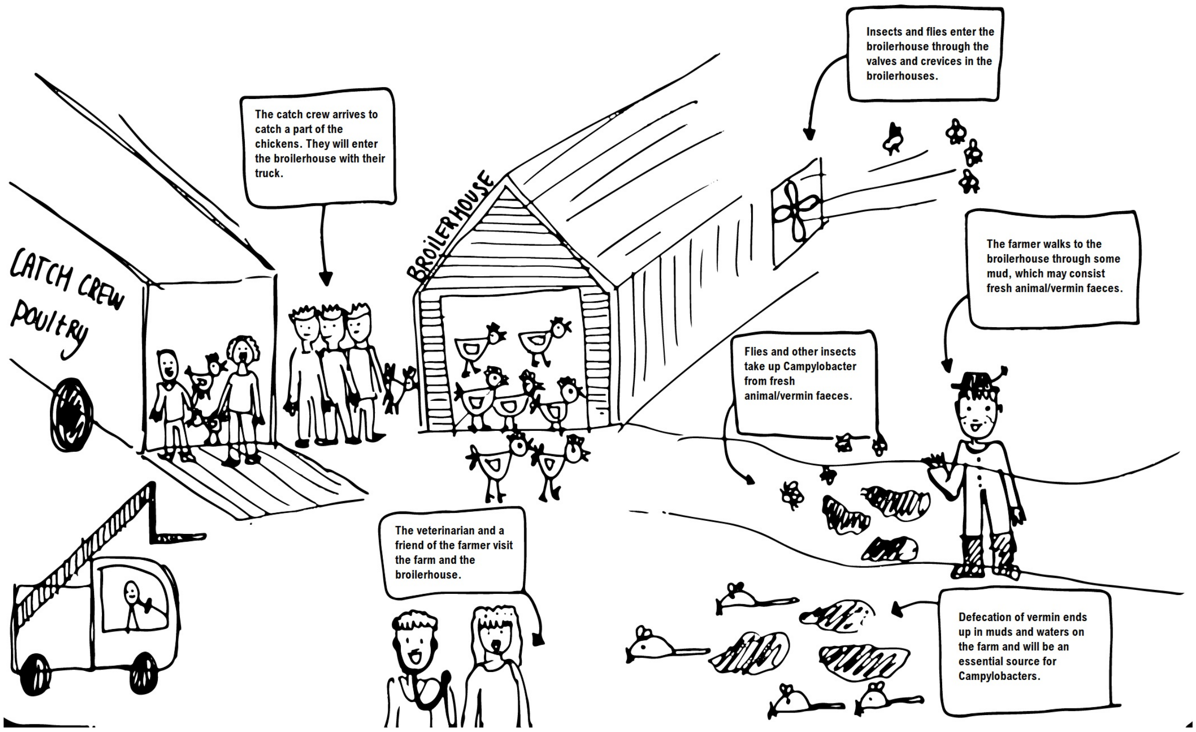


Figure 4.3: Overview of the transmission routes for Campylobacter jejuni (for bigger image: see figure A.3) in Appendix

Different risk factors are identified in the first part of the production process, which is the rearing of the chickens on farmhouses. Campylobacters are common in wild and domestic animals. The defecation of these animals consist Campylobacters which will stay on and around the farm site. It is important to minimize contamination of chicken rearing houses from such sources (Silva et al., 2011). As can be read in different interviews [Interview B.2.3] and in literature studies, (Magazine, 2017), the two main transmission routes of Campylobacter entering the broiler houses, are through insects or visitors and their equipment, which is shown in figure 4.3. Therefore the main infection rate *Infection rate in broiler houses* is split up into *Insects infection subrate* and *human infection subrate*, which are both colored in figure 4.4.

No direct contact between broiler flocks and animals outside the broiler house is possible, because the chicken meat production systems are closed. Although, indirect contact can be possible by flies that take up Campylobacter as they forage on fresh animal faeces (Hald et al., 2004). The study by Hald et al. (2004) has showed that flies are a significant threat of Campylobacter infection for chickens. Especially from April to October when insects are in season, they form a threat for infections. Hald et al. (2004)

shows that flies enter broiler houses in large numbers through the ventilation systems, which will be working more often in summer- than in wintertime. This suggests that flies may be an important vector in summer. Besides flies, also other insects will transmit Campylobacter into the broiler houses. According to some of the farmer interviews [Interview B.2.11], insects such as beetles, are often found in the broiler houses.

In the model the factor *Insects infection rate in broiler houses* is influenced by the *development rate of insects*, *probability insects entering the broiler house* and *probability that insects carry Campylobacter*. This is shown in figure 4.4. Climate seasons are causing the seasonal activity patterns of living organisms (Wolda, 1988). In most regions of the world, the growing conditions for living organisms such as insects, generally overcome during specific seasons. To survive during unfavourable periods, many insects undergo a state of dormancy (Wolda, 1988). So if the *temperature* gets higher, the development rate of insects will increase (Tauber and Tauber, 1976), and the ventilator systems will start working. The combination of these two factors, let the insects infection rate increase. So when the temperature is higher, there are more insects, and these insects can easily enter the broiler houses when the ventilator systems are working [Interview B.2.11]. When the ventilator systems are working, the valves in the walls of the broiler houses will open wider. Through these valves, insects can enter the broiler house. However, insects do not only enter the broiler houses through the valves but can also enter them through crevices in the broiler houses [Interview B.2.11]. The insects infection rate is also dependent on *Insects getting infected by vermins*. This factor gives the probability of insects getting in touch with Campylobacter positive defecation of wild domestic animals.

Campylobacter can be found in standing waters or puddles on-farm sites, because they survive well in water (Newell et al., 2011). As can be read in the Interview with veterinarian 1 [Interview B.2.1], defecation of vermin will end up in mud and waters on the farm and will be an essential source for Campylobacters. When the temperature increases, more wild domestic animals will be around farmhouses. The *level hygiene on a farm* is a factor that can decrease the number of pests and vermins on a farm. When the farm is clean, the *probability of Campylobacter infected vermin on farms* will be low. The level of hygiene on a farm also influences the *probability of walking through mud/water before entering the broiler house*. When the farm is cleaned up, the probability of mud/water on the farm will be low. This will lead to a decrease in the *probability of human physically carrying Campylobacter*, which influences the *human infection rate in broiler houses*, as can be seen in figure 4.4. A second influence on this probability is the fact if visitors do follow the hygiene protocol [Interview B.2.4]. Prevention is essential to avoid spreading pathogens and other infections (PLUIMNED, 2019). If the total amount of visits increases, the probability of not following the protocol does increase. According to interviews with farmers, different farmers acknowledged that when they or other visitors need to visit the farm more often, they do not always follow the protocols anymore. The amount of visitors in a broiler-house is based on three different visitors called *visits of the farmer*, *visits of the veterinarian* and *visits of other people*. The visits of a farmer in his/her broiler houses and the probability of following the hygiene protocol are influenced by the temperature variable. If the temperature is higher, farmers are more worried about the health of their chickens and will visit their broiler houses more often. In summer the probability of switching clothing (part of following the protocol), will be lower. According to various interviews [Interview B.2.11], some farmers assumed that in summer, they do not wear their overalls but just their t-shirt and short pants.

According to Magazine (2017) drinking water could be a source for Campylobacter. Some studies isolated Campylobacter genotypes from the drinking system and then from subsequent flocks, which showed that water is not a significant source of Campylobacter in conventional chicken meat production systems. Also, feed and fresh bedding material for in the broiler houses (wood shavings), are not considered to be potential sources of Campylobacter.

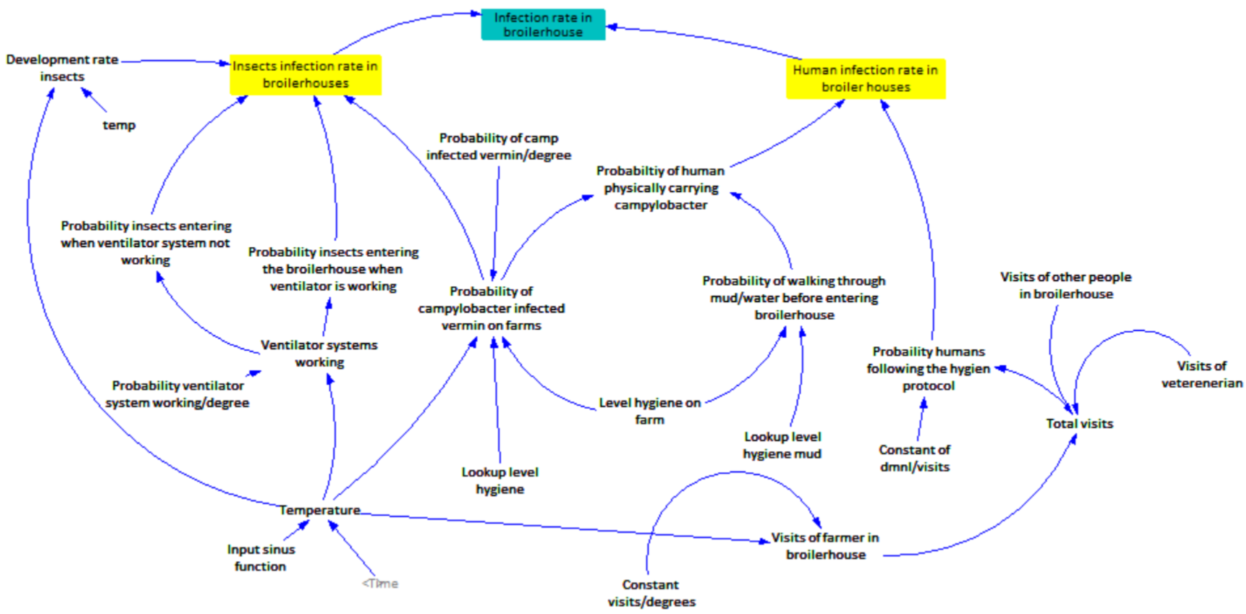


Figure 4.4: Conceptual model of infection rate in farmhouse

4.3.2 *Conceptualization submodel 2: Thinning process*

During the thinning or depopulation process, both the removed chickens and the remaining chickens can get infected. The sub-model called "thinning process" is focused on the *infection rate after thinning*, which can infect the remaining chickens. According to Allen et al. (2008) there is a probability that the Campylobacters may come from the boots, clothing, and hands of the so-called catching team, the transport crates, or forklift trucks. According to the interview B.2.9 the *infection rate after thinning* is based on the *Catchers infection rate* and the *material infection rate*. The catchers' infection rate is based on three different variables, which are *Probability of getting infected by other farmhouse*, *probability of catchers getting in touch with Campylobacter on the farm* and *probability of catchers following the hygiene protocol*. The probability if farmers already wear Campylobacter with them, is based on the *infection rate in broiler-houses* and the *probability that the catching group arrives from another farmhouse*. To get in touch with Campylobacter, the catching group will be seen as extra visitors, entering the broilerhouse at one point in time. So the *probability of human physically carrying Campylobacter* in combination with the amount of the catching group, will influence the probability of catchers getting in touch with Campylobacter positively. The amount of the catching group also affects the *probability of infecting chickens by catch group*. This factor also depends on the fact if the catching group follows the hygiene protocol.

In the EU, containers and trucks are always cleaned and disinfected before re-use for a different farm. However, many studies report that crates and boxed are still contaminated with Campylobacters after cleaning and disinfection (Rasschaert et al., 2020). Based on this, the *Material infection rate* will be different for different countries and different slaughterhouses. The use of containers contaminated with Campylobacter can possibly cause a scenario of partial depopulation. Campylobacters, which are present on the crates, will be introduced into the broiler house with a significant remaining part of the chickens (Rasschaert et al., 2020).

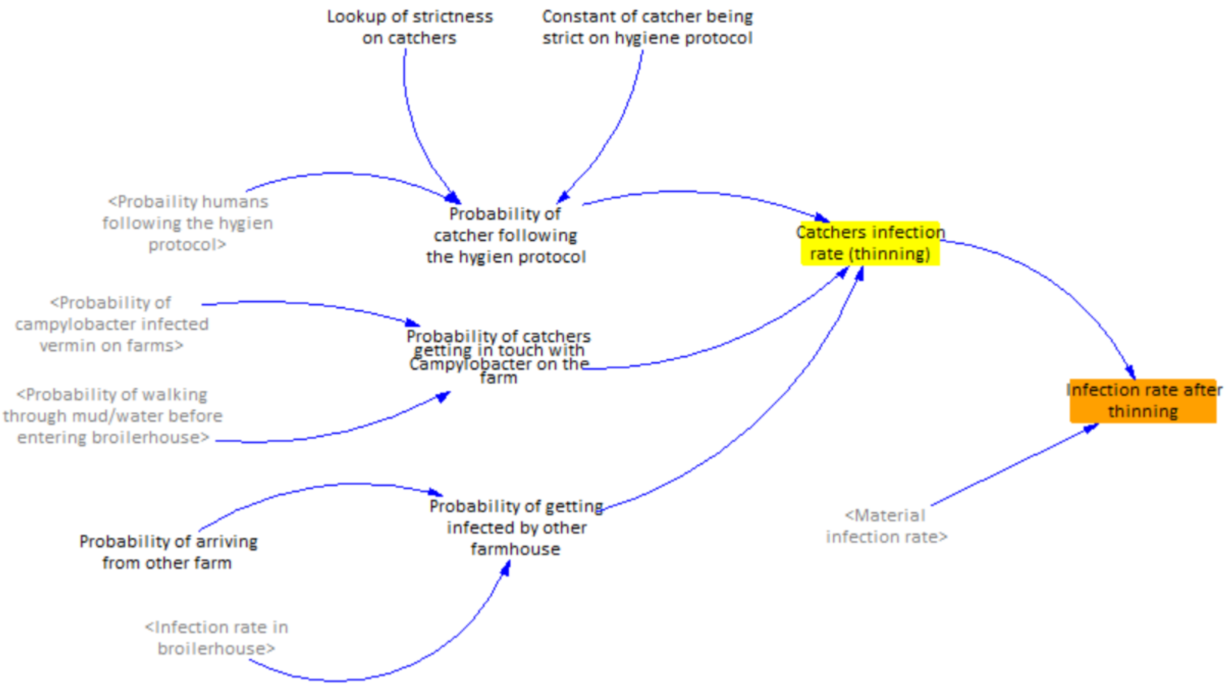


Figure 4.5: Conceptual model of infection rate thinning process

4.3.3 *Conceptualization submodel 3: Transport process*

The third submodel is developed to estimate the *transport infection probability*, which is the probability of chickens getting infected on transport to the slaughter houses. A significant correlation was found between the contamination of chickens and the faecal material of these chickens from the transport crates to the slaughterhouse (Rasschaert et al., 2020). In research for 14 flocks, the faeces in the crates were found Campylobacter positive, of which seven flocks were already Campylobacter positive during rearing. The other seven flocks were Campylobacter negative during rearing (Herman et al., 2003). Transport containers, even after the cleaning and disinfection process, can still contain various Campylobacters (Rasschaert et al., 2007). After transporting the flocks in containers, no significant intestinal colonization of the flocks by Campylobacters present in the transport containers is observed (Rasschaert et al., 2007), which means the infection probability on transport caused by material should be really small.

Besides the material infection rate, another factor that can influence the infection rate on transport is *feed withdrawal time*, which is the total time that chickens are deprived of food (Rasschaert et al., 2020). Insufficient feed withdrawal time may result in intestines still partially filled with feed and faeces.

During loading and transport of the birds, the animals may be subjected to stress due to crowding, motion, temperature fluctuations and food and water deprivation (Rasschaert et al., 2020). In stressed animals, the peristaltic movement of the intestines may increase, leading to more excretion of faeces and pathogens [Interview B.2.1]. This is shown in the model with the factor called *Probability of excretion of faeces and pathogens*. If this probability increases, this will also influence the *material infection rate*.

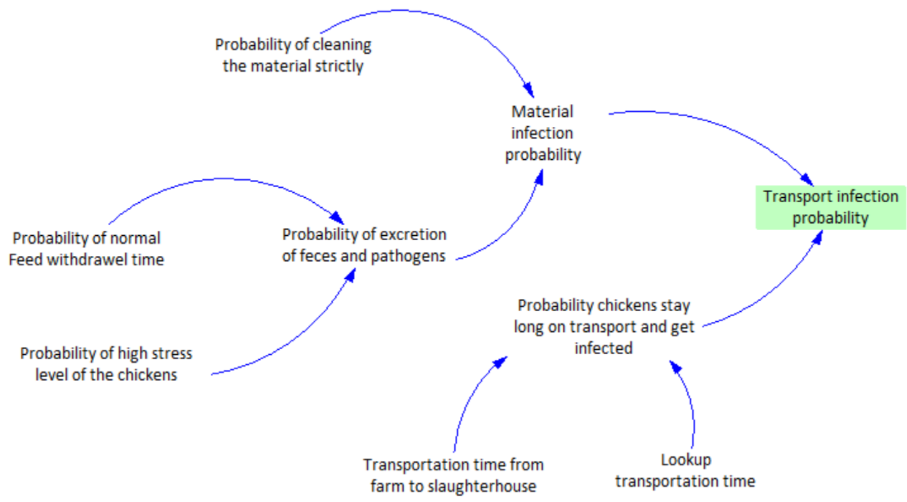


Figure 4.6: Conceptual model of transport process

4.3.4 *Conceptualization submodel 4: Campylobacter in Slaughterhouses*

According to (Herman et al., 2003) four of the seven slaughterhouses, which received Campylobacter negative chickens, were able to deliver them almost all as negative chicken carcasses. Although in two other slaughterhouses, all or nearly all the carcasses were contaminated with Campylobacter. In the slaughter process, it is crucial to take into account two contamination moments. The first one is the carcass contamination during slaughtering, which can occur during three different slaughter proccesses: scalding, plucking and evisceration (Rasschaert et al., 2007). An overview of these three steps in the complete slaughtering process is given in the figure 4.7 below. In the model, these three different moments are modelled as three separate probabilities which end up in one main factor, which is called *probability of carcass contamination*. When this happens, the gastrointestinal tract leaks Campylobacter-contaminated faecal material [Interview B.2.8]. The second one is the cross-contamination of previously slaughtered flocks or via the slaughter equipment. Therefore two different probabilities are given: *Probability of contamination via the slaughter equipment* and *probability of cross-contamination of previously slaughtered flocks*. These two form the *Probability of cross contamination* [Interview B.2.8].

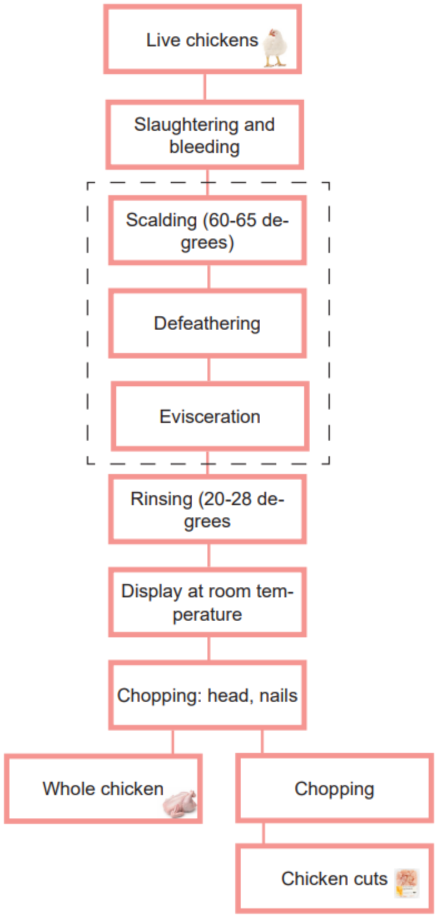


Figure 4.7: Production process in chicken slaughterhouses

During the different steps described in the figure above, Campylobacter contamination can occur from equipment, surfaces and water. Bacteria from the air and the environment in slaughterhouses can contaminate chicken meat (Rouger et al., 2017). The skin of poultry carcasses and cuts is directly in contact with air and equipment surfaces and so easily contaminated with Campylobacter (Rouger et al., 2017). At the slaughterhouse contamination could originate from other broiler flocks or it could be due to poor cleaning (Rossler et al., 2020). Therefore the *Probability of poor cleaning* is also integrated into the submodel and influences the probability of contamination via the slaughter equipment. The probability of poor cleaning is split up into *probability of human working in the slaughterhouse strictly* and *probability of using the right water temperature*.

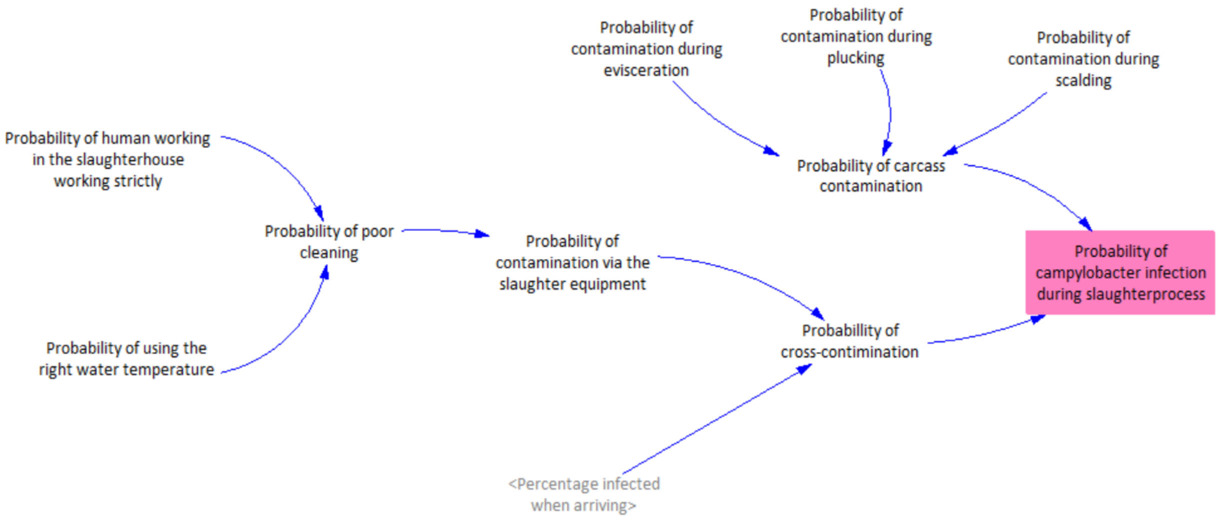


Figure 4.8: Conceptual model of slaughter process

4.4 Model formalization

According to Pruyt (2013), the model formalization phase formulates an SD simulation model of the causal theory, which is developed in the model conceptualization phase. The formalization can be seen as the switch from a qualitative model to a quantitative model. In this section first, the details of the leading stock-flow structure will be elucidated, followed by the explanations of the equations and variables used in the different sub-models. In appendix C, an overview of the factors and its details (names, equations, units and references) is given.

4.4.1 *Model formalization of the main model*

The period for conventional chickens to grow up in a broiler house is six weeks. After these six weeks, the broiler house will be cleaned and will be prepared for new chickens arriving from hatcheries. The total duration of the process happening on-farm is seven weeks. For this model, the assumption is made that every week on 1/7th of the farms, new chickens arrive, on 1/7th of the farms' chickens are thinned out, and on 1/7th of the farms, the left-over (after the thinning process) chickens are caught by the catch crew to transport to the slaughterhouses. Every week 1/7th of the broiler houses will be empty. Therefore, the total occupancy is 6/7th of the total amounts of chickens that fit in the broiler houses in the Netherlands. This is shown in figure 4.9 below.

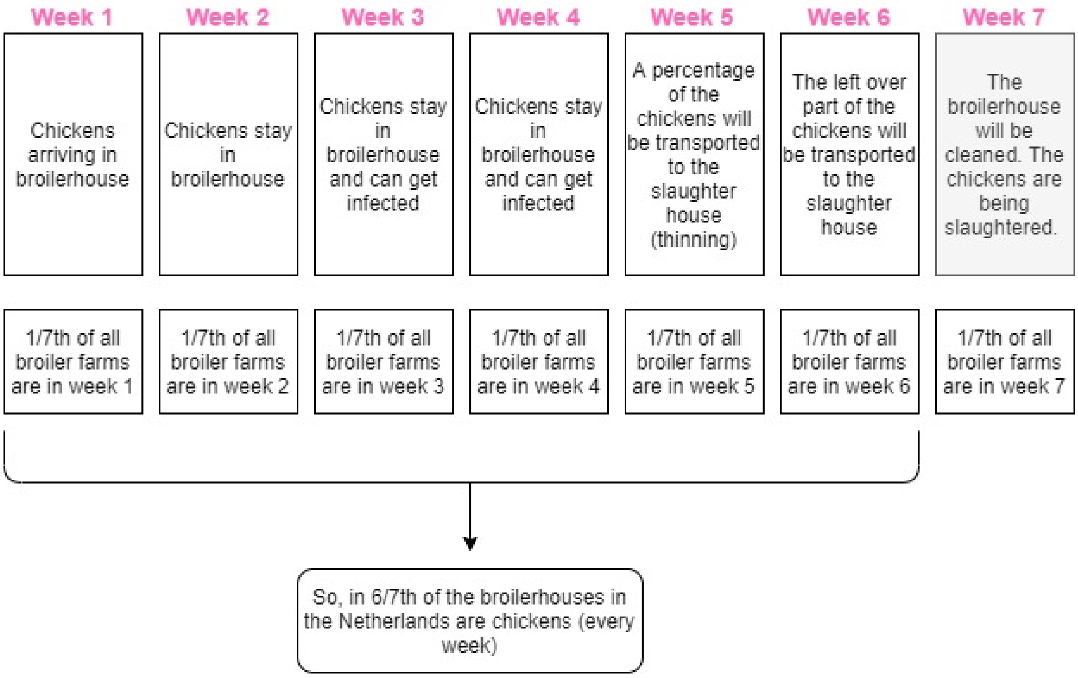


Figure 4.9: Overview of the weeks

In figure 4.10 an overview of the main stocks, flows, infection probabilities and explanations is given. The pink text shows what the probabilities and flows are called in the Vensim model.

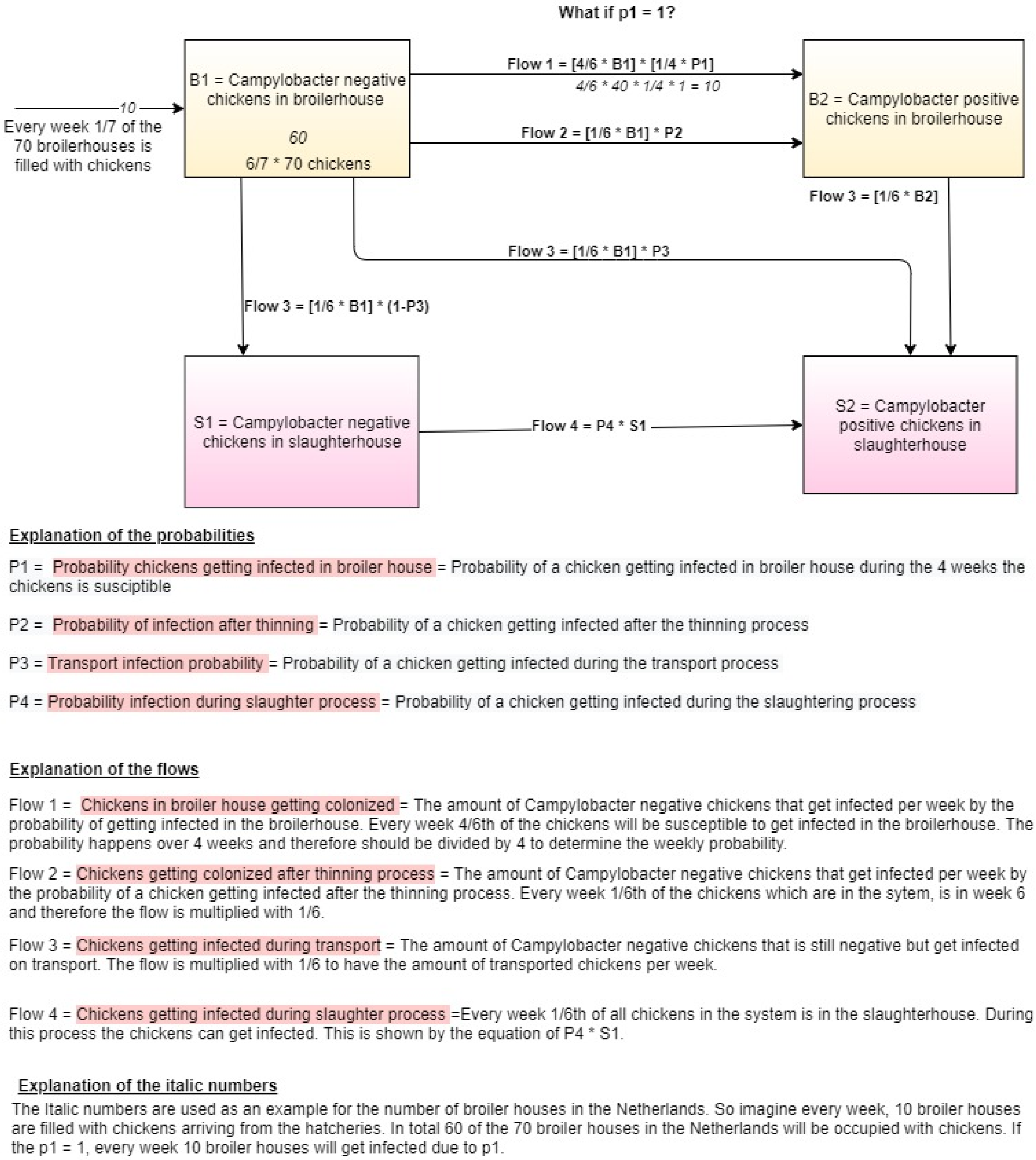


Figure 4.10: Explanation of the different infection probability flows

As can be seen in figure 4.10 every week, new chickens will arrive from hatcheries to different broiler houses in the Netherlands, which will be 1/7th of the total occupancy of the broiler houses. The chickens coming from hatcheries transported to broiler house variable, therefore, is the complete number of chickens in the Netherlands at this moment divided by 7. This flow ends in the stock *Campy negative chickens in broiler* *houses*, which has five different outflows. The first outflow, flow 1, indicates the *chickens in broiler houses getting colonized*, which is influenced by the factor *Probability of Campylobacter infection in broiler house* (P1). Most flocks become infected only 2 to 3 weeks after the placement in the broiler houses, which is the so-called lag phase (Newell and Fearnley, 2003). The reason for this lag phase is not fully understood but may include immunity passed on from parent stock (Magazine, 2017). Therefore the chickens can only get infected 4 out of the six weeks that they are in the broiler house, so in the equation, an extra factor of 4/6 is added in the model.

A second moment that the chickens can get infected in broiler houses is during and after the thinning process (flow 2), as can be seen in figure 4.10. After five weeks in the process, a part of the chickens will be caught to be transported to the slaughterhouses, which is assumed to be on average 30%, based on different interviews. The flow *Chickens getting colonized after thinning process* is influenced by P2, which is the *probability chickens getting infected after thinning process*. The dead chickens in broiler-houses are estimated by the multiplication of the chickens in broiler houses and the *death rate in broiler houses*. The death rate is the rate per cycle, and therefore this flow is divided by the total time of one period, which is six weeks. According to the European broiler regulations (2007), the chicken loss should be lower than (1 + 0.06* age of the flock)%. So when the flocks are around six weeks old, the percentage of chickens who die in the broiler-houses before getting slaughtered should be lower than 3.52% (Lourens and Steentjes, 2008). Based on this percentage and on the information obtained from the interviews which are summarized in the table B.1 below, the death rate in farmhouses is developed, which will be between the 2% and 3%. Every week in one-seventh of all broiler houses the chickens are placed on transport to be transported to the slaughterhouses. In the system, this is 1/6th of the total chickens as can be seen in flow 3 in figure 4.10. On transportation, chickens can get infected. In subsection 4.4.4, this infection process will be explained in detail. The flows are divided by seven because this is the total cycle time. So every week 1/6th part of chickens will be placed on transport. The negative chickens in the broiler houses can turn into positive chickens if they get infected during the transport process. The probability of getting infected during the transport process is based on different other variables and parameters which are explained in subsection 4.4.4. This flow ends in the same stock as the *Campylobacter positive chickens transported*, which shows the flow of chickens who were already infected in the broiler houses. Another part of the chickens will not get infected on transport, and this flow is estimated by multiplying the Campylobacter negative chickens and (1-probability of transport infection). This chicken flow is also divided by 6.

The chickens all end up in the slaughterhouse stocks. The Campylobacter negative chickens in the slaughterhouse can get infected during the slaughter process (flow 4) and are therefore multiplied by the *probability of Campylobacter infection during slaughter process* (p4). A more in-depth explanation of the infection in slaughterhouses is given in subsection 4.4.5. The chickens which are not getting infected are estimated by the multiplication of the negative chickens and 1-*probability of Campylobacter infection during slaughter process*. The stock of Campylobacter positive chickens arriving in the slaughterhouse has one outflow, which is called *Campylobacter positive chickens being slaughtered* per week. This outflow and the outflow of chickens turning positive during the slaughter process should be divided into the total of chickens being killed. The percentage of infected chicken meat will be the output of the model and will show per week what the rate of Campylobacter positive chicken meat is over time.

4.4.2 *Formalization submodel 1: Infection rate in broiler houses (P1)*

The infection rate in broiler houses is developed based on the *insects infection rate in broiler houses* and the *human infection rate in broiler houses*. The temperature has an influence on both of these factors. An explanation of the most important variables is given below.

Temperature

In the model, the factor *Temperature* shows the average temperature in the Netherlands at a certain *Time*, which is based on data [Maximum average monthly temperature in the Netherlands 2017]retrieved from Statista (2017). This variable is dependent on the *Time* variable. The following sinus equation is therefore estimated, which is based on data retrieved from figure C.1:

$$Temperature = 13.45 + 8.45 * \sin(\frac{2 * 3.14}{52}) * (Time - 17)$$

Development rate of insects

The development rate of insects is based on *temperature*. According to Régnière et al. (2012) "*The development rates of insects are calculated as the inverse of observed development time and are expressed as proportions of total stage duration per unit of time*". Several studies tried to to quantify the influence of temperature on insect development rates (Damos and Savopoulou-Soultani, 2012). Insects are slow developing in spring, but rapid developing in summer. This explains the fact that the growth and development rates increase almost linearly with temperature (Gilbert and Raworth, 1996).

This insect development rate is based on the following equation, which is retrieved on data from Damos and Savopoulou-Soultani (2012), which is shown in appendix C. By knowing different data points a linear equation could be developed.

$$Insect\ Development\ rate = 0.041 * Temperature - 0.0412$$

Insects infection rate in broiler houses

The insects' infection rate is, as can be seen in the conceptual model in figure 4.4, based on four different factors. Two of these factors are based on the fact if the ventilators systems are working. The *Probability insects entering when ventilator systems not working* is based on (1-*ventilator systems working*)*0.5. While the *Probability insects were entering when the ventilator system is working* is based on ventilator systems working*0.5. The number of 0.5 is chosen to show that insects will not always enter the broiler house through the ventilator systems. The factor ventilator systems working is based on the temperature. If the temperature is high, the probability that the ventilator system is working will be higher.

Visits of a farmer in broiler house

If the temperature increases, the farmer will visit the broiler house more often [Interview B.2.11]. The farmer visits his/her broiler house at least once per day, which is weekly visits in the model. When the temperature is high, the farmer will visit the broiler house around three times per day. These visits are also depending on if the chickens are sick, but this is not included in this model. The table 4.1 shows the numbers that are used for creating the following linear equation.

$$Visits\ of\ farmer\ in\ broiler\ house = 0.82 * Temperature + 2.8$$

For the directional coefficient of 0.82, a constant variable is created to show the visits per degree easily. In the table the on average minimum and maximum temperature are shown in the Netherlands. Also, the maximum and minimum visitors are shown, which numbers are based on assumptions obtained from the interviews.

Table 4.1: Visits of farmer in broiler house depending on the temperature

Factor	*Value*
Maximum visits of farmer in broiler house	21
Minimum Visits of farmer in broiler house	7
Maximum temperature	22
Minimum temperature	5

Probability humans following the hygiene protocol

The probability of visitors are following the hygiene protocol is depending on this model on the number of visits. From the interviews with different actors [Interview B.2.3 and B.2.11], it became clear that farmers become looser in following their protocols when more visits take place. A perfect example to illustrate this is based on the outside temperature. When the temperature increases, farmers will have to visit their broiler house more often to see if the chickens still are feeling well. When entering three times or even more the broiler house, people will quickly forget about switching clothing. In table 4.2, an overview is given of the numbers that are used to create the following linear equation to estimate the probability:

$$Probability\ of\ humans\ following\ the\ hygiene\ protocol = -0.029 * Visits + 1.16$$

For the number -0.029, a constant variable in the model is developed to show the decrease in probability per visit. The assumption is done that the probability of a visitor following the hygiene protocol is similar for all different visitors, such as veterinarians or family.

Table 4.2: The probability of humans following the hygiene protocol depending on the total visits

Factor	*Value*
Maximum visits/week	23
Minimum visits/week	9
Maximum probability humans following hygiene protocol	0.9
Minimum probability humans following hygiene protocol	0.5

Probability of Campylobacter infected vermin on farm

The probability of Campylobacter infected vermin on farms is influenced by two different factors, which are temperature and the hygiene level. A linear function is developed in which the probability is chosen as the dependent factor and temperature is the independent factor. The values determined to create this linear function are given in table 4.3. The level of hygiene is implemented in the so-called "B" value in the linear equation. When the level of hygiene is high, the "B" value will decrease, so the probability of vermin will be lower. When the level of hygiene is low, the probability of vermin will be higher.

$$Probability\ of\ Campylobacter\ infected\ vermin\ on\ farm = 0.03 * temperature - 0.05 + (LookupLevelHygiene"B")$$

Table 4.3: Infected vermin on farms depending on temperature and hygiene level

Factor	*Value*
Minimum temperature	5
Maximum temperature	22
Minimum probability of Campylobacter infected vermin	0.2
Maximum probability of Campylobacter infected vermin	0.9

A lookup function is used to change the level of hygiene on the farms. The table 4.4 below shows which values are used.

Table 4.4: Values used in lookup "level hygiene"

Hygiene level (0 = low, 4 = high)	*Value used in equation (B)*
0	0.2
1	0.18
2	0.15
3	0.1
4	0.05

Ventilator systems working

The factor *ventilator systems working* is dependent of the variable called *temperature*. The assumption is made, which is based on the conversations with the farmers that the ventilator systems are more often used when the temperature is higher. Based on this information the table 4.5 is created. Based on if the ventilator systems are working a probability is given to the "insects entering the broiler house" variable. If the systems are working the probability will be 0.6, and when the systems are not working, the probability will be 0.4. These numbers are close to each other because insects can also enter the broiler houses through different other ways, such as through crevices.

The equation to estimate the factor *Ventilator systems working* is the following:

$$Ventilator\ systems\ working = Probability\ of\ ventilator\ systems\ working\ per\ degree * Temperature + 0.04$$

Table 4.5: Ventilator systems working depending on temperature

Factor	*Value*
Minimum temperature	5
Maximum temperature	30
Minimum probability of ventilator systems working	0.1
Maximum probability of ventilator systems working	1

4.4.3 *Formalization submodel 2: Infection rate after the thinning process (P2)*

The second sub-model shows the factors which influence the *infection rate after thinning*. This infection rate is based on two infection rates which are called *catchers infection rate (thinning)* and the *material* *infection rate*. The material infection rate will be explained in the following submodel. For this model, the choice is made not to split up the percentage of chickens which are caught earlier. Because in 1/7th of the broiler houses will happen the thinning process (10 per cent of the chickens), and in another 1/7th of the broiler houses will the left-over chickens be caught (90 per cent). This means that every week 1/7th of the total of all chickens in the Netherlands is caught or 1/6th of all chickens in this system (100 per cent).

The catcher's infection rate is based on the multiplication of (1 - probability of catcher following the hygiene protocol) and the sum of the probability of catchers getting in touch with Campylobacter on the farm and the probability of getting infected by another farmhouse. The sum of these two probabilities gives the total probability that the catchers get in contact with Campylobacter. However, when they are wearing Campylobacter and they follow the protocol, there is a probability they do not transmit it into the broiler house. Therefore the sum is multiplied with 1 - probability of catcher following the hygiene protocol.

Probability of catcher following the hygiene protocol

The probability of catchers following the protocol is based on a lookup function which is called *lookup of strictness on catchers* and the *probability humans following the hygiene protocol*.

The assumption is made that the probability of catchers following the hygiene protocol is influenced by the probability of humans following the hygiene protocol. When in general, this probability is more significant, the assumption is made that the farmer will be strict on the catchers following the protocol. Besides this, the probability of catchers following the protocol is also based on the *strictness of the catchers on the protocol*. If the catchers are strict on the protocol, the probability of following it will be higher.The table 4.6 shows the values that are used in the lookup function. All values are between 0.9 and 1 because the assumption is made that in general, the catchers will be strict on following the protocol and will often follow the protocol of the farmers.

Table 4.6: probability catchers following the hygiene protocol

Strictness of catcher on hygiene protocol (0 = low, 1 = high)	*Value used in equation (B)*
0	0.9
0.2	0.91
0.4	0.92
0.6	0.93
0.8	0.94
1	0.95

Probability of catchers getting in touch with Campylobacter on the farm

The probability of catchers getting in touch with Campylobacter on the farm is based on the multiplication of the two factors *probability of Campylobacter infected vermin on farms* and *probability of walking through mud/water before entering the broiler house*, which are in the first submodel. A multiplication of these two factors is necessary. People or catchers can walk through mud, which is not infected with vermin. The probability of then getting infected with Campylobacter is zero. Also, the mud can be infected with Campylobacter, but people do not walk through the mud. In this way, the catchers will also not get infected. The probability will then be zero.

Probability of getting infected by other farmhouses

The probability of getting infected by another farmhouse is based on the *infection rate in broiler house* from the first sub-model and the probability of the catch crew arriving from another farm. The assumption is made that the catch crew will come half of the time from another farm.

4.4.4 *Formalization submodel 3: Infection rate on transport (P3)*

The infection rate on transport is based on the multiplication of the material infection rate and the probability that chickens stay long on transport and get infected. The two probabilities are multiplied with each other to show the transport infection probability is depending on both. When the material infection probability is zero, the probability of chickens staying long on transport is negligible. When chickens stay long on clean transport, they can not get infected. A lookup function is developed, which shows the time that chickens stay on transport and the probability the chickens get infected.

According to **?**, within four hours after exposure to Campylobacters in naturally contaminated crates chickens became Campylobacter colonized. Another study showed that birds were transported in crates that were still harbouring Campylobacters after cleaning and disinfection. Although, those birds were not colonized. They were in the crates for about only two hours. Based on this information, the following lookup table is developed.

Table 4.7: probability chickens stay long on transport and get infected

Time on transport (1 hour = low, 8 hours= high)	*Probability of chickens getting infected*
1	0
2	0
3	0.01
4	0.02
5	0.03
7	0.04
8	0.04

The *material infection rate* is based on *probability of cleaning the material strictly* and the *probability of excretion of faeces and pathogens*, which is a multiplication of the probability of the *stress level of chickens* and the *probability of a standard feed withdrawal time*. To estimate both probabilities multiplications are used to show the dependence of the probabilities on each other.

4.4.5 *Formalization submodel 4: Infection rate in slaughterhouses (P4)*

The probability of Campylobacter infection during the slaughter process is based on the probability of carcass contamination and the probability of cross-contamination. Concerning Campylobacter and poultry slaughter, the available literature often showed common trends: reductions by scalding, instead increase by plucking, no changes or increases by evisceration, and decreases by washing and chilling (Rasschaert et al., 2020). Based on this information probabilities are assumed for the different factors which influence the *probability of carcass contamination*.

The three different probabilities are based on data which is retrieved from the article of Rasschaert et al. (2020). The mean increases (cfu/g) of Campylobacter after the specific steps are divided by the mean concentration on the carcass before the specific intervention step. In the table below is shown which values are used.

Table 4.8: Probabilities of contamination after processing steps

	Mean concentration on the carcass before processing step	Mean concentration on the carcass after processing step	Equation to estimate probability	**Used probability**
Scalding	3.2	1.8	(1.8-3.2)/3.2	-0.4375
Plucking	1.4	2.1	(2.1-1.4)/1.4	0.5
Evisceration	2.1	2.5	(2.5-2.1)/2.1	0.19

The probability of cross-contamination is based on the probability of contamination via the equipment multiplied with the percentage infected chickens when arriving in the broiler house, which value is based on different parameters from the primary stock-flow model. Multiplication is used. This can be explained by the example of a probability of zero of contamination via the slaughter equipment. If this probability is zero, cross-contamination will not be possible.

4.4.6 *Simulation setup*

The time step tells how often computer calculates the values of all variables. For this model a time step of 0.5 is used. The time units for this model are 1 week. The integration method that is implemented is runge kutta 4 fixed.

4.5 Base Case Analysis

This section shows the results of the model after the implementation of the base case. The base case shows the current situation of the Campylobacter problem. Figure 4.11 shows the percentage of infected chicken meat over time in weeks. From the figure, it is clear that the portion of infected chicken meat has a big difference over time. Around week 33 (begin of august), the top of the function is reached, and the percentage of infected chicken meat is around 70 per cent. The lowest value is in week 60 (February), which is about 25 per cent of infected chicken meat. The seasonality peak is a striking appearance. As according to Wagenaar et al. (2006) in the warmer months, the percentage of infected chicken meat is higher, which corresponds with the results of the graph.

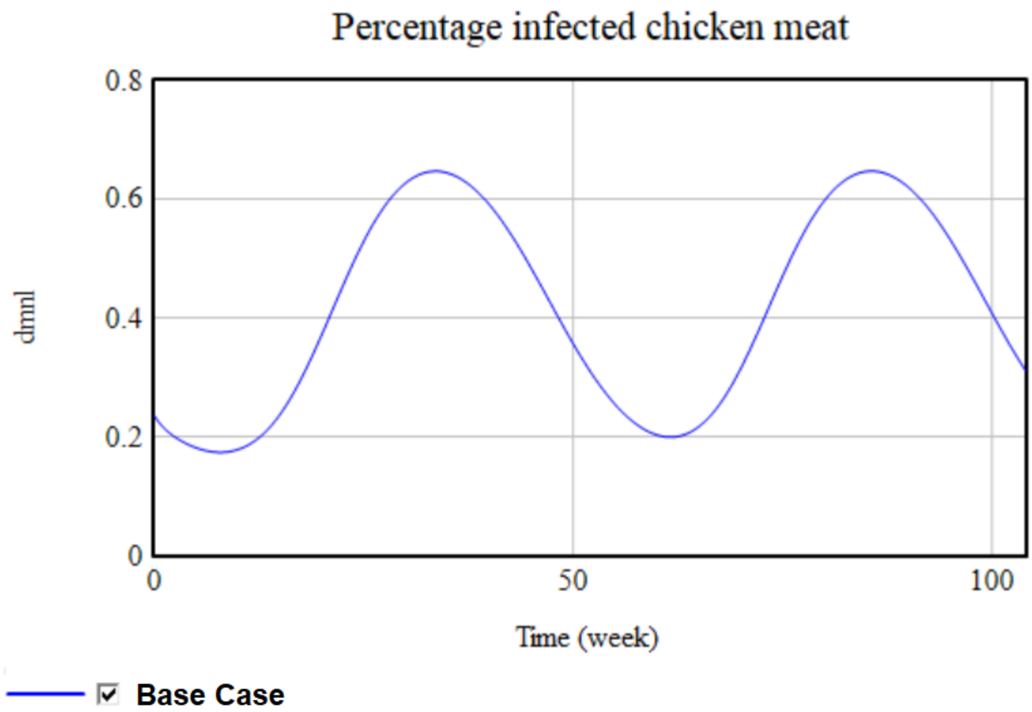


Figure 4.11: Percentage infected chicken meat over time

Figure 4.12 shows an overview of the four different flows of chickens per week getting infected by different infection probabilities in the process. The grey upper line, line 4 in the figure, shows the chickens which get infected during the time they are in the broiler house. Both this graph and the graph of the chicken flow getting infected after thinning, show a clear seasonality effect. A study conducted by Allen et al. (2008) provided significant evidence that flock thinning can be the cause for Campylobacter infections. In the study of Allen et al. (2008), more than half of the flocks studied became Campylobacter positive within a few days after thinning. In figure 4.12, line 1 shows a high number of chickens getting infected after the thinning process. The graph of chickens getting infected during transport is small. Based on the model outcome, only 3000 to 5500 chickens will get infected during transport. The red graph (line 2) shows the flow of chickens getting infected in slaughterhouses per week. This flow seems quite stable over time and is less influenced by the seasonality peak. However, a peak is visible around the same number of weeks as the other two flows which are influenced by temperature.

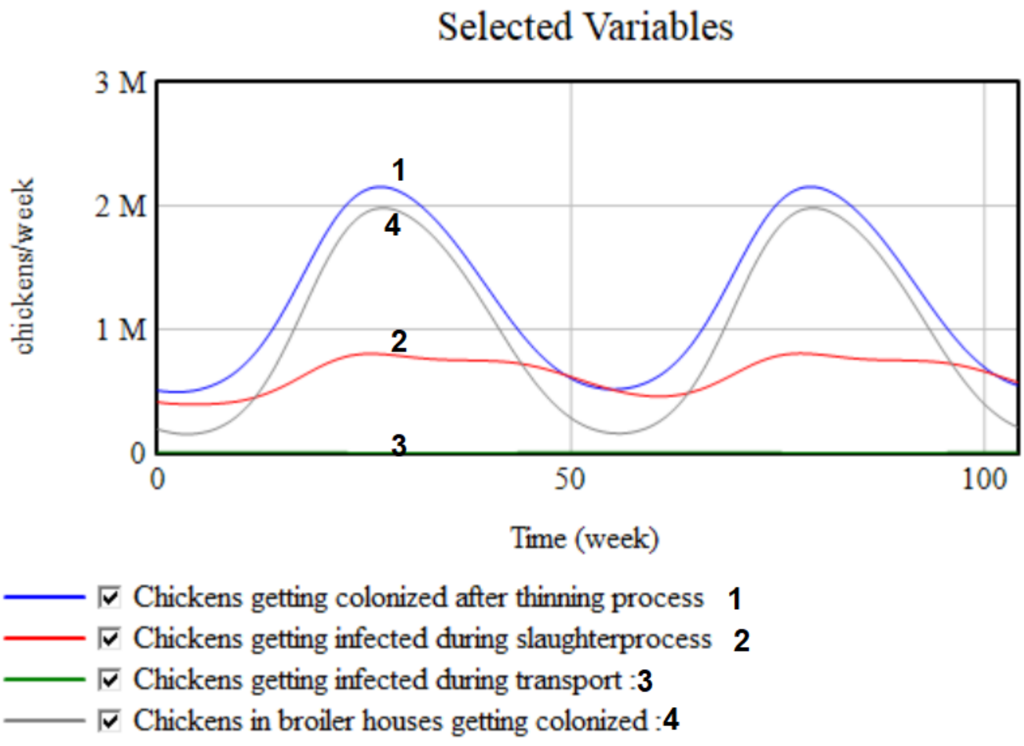


Figure 4.12: The number of chickens getting infected over time in different phases of the chicken meat production process

4.6 Summary

The behaviour of Campylobacter positive chicken meat over time without implementing measures to prevent contamination can be described by focusing on the seasonality peaks. Around the summer, the number of Campylobacter infected chickens increases. This increase is caused by the various infection probabilities which are depending on temperature variables. For each of the infection moments, a submodel was developed. The likelihood of infection in broiler houses are based on insects- and humans behaviour during different seasons. The thinning infection probability submodel gives an overview of the infection probability of the leftover chickens after the thinning process. The transport infection probability and during slaughtering probability are small probabilities compared to the other two. In the following chapter, the model will be verified and validated.

5

Verification and Validation

According to Sterman (2002b): "*model testing is a process to uncover errors, improve models, learn and build confidence in the usefulness of models for particular purposes and in the recommendations that follow from modelling studies*". The model testing consists of verification and validation, which are the main processes for building credibility and trust in a model (Sterman, 2002b). System Dynamics models only capture a part of reality in a simplified manner. Therefore, the validation and verification phases are essential.

All components of the model are continually tested and improved through an iterative process. To build confidence on the suitability of the model to be fit for assessing the influence of different biosecurity measures on the transmission of Campylobacter in the chicken chain. The main findings of various validation tests carried out are stated in this chapter.

To test an SD model, a wide range of tests are suggested by Sterman (2002b), which are testing boundaries, equations, behaviour, sensitivity and performance. It is essential to ensure that the model is useful for the model, which is implementing different biosecurity measures in different uncertain scenario's. The model tests performed for this research are structure verification, boundary adequacy, dimensional consistency, integration error, extreme conditions, sensitivity analysis, face validation and historical data validation. The focus of the tests will be mainly on the qualitative aspects of the model because the model will be used to investigate in the behavior of the output over time. Therefore, the model is based on information obtained from literature and interviews. The validation and verification step bring valuable insight into the uncertainties in the model, which are eventually needed to answer the main question. Structure verification test and boundary adequacy are the first tests that are done to test the development of the conceptual model (Qudrat-Ullah and Seong, 2010).

5.1 Boundary Adequacy

The boundary adequacy analysis indicates whether the concepts and structure of the model are modelled within the given system boundaries (Senge and Forrester, 1980; Qudrat-Ullah and Seong, 2010). Also, it is essential to check whether the KPI used to answer the research question is modelled endogenously in the model, which means the KPI variable must be determined within the model. As can be seen in the model, the KPI for this research, *percentage infected chicken meat*, is based on three different outflows. These three outflows are based on the different sub-models influencing the total number of Campylobacter positive and Campylobacter negative chickens.

The research focus is the transmission routes of Campylobacter in the chicken meat production process in the Netherlands. The moments that the Campylobacter can infect chickens are modelled as seperate endogenous infection rates, which are based on the dynamics happening in the various submodels. In all four of these submodels no loops, and other exogenous parameters are used. Nevertheless, some variables such as *probability chickens getting infected in broilerhouse*, are developed in one submodel and then used as an input parameter in another submodel. The KPI *percentage infected chicken meat* is just an output variable and is not used again in the model or submodel as an input parameter.

5.2 Dimensional Consistency

The parameters used in the equation of a system dynamics model refer to real-world concepts. For instance, the factor *Campylobacter negative chickens transported* is measures as chickens/week. The iterative process of modelling will stop when unit errors are no longer appearing. The unit test is committed continuously during the development of the model. Vensim offers a units check, which determines if all parameters of all equations in the model are consistent. This unit check was performed, and zero unit errors were indicated.

5.3 Integration Error and Time Step

The integration method and time step used for simulation can influence the behaviour of the model. The test indicates whether model errors or warnings concerning the numerical integration method are used (Sterman, 2000). As is stated by Pruyt (2013), the RK4 integration method is the best for continuous models, with possibly, oscillatory behaviour. Therefore in this model, the RK4 integration method is used. Different time steps are tested, as is shown in figure 5.1, but no significant changes are determined. So the time step of 0.5 is implemented.

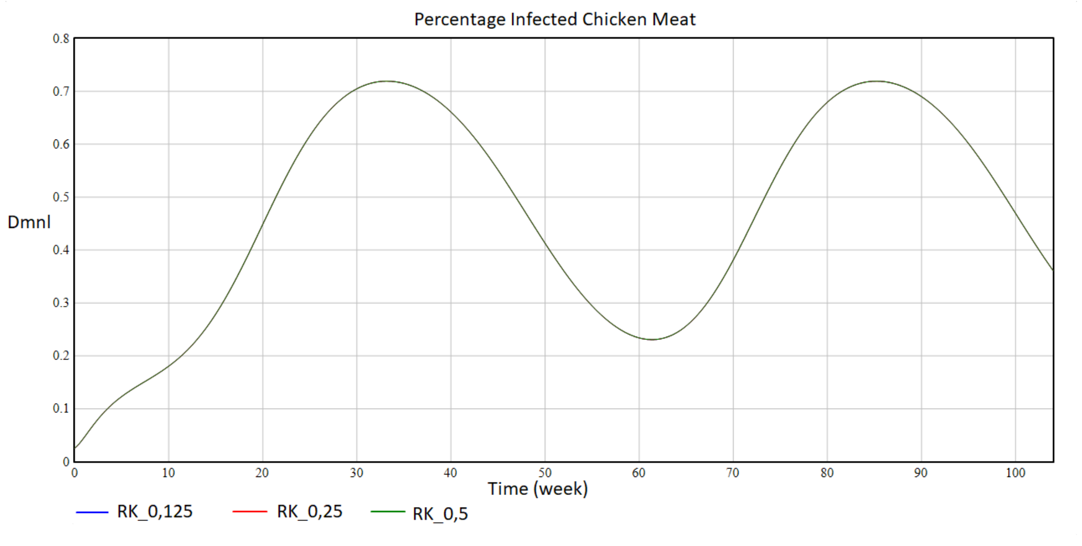


Figure 5.1: Overview of results when different time steps are implemented

5.4 Extreme Conditions

An extreme-conditions test was performed to further test the structure of the model. Various parameters are set to extreme conditions to evaluate if the model behaves the way it is expected in such conditions. The extreme conditions test should see whether the model will break given different extreme values to parameters, and it should see whether still consistent results will be given. The results of the changes in the parameters will be evaluated as to their impact on the *percentage infected chicken meat*, as this is the final parameter of the model. All variables are tested using an extremely low and an extremely high value for this specific variable. The results of five of these parameters will be explained below shortly and in the appendix more thoroughly. The table shows what lower and higher input values are used for the parameters. These five parameters are chosen based on the idea that all parameters are in a different sub model.

Table 5.1

	Current value	**Low value**	**High value**
Chickens arriving from hatcheries transported to broiler houses	(4.86843e+07)/7	0	(4.86843e+09)/7
Visits of veterinarian	1	0	100
Probability of arriving from other farm	0.8	0.2	1
Probability of high stress level of the chickens	0.3	0	1
Probability of contamination during plucking	0.05	0	0.5

In figure 5.2, the impact is shown of an extremely high and extreme low value for the parameter *Visits of veterinarian* per week in the broiler house. The current value of the visits to the veterinarian per week is one. Therefore, the difference between the extremely low value (which is 0), is very small. The extreme high value shows a large difference with the base case result of the percentage of infected chicken meat. The line reaches in his top close to a rate of 1, which means that almost 100 per cent of the chicken meat is infected. When the visits of the veterinarian increase, the total visits increases. The visits influence the *probability of humans following the hygiene protocol* positively. Finally, the *probability chickens getting infected in broiler house* will increase. This model behaviour, is similar to the expected behaviour.

In figure 5.3 the impact is shown of an extremely high and extreme low value for the parameter *chickens arriving from hatcheries* per week in the broiler house. When zero chickens arrive in the system, no chickens will get infected. When the number of arriving chickens increases, the graph of percentage getting infected, is similar to the base case graph. This is a logical outcome, as the percentage is estimated by various probabilities and rates.

The results of the impact of the other parameters on the KPI are shown in appendix D.1. From these results can be concluded that their behaviour is as expected before doing the extreme value tests. When the values of the three probabilities which are in table D.1, increase, the outcome of the percentage infected chicken meat increases. When a lower value is chosen, the height of the percentage infected chicken meat graph decreases. The different extreme value graphs show not a significant difference with the current graph. The impact of changing these values is for most of the values not significant on the final percentage of infected chicken meat.

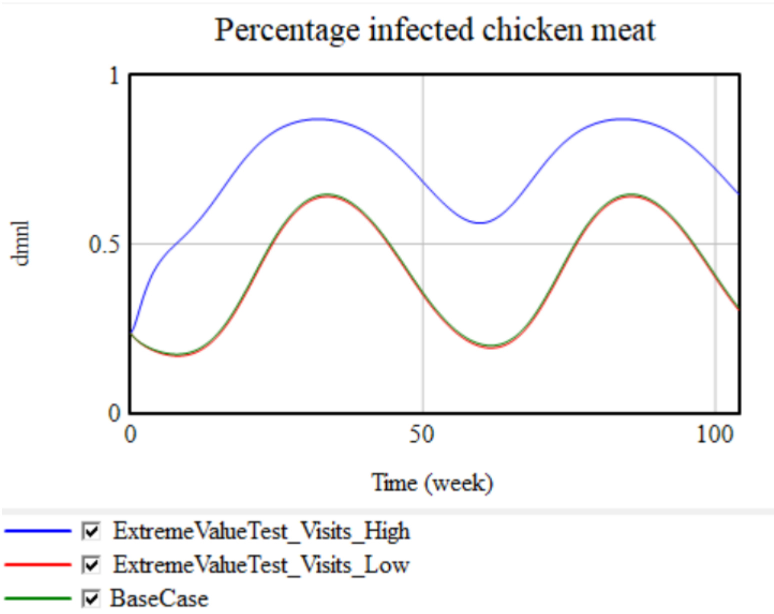


Figure 5.2: Result of percentage infected chicken meat of an extreme conditions test with increased visits as one extreme condition (blue line),the base case result of percentage infected chicken meat (green line), and the decreased visits as another extreme condition (red line)

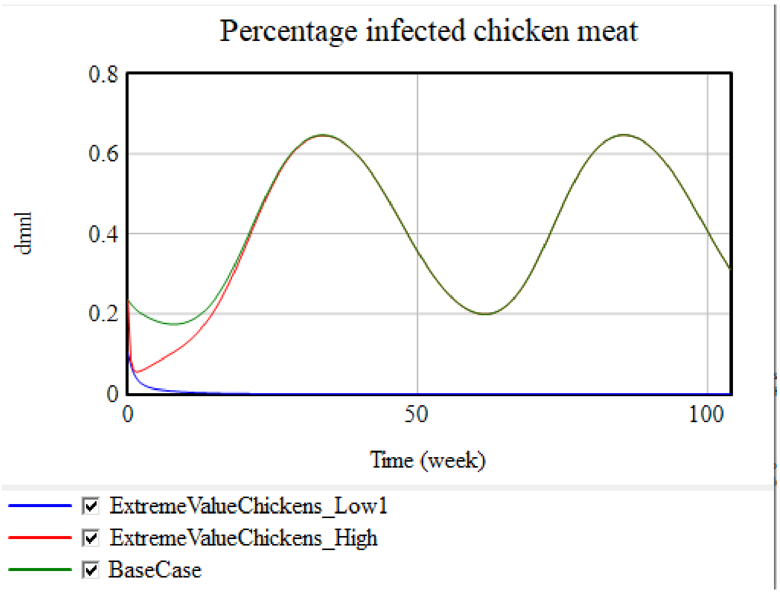


Figure 5.3: Result of percentage infected chicken meat of an extreme conditions test with increased chickens arriving from hatcheries as the extreme condition (red line), the base case result of percentage infected chicken meat (green line) and the decreased chickens arriving from hatcheries as another extreme condition (blue line)

5.5 Sensitivity Analysis

As the model is built based on various assumptions and relations, it is necessary to test how different values, which are used in different parameters or equations influence the outcome of the overall model and, hence, cover for the uncertainty inherent to these values. According to Sterman (2000), "*sensitivity analysis determines the effect of variations in assumed information on the model output. Also, it helps to develop intuition about model structure*". The sensitivity analysis can be used to see if the behaviour makes sense, and to investigate the uncertainties. In this section the focus lies more on investigating the uncertainties.

Sensitivity analysis is conducted for variables or concepts about which is uncertainty about specific values or on how relations are modelled. This helps to identify the parts for which it is essential to reduce that uncertainty further because it has a significant influence on the results. For this research, various input parameters and variables with some uncertainty were used. Therefore it is important to see the influence of these uncertainties on the model output. This was done using univariate testing. The value of one parameter is varied while maintaining the others constant. The first step is to identify the criteria on which the model results will be evaluated. A sensitivity analysis will be performed for both the main stock-flow model with the percentage of infected chicken meat as an outcome, as for the different submodel outcomes, which are the various infection probabilities. The following KPI's are chosen:

- percentage infected chicken meat
- probability of infection in the broiler house
- probability of infection after thinning
- probability of infection during transport
- probability of infection during the slaughter process

Sensitivity analyses are performed for the different probabilities by changes these outputs by +/- 10% seperately at a time. The result of changing these variables, is shown by the changing percentage of infected chicken meat. In this way, the most sensitive probability can be identified. Selecting it as the most sensitive probability, this infection probability has the most effect on the percentage infected chicken meat. In figure 5.5, the results of changing the various probabilities by + or - 10 per cent are plotted. This figure shows that the results are still close to each other. Nevertheless, when zooming in on a specific area, more difference is observed. This is shown in figure 5.6. This figure shows that the difference between the base case and line 1 and 4, which are the changed infection probabilities in broiler houses, is the greatest. This is followed by the infection probability after thinning. The infection probability during transport is not visible, because the impact is rarely significant. In figure 5.4 below an overview of the level of sensitivity is given.

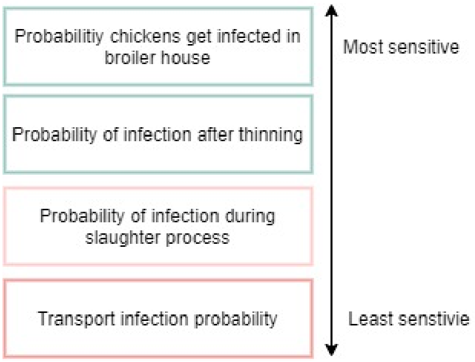


Figure 5.4: Summary of the sensitivity analyses results performed for the four infection probabilities (from most sensitive to least sensitive

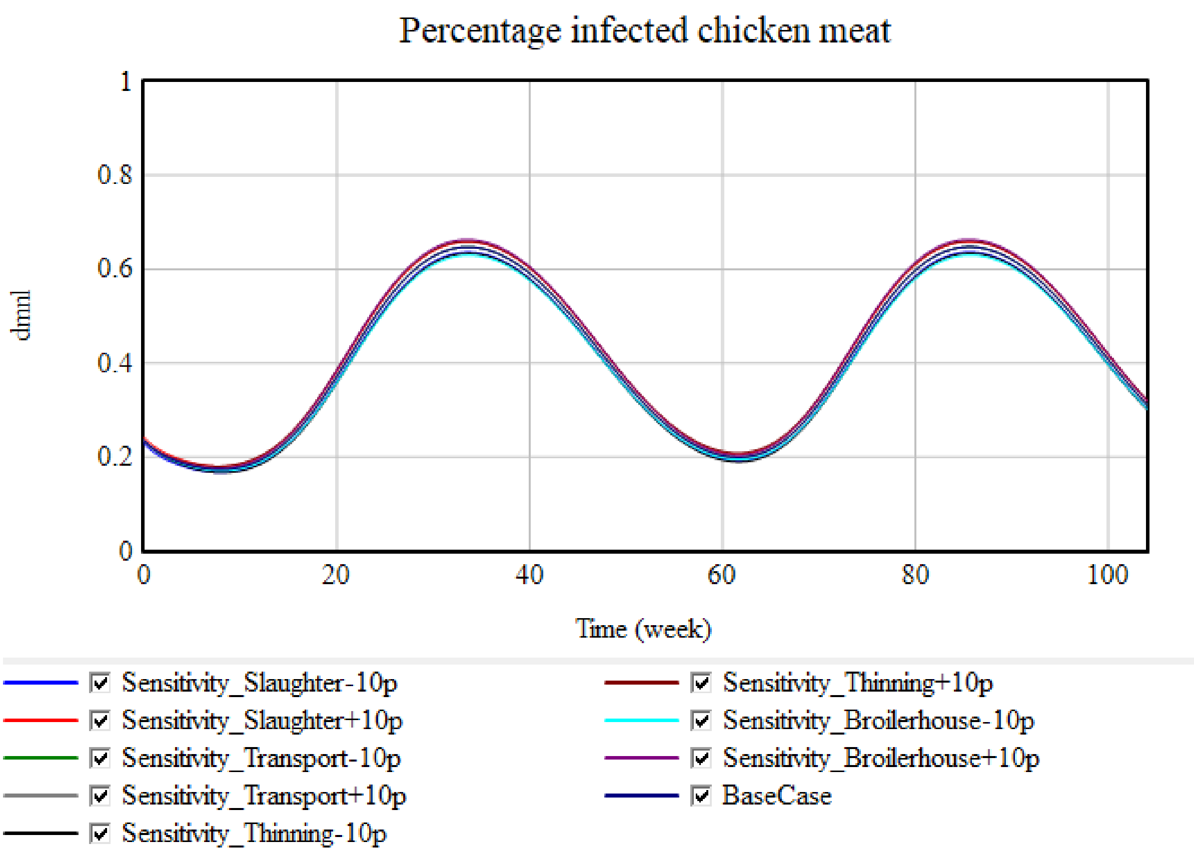


Figure 5.5: Overview of the base case graphs and the results of the sensitivity analyses performed for the four infection probabilities

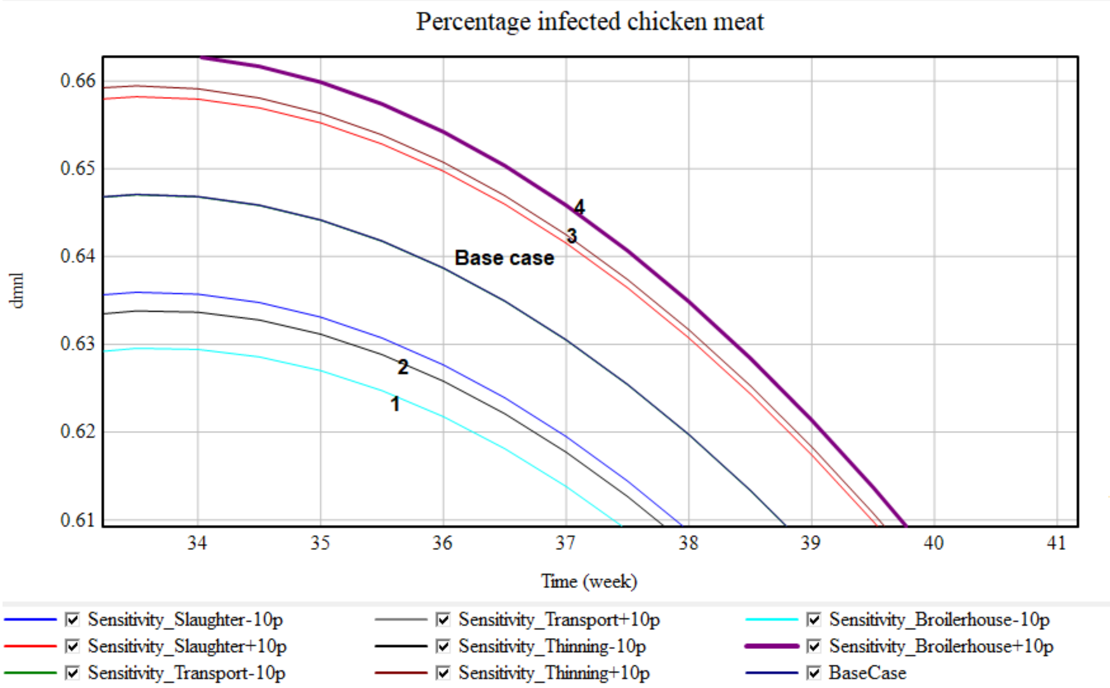


Figure 5.6: Zoom part of figure 5.5 (graphs 1 and 4 = probability of infection in broiler house, graphs 2 and 3 = probability of infection after thinning

From each submodel, different parameters are chosen to test their sensitivity. Some of these parameters can be influenced by actors in the system. Although another part of the parameters may also be uncertain parameters, which can not be influenced by actors or policies. Therefore, it is essential to recognize their level of sensitivity and their level of influence on the output of the system. In figure 5.7 an overview is shown of the different variables and parameters which will be used in the sensitivity analysis per KPI. In this research, the sensitivity analysis is committed by Vensim, by changing each exogenous model parameter by +/- 10% separately at a time.

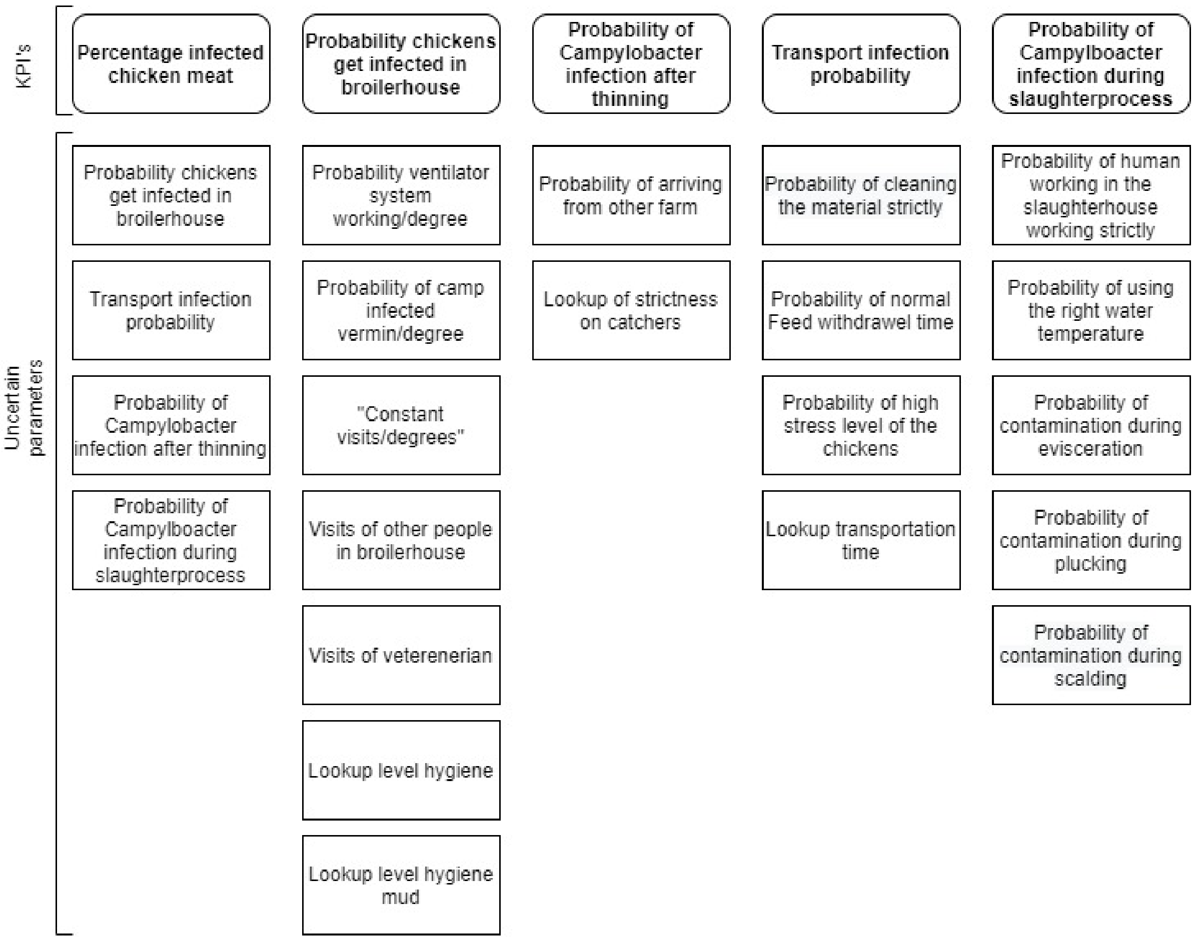


Figure 5.7: Overview of the structure of the sensitivity analyses (the four chosen KPI's and below these, the tested/changed uncertain parameters)

In appendix D, the impact of changing different parameters on the different infection probabilities is shown. For every infection probability, some specific parameters are more sensitive than others. The two figures below show the impact of the changed infection probability parameters on the *percentage infected chicken meat*. In this way, it is explained which infection probability is the most sensitive. As can be seen in figure 5.6, is the probability of infection in broiler houses the most sensitive parameter. However, it can be concluded that the impact of the different probabilities on the output of the KPI is not significant.

From the figures which are shown in the appendix, it became visible that some of the parameters were more sensitive than others. For the KPI *probability infection in broiler house*, the parameter *infected vermin on farm* was the most sensitive. This is an uncertain parameter, which will be used for the uncertainty analysis. The *strictness of the catch crew* showed another sensitive impact on the *probability infection after thinning*. This parameter is uncertain and can be used as a biosecurity measure in the experiments. The parameter *cleaning the transport strictly* can be used as another biosecurity measure which is also sensitive. As well as the parameters *People working precisely in the slaughterhouses* and *Water temperature*.

The *temperature* variable is a variable which influences the model output on different parts. A sensitivity analysis is performed on this variable to see if the effect of changing this variable by + and - 10 per cent on percentage infected chicken meat is significant. In figure 5.8 the graphs of this sensitivity analysis are shown. The graphs are behaving according to what is expected. When the temperature increases, the percentage infected chicken meat will increase. When the temperature decreases, the percentage infected chicken meat will decrease.

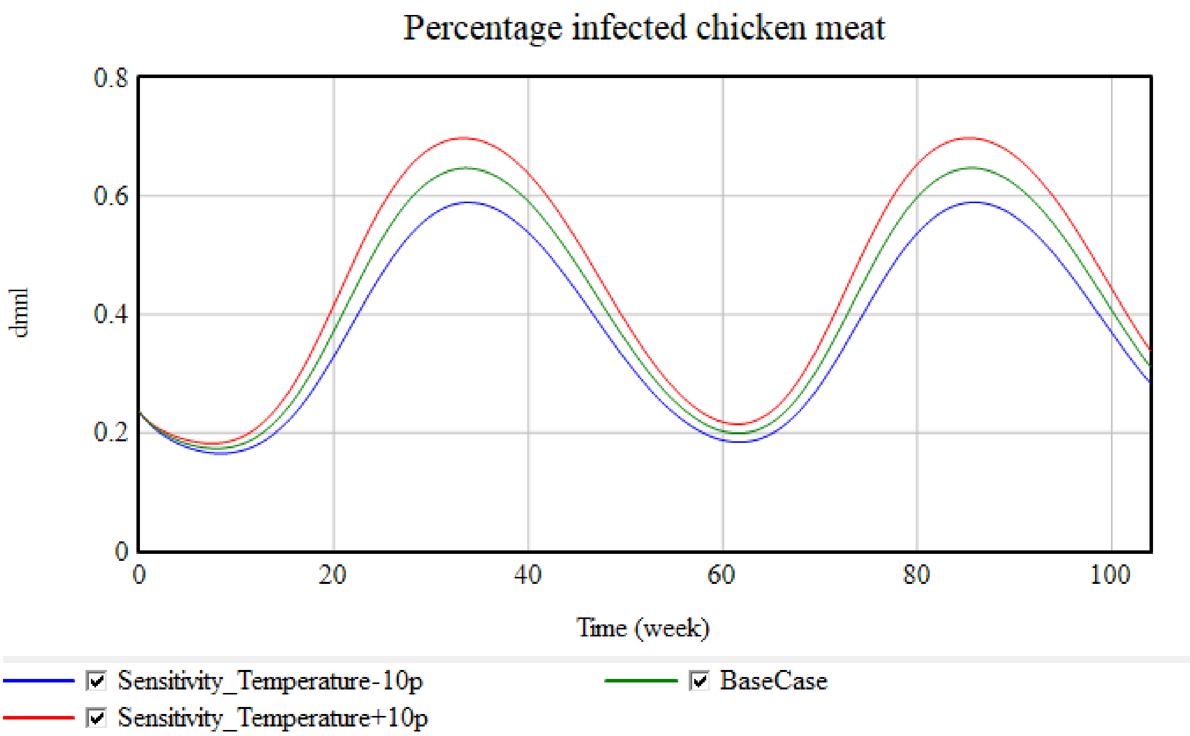


Figure 5.8: Overview of the base case and the sensitivity analyses output performed for the four infection probabilities

Overall, it can be concluded from the sensitivity analysis that the impact of the changed values on the outputs of the system are not very significant. Although, it is possible that uncertainties interact with each other, and therefore it is essential to run an uncertainty analysis to evaluate the policies that are recommended taking into account this issue.

5.6 Face Validation Test

The model structure should not contradict knowledge about the structure of the actual system (Senge and Forrester, 1980). The face validation test includes a review of model assumptions by persons highly knowledgeable about the design of the entire Campylobacter system. The model was discussed during the modelling process at different moments with Campylobacter Expert 1. This expert was part of the iterative modelling building process. This person pointed out the importance of the broiler house process and the actions of the farmers do. During the discussions, many uncertain parameters arose.

In the end, the model was discussed with two Campylobacter experts, both of whom are participants of the Campylobacter research group. During a skype session of one hour, the model, submodels, values and equations used, were explained to them. During the explanation, there was time to discuss the different assumptions. A summary of these face validation conversations is given in figure 5.9. Expert 1 was enthusiastic about the structure of the model and confirmed most of the used structures as valid. However, the expert noticed some structures or better said, parameters, which were missing in some of the submodels. According to the expert, it is important to include two extra probability parameters in the 4th submodel (slaughterhouse submodel). The first one is about adjusting the machines precisely, to ensure the intestinal package is carefully removed. This probability is already modelled in the probability of human working accurately. The second parameter is about cooling the carcasses. the expert explained that this is a new but still uncertain probability which can influence the amount of Campylobacter in chicken meat. In conclusion, the expert emphasized the human factor, which is visible in every sub-model. Expert 2 was specifically positively surprised by the separate submodel created to show the importance of the probability of getting infected after the thinning process. The expert emphasizes the importance of this process for the Campylobacter transmission problem. Moreover,the expert suggests logistical slaughtering as a new measure for the Campylobacter problem in slaughterhouses. This method implies that before slaughtering the positive chickens, the negative chickens should be slaughtered.

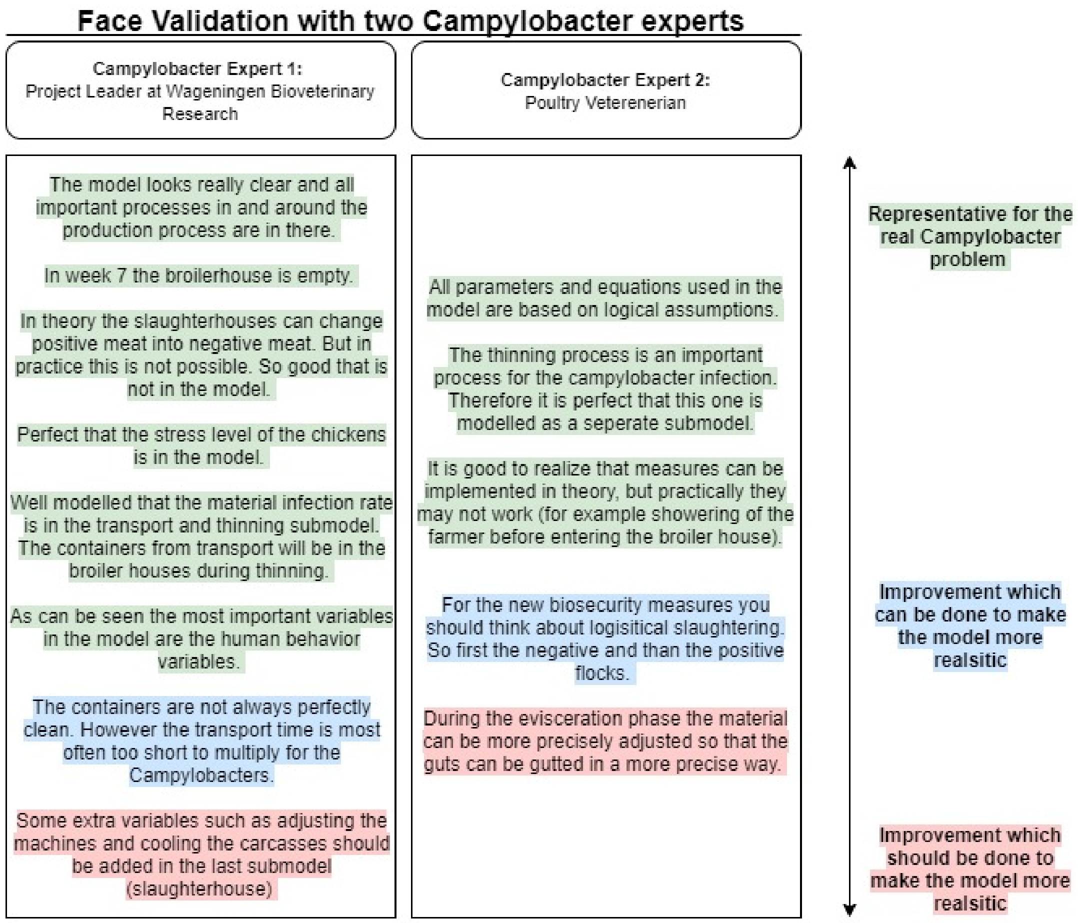


Figure 5.9: Face Validation with two Campylobacter experts

5.7 Historical data validation

In this last section, a comparison will be made between the output of the model and historical data which is received from Nepluvi (NEPLUVI, 2019). From the model, figure 5.10 is generated, which shows the percentage of infected chickens when arriving at the slaughterhouse. This figure is used to be compared with figure 5.11. Both similarities and differences can be identified. The behaviour of both graphs is similar, and both show a strong seasonality peak around summer. The model output curve is shifted a couple of weeks, in comparison to the historical data curve. The lowest value of both graphs is around 20 per cent. However, there is a difference between the higher values of both graphs. For the historical data is the highest percentage of infected chickens, around 70 per cent. In the output model curve, this is about 60 per cent.

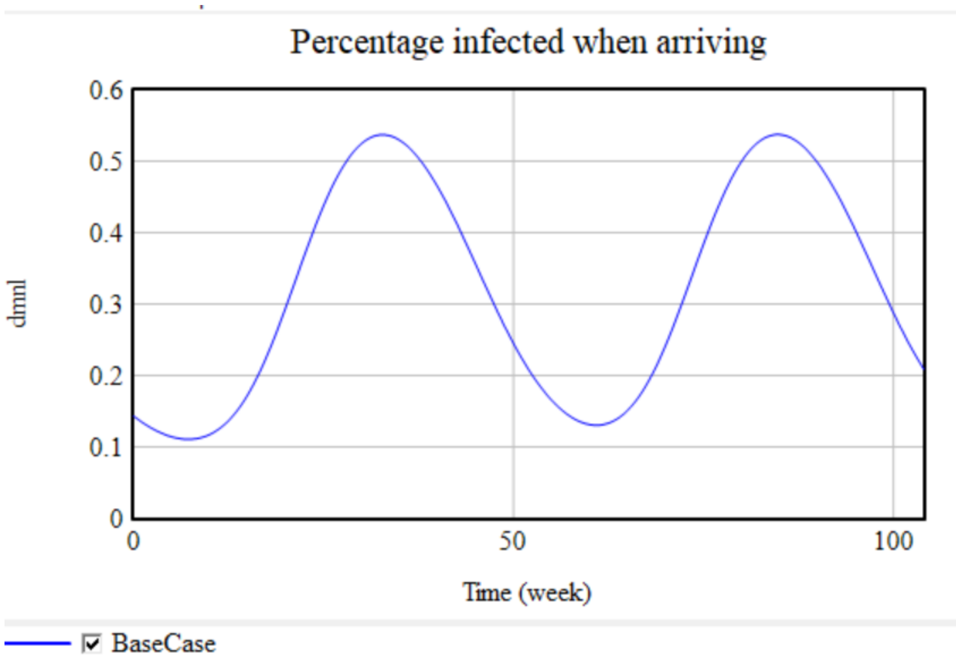


Figure 5.10: Output of the model: Percentage of arriving infected chickens in slaughter houses before entering the slaughter process

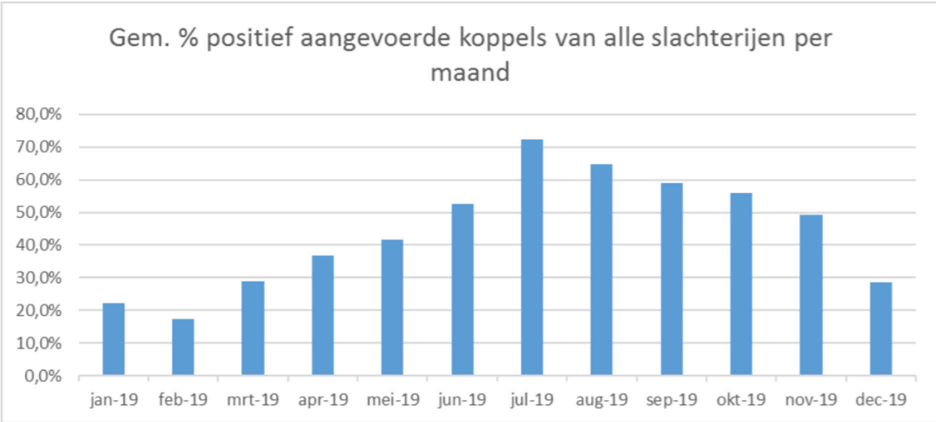


Figure 5.11: Historical data of 2019: Percentage of arriving infected chickens in slaughter houses before entering the slaughter process (NEPLUVI, 2019)

Figure 5.12 shows an overview of the flow of chickens per week getting infected after the thinning process. A study conducted by Allen et al. (2008) has provided more definitive evidence that flock thinning can cause Campylobacter infection. Twenty-seven of the 51 flocks, which were studied, became Campylobacter positive within a few days of thinning, and molecular typing of isolates was able to identify their likely sources (Allen et al., 2008). The figure 5.12 shows the number of chickens getting infected after the thinning process. From this graph, it can be concluded that this is a high number per week.

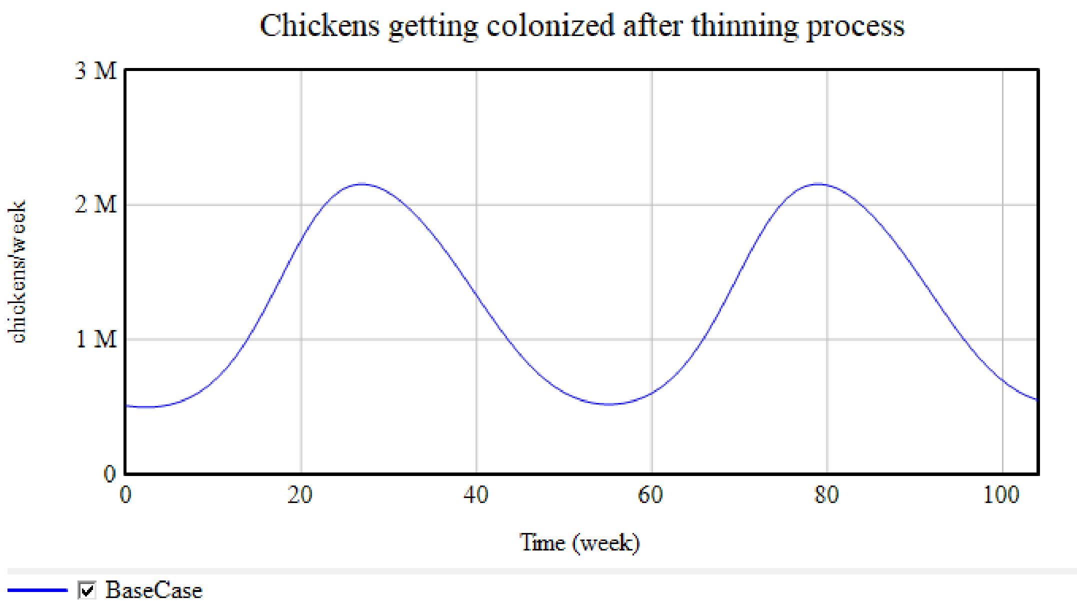


Figure 5.12: Chickens per week getting infected after the thinning process of the chicken meat production process

5.8 Summary

Further validation and verification tests are conducted. The face validation, which was done with two different Campylobacter experts, showed that the model structure was build in the right representative way. However, the values of the input parameters are very uncertain. The historical data validation demonstrated various similarities between the historical data and the data produced by the model. Nevertheless, the model graph showed a peak at a later time, than the historical data graph. The sensitivity analysis showed that the parameters for infection probabilities in broiler house and after thinning were the most sensitive. In the following section, the focus will be on implementing policy measures for reducing these two infection probabilities.

6

The effects of biosecurity measures

This chapter presents how the model is used for implementing different biosecurity measures in different uncertain scenario's. This chapter starts with identifying the most relevant biosecurity measures and policies from the literature and the interviews. This is followed by the experimental design to analyze the implementation of different policies and standards. The results will be presented first in the base case and then applied for the uncertainty analysis.

The most Campylobacter infections are occurring during the on-farm phase. The infection probabilities in broiler houses and after thinning are affecting the percentage infected chicken meat the most. Therefore the policy measures will be focused on this Campylobacter transmission part of the model. So this means the focus of the policy and biosecurity measures part will be on the on-farm part of the model.

6.1 Identification of possible policies

Intervention at the first part of the chicken meat production process to reduce Campylobacteris is preferable. The chicken intestinal tract is the only place where Campylobacters can multiply in the production process. Various intervention methods have been studied, such as vaccination, pro- and prebiotics, competitive exclusion, phage therapy, and feed and water additives, but none of them is effective on reducing Campylobacter on farm level (Rasschaert et al., 2020). According to the Ministry of Agriculture [Interview B.2.3], the problem is difficult to control, but overall is told that hygiene in the farm phase is essential for the prevention of Campylobacter bacteria. In general, the assumption is made that the better the health biosecurity and hygiene are in farmhouses and slaughterhouses, the fewer Campylobacter bacteria will infect the chickens. But as he said: "frankly speaking, it is questionable whether slaughterhouses and farmers live up to their standards in daily practice" [Interview B.2.3]. The ministry of Health, Welfare and Sports confirms that farmers who nowadays produce Campylobacter negative chickens, appear to take care of their biosecurity measures [Interview B.2.4].

Different strategies and monitoring programs in the primary poultry production chain have been established (Skarp et al., 2016). It is important to improve the hygiene barriers and to have restricted access to prevent Campylobacter transfer from the outside environment into broiler houses (Ridley et al., 2011). Therefore the human factor is of significant importance in the hygiene problem. Farmer 2 explains that he is strict on other people entering the farmhouses, and to see if they follow his hygiene protocol. He admits that he thinks the farmers should have a look in the mirror and ask themselves if they "Always" mind their protocol...[Interview B.2.6]. According to both ministries, it is important to educate farmers to be more aware of improving management and biosecurity procedures.

Besides improving the hygiene barriers and restrict access, abandoning the thinning process during the rearing period, could be a measure to reduce the number of Campylobacter infections in broiler houses (Ridley et al., 2011). Various farmers, such as farmer 1 [Interview B.2.5], mentions the infection probability of the remaining chickens after the thinning of the flock. Further studies confirm that people, vehicles and equipment entering the broiler house for flock thinning purposes are frequently contaminated with Campylobacter and are a high risk of infection of the remaining chickens in the broiler house (Ridley et al., 2011). As farmer 1 [Interview B.2.5] claims, the poultry catch group always have to wear clothing and shoes provided by himself. When they enter different broiler houses, they do not change boots, because then you would need 100 different boots. Besides, the equipment, like the truck, they use also will be transported from one broiler house to another broiler house, without being cleaned. He agrees that he does think it is weird to follow your protocol so not, but according to him, there is no better option. He is wondering, why not testing the chickens on Campylobacter before starting the thinning process? So then you know which flocks should be caught first [Interview B.2.5].

To conclude increased biosecurity to reduce Campylobacter contamination in the broiler houses and the abandoning or changing of the thinning process should be taken into account in the policy testing.

6.2 Experimental Design

The experimental design helps to understand in what way the experiments were set for the results generation of this research. Therefore figure 6.1 shows the flow of the results generating process. The input will consist of uncertain parameters, certain parameters and policy parameters. The values of all three are based on information from interviews with stakeholders and news obtained from the literature. The middlebox of the figure shows the model itself, in which the results are generated. The output or the results of the model are the percentages of infected chicken meat over time. For the uncertain parameters, different values are used because the current values are uncertain. For the policy parameters, other values are used based on the policies.

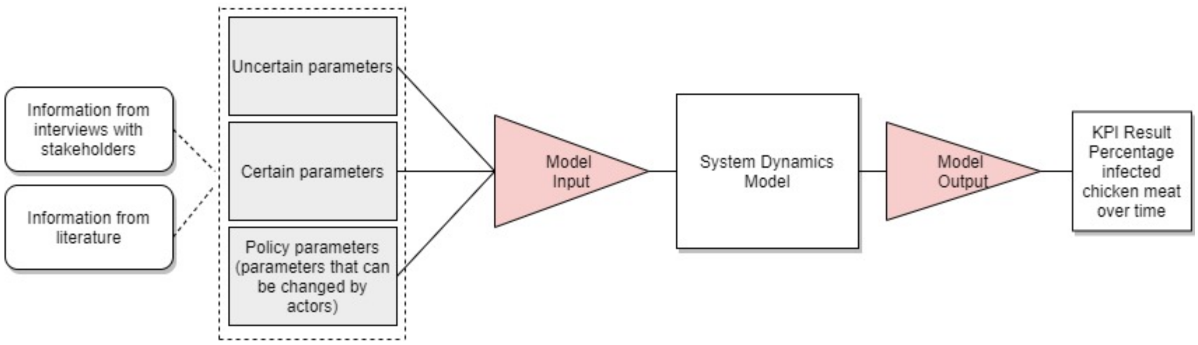


Figure 6.1: Experimental design

6.2.1 *KPI's*

The main KPI is the percentage of infected chicken meat. Two other KPI's which will be used in the experiments are *Chickens getting infected in broiler house* and *Chickens getting infected after thinning process*. These two KPI's are relevant to the policies that are chosen.

6.2.2 *Uncertainties*

The Campylobacter transmission problem is an uncertain issue, in which uncertainty refers to the lack of knowledge about past, present, and future (Pruyt and Kwakkel, 2014). It is essential to realize that many different sources and types of uncertainties exist. Multiple uncertainties inherent to the model are tested using sensitivity analysis and studying the current model structure. The uncertainties can be either structural or parametric (Kwakkel et al., 2010). In this research, parameter uncertainty is relevant because various parameters have uncertain values. To account for the parameter uncertainty inherent to the model, sensitivity analysis is used for assumptions. The different uncertain parameters are shown in the table below. An uncertainty analysis will be conducted for these parameters, because their values is based on assumptions. These assumptions are based on what came up in the interviews. However, from the interviews, different relations between factors became clear, but the values of parameters are unknown.

Table 6.1: Lower and higher value for various uncertain parameters

Uncertain parameters	*Current value*	*Lower value*	*Higher value*
Probability ventilator system working/degree	0,042	0,030	0,050
Probability of camp infected vermin/degree	0,030	0,020	0,040
Constant of dmnl/visits	-0,029	-0,050	-0,010
Probability of arriving from other farm	0,800	0,400	1,000
Probability of high stress level of chickens	0,300	0,100	0,900
Probability of normal feed withdrawel time	0,2	0,000	0,900
Probability of contamination during plucking	0,05000	0,04000	0,06000
Probability of contamination during evisceration	-0,04375	-0,06000	-0,03000
Probability of contamination during scalding	0,01900	0,01000	0,03000

For each of these uncertain parameters, a sensitivity analysis is conducted. These graphs obtained from these analyses are shown in the appendix. Based on these graphs, it can be concluded which uncertainties have the most impact on the final KPI *the percentage infected chicken meat*. These uncertain parameters are used for policy analysis. These parameters are the following:

- Probability of Campylobacter infected vermin/degree; This parameter gives the probability of Campylobacter infected vermin per degree on a farm. This parameter is used to estimate the probability of intected vermin on a farm, which is related to the temperature. When the temperature increases, more vermin will be on the farm.
- Probability humans following the hygiene protocol/visit; This parameter gives the probability of humans following the hygiene protocol per visit. This constant is used to estimate the probability that a person follows the protocol based on the number of visits.
- Probability of a high-stress level of the chickens: this parameter shows the probability of chickens having a high-stress level.

The Probability of Campylobacter infected vermin per degree is a parameter which is based on assumptions. It is uncertain what the exact increase is in vermin per degree that it is getting warmer or colder outside. However, it is true that when the temperature increases, the vermin increases. The Constant of dmnl/visits is a constant which is created to show the Probability that people follow the hygiene protocol, based on the number of visits in the broiler house. This linear dependency is based on information obtained from interviews, which showed that when a farmer or visitor has to enter the broiler house very often, he or she forgets about the hygiene protocols. The last uncertain parameter is the stress level of chickens. This parameter is the most uncertain one since chickens can not be asked how stressed they are and how this influences the infection rate.

6.2.3 *Policies*

The different policies that will be tested are based on the processes happening in the broiler house and during the thinning process. In the table below an overview of the chosen policies is shown.

Table 6.2: Overview of policy names, changed values and explanations

Policy Name	*Values changed in the model*	*Explanation of the policy*
No visitors allowed	Visits of veterenerian = 0 Visits of other people = 0	In the policy measure 'No visitors allowed', are no people except the farmer him/her self allowed in the broiler house. Therefore in the model the values of "visits of veterenerian" and "visits of other people' will be changed to zero.
A closed broiler house	Visits of veterenerian = 0 Visits of other people = 0 Visits of the farmer = 0	The policy measure "A closed broiler house" is similar to the measure of no visitors allowed. The only difference is the visits of the farmer which will be in this measure set to zero. In the current situation this value is based on temperature.
Think about on farm hygiene	Level of hygiene = 4	The third policy is called "imporving the on farm hygiene". This policy will take into account the level of hygiene on the farm.
Strict catching	Strictness of catcher on hygiene protocol = 4	The "strict catching" policy means improving the thinning process. Catchers should take more responsibility and be aware of the hygiene level during the thinning process.
Bye thinning	Probability of Campylobacter infection after thinning = 0	The last policy is called "Bye thinning". In this policy scenario the thinning process will be deleted.

From the table, it is clear what the changed values are and what the policies mean. The policies are based on the parameters from the first and second submodel. From the sensitivity analysis was concluded that the thinning infection probability and the broiler house infection probability were the most sensitive and had the most impact on the final percentage of infected chicken meat in the Netherlands.

The first policy is called "No Visitors Allowed", which means no random visitors except the farmer him/her self are allowed to enter the broiler house. By reducing the total amount of visitors will decrease the infection probability in broiler houses. The second policy, called "A closed broiler house" was initially meant to allow nobody entering the broiler house. However, taking into account the interviews with various farmers, this would not be a realistic option. Therefore the farmer visits are reduced by half. The last broiler house-policy-measure is called "Think about on-farm hygiene". The level of hygiene could be changed in the model (it is a lookup function). The level of hygiene is changed to the highest level in this policy.

Two other policies were created more focusing on the thinning process of the chicken meat production process. The first one is called "Strict catching", which means that the strictness of the catchers on the hygiene protocol is set to the highest level. The second one is called "Bye thinning". The name already tells what it means: No more thinning process during the chicken meat production process.

6.3 Results

In the following section first the base case results are illustrated, followed by the uncertainty analysis results.

6.3.1 *Base case results*

In the following figures, the graphs of the results of the implementation of different policy measures in the base case illustrated over time. All base case graphs show similar behavior with similar seasonality peaks. Figure 6.2 shows the implementation of three different "broiler house" policy measures on the base case. The grey line shows the base case graph in which no policies are implemented. As can be seen are all policies effective, as they are all showing a lower line than the base case line. However, the green line which shows the policy "No visitors allowed" does not show a significant impact. Nevertheless, the other two policies do show a significant change in the percentage of infected chicken meat. The hygiene on farm policy shows a change in percentage of about 15 per cent.

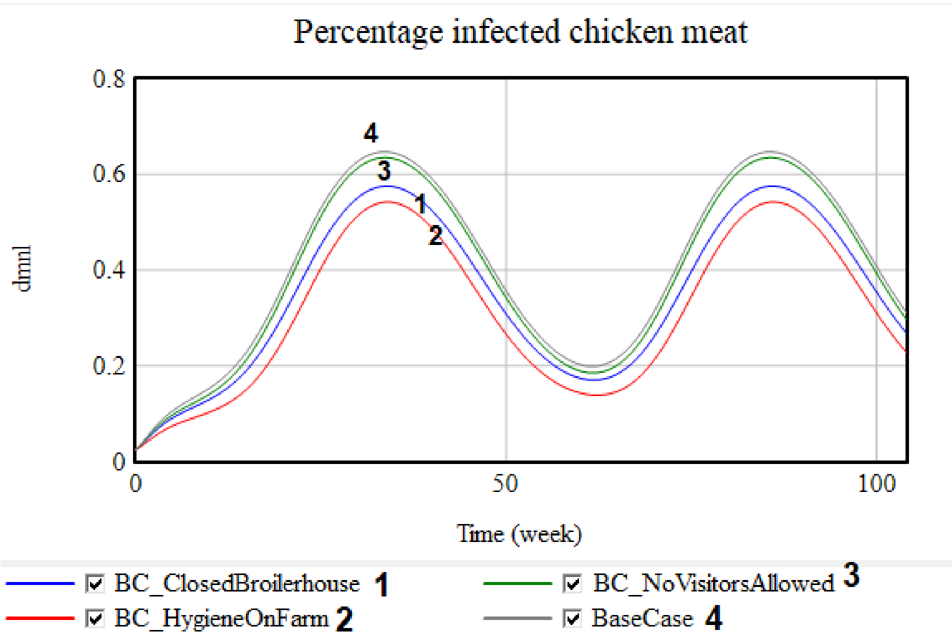


Figure 6.2: Percentage infected chicken meat when various broiler house policies are implemented on the base case

Figure 6.3 illustrates the impacts of different thinning policies on the base case situation. The effect of the "strictness of the catchers" policy is minimal. The lines are closely behaving precisely in the same way on the same level. Nevertheless, the "Bye thinning" policy shows a significant impact on the percentage of infected chicken meat over time. This impact is around 20 per cent.

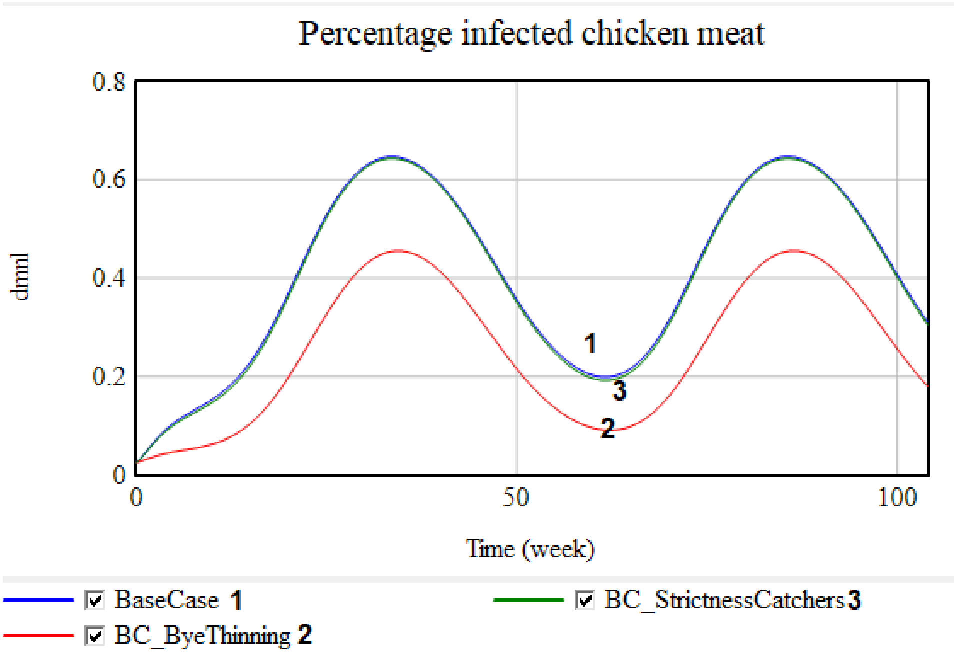
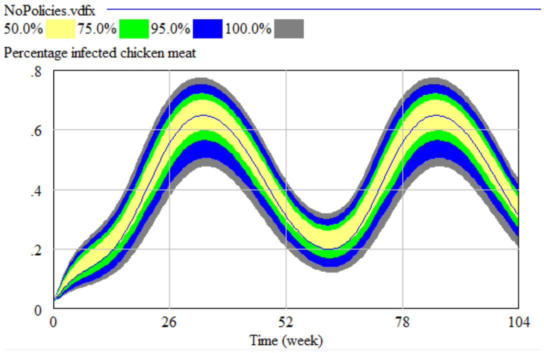


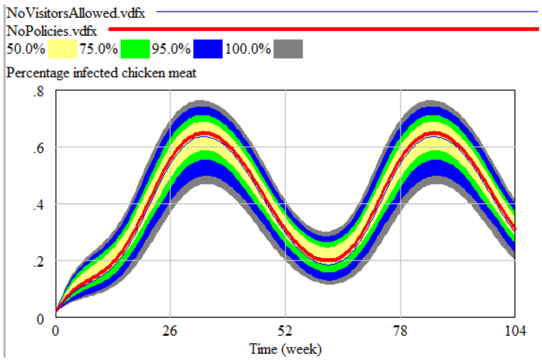
Figure 6.3: Percentage infected chicken meat when various thinning policies are implemented on the base case

6.3.2 *Uncertainty Analysis results*

In the following figures the results are shown of the behavior of implemented different policies in uncertainty analyses. The first figure shows the uncertainty analysis of the base case in which no policies are implemented. As can be seen (also in the other figures), is the behavior of the graph valid. However, the uncertainty outcome range is in the top of the graphs between almost 0.8 and 0.5. For all other graphs, except for the "Bye thinning policy" graph, can be concluded that the output of the sensitivity analysis of the implemented policy, overlaps with the "no policies implemented graph". The last graph shows the graph in which the "By thinning" policy is implemented. The higher and lower level of the sensitivity graphs are closer to each other than in the other graphs. Also, the sensitivity graph does not overlap with the no policies graph.

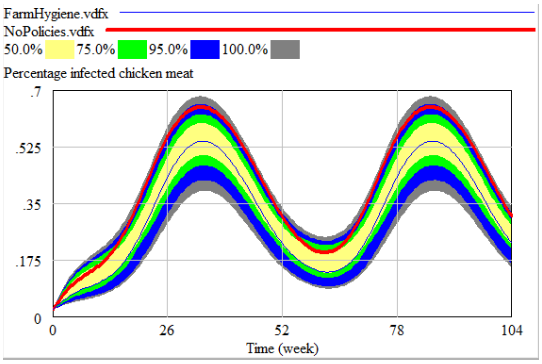


(a) No policies are implemented

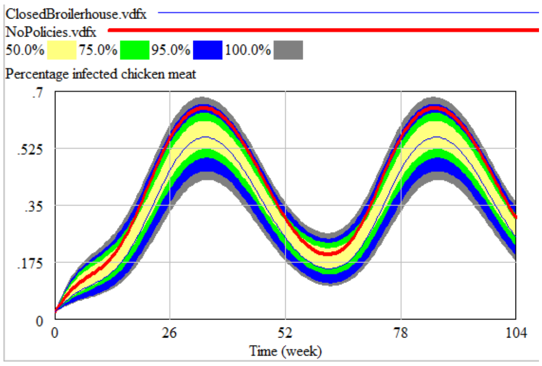


(b) No Visitors allowed

Figure 6.4: Sensitivity analysis of different implemented policy measures [No policies, No visitors allowed]

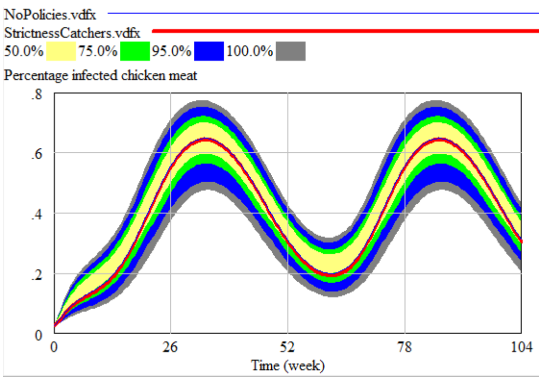


(a) Farm Hygiene

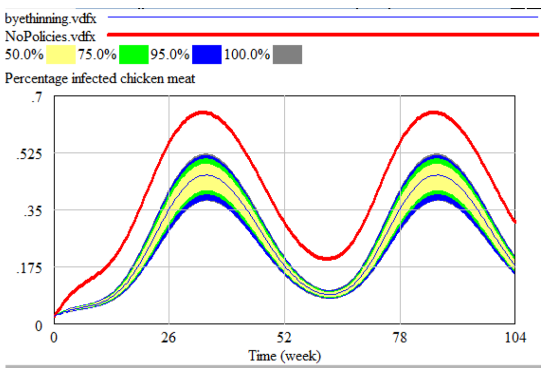


(b) Closed broiler house

Figure 6.5: Sensitivity analysis of different implemented policy measures [Strict farm hygiene, Closed broiler house]



(a) Strictness Catchers



(b) Bye Thinning

Figure 6.6: Sensitivity analysis of different implemented policy measures [Strict catchers, Bye thinning]

6.4 Analysis of the results

Based on the outcome of the base case results and the uncertainty analysis results, this section will give an analysis and reflection on these results. Some general observations which count for all policies are the fact that they all have a positive impact on the percentage of infected chicken meat. The positive impact means a reduction in the number of infected chicken meat. Also, all graphs have similar behaviour, and all showed clear seasonality peaks around august. These seasonality peaks are the result of an increase in insects and vermin combined with working ventilator systems and more visits of the farmer.

It could be seen as striking, but also as evident and logical that the policy "Bye thinning" shows the biggest significant impact on the percentage of infected chicken meat. The thinning infection probability is relatively high, and therefore, it is logical that the effect is significant when this process will be left out. The infection probability after thinning is based on the sum of the *catchers infection probability* and *material infection probability*, which let the probability increase. Also, in the thinning submodel is the broiler infection probability modelled. When this infection probability, increases, the thinning probability will as well. During the thinning process, the hygiene protocol is not well considered. Therefore the policy "Strictness catchers" was also implemented as a policy. However, as can be seen in figure 6.3, the impact of implementing this policy by changing the *strictness of the catchers*, was not significant. In the model, the *probability of following the hygiene protocol of the catchers* is also dependent on the general *likelihood of humans following the protocol*. This probability is based on the number of visits in the broiler house, which is based on visits of the veterinarian, visitors and the farmer him or herself. Therefore only changing the catchers strictness does not give a significant effect on the percentage infected chicken meat.

A higher strictness of the visitors is another implemented policy which does show a significant impact on the percentage of infected chicken meat over time. This strictness probability does not only affect the infection probability in broiler houses but also affects the infection probability after thinning. In the thinning submodel the variable *probability humans following the hygiene protocol* is used which is estimated in the broiler house submodel. The interviews with farmers and the catch crew showed that the catch crew most of the time follows the protocol of the farmer. Hence, the strictness of the catch crew depends on the way the farmers adhere to their protocols.

Another policy measure which shows a reduction of around 10 per cent, is the "Closed broiler house" policy. This policy measure overlaps with the "No visitors allowed" policy. Both policies tell that no external visitors as friends or veterinarians are allowed to enter the broiler house. The closed broiler house policy has an extra dimension which also says that the farmers may visit the broiler house half the number of visits they do know. These policy measures show an impact, but the implementation of these policies will be hard. For farmers and veterinarians, it is crucial to see the behaviour of the chickens to recognize how they are feeling. The impact of adding the reduction of the visits of the farmer by half, shows a big difference in impact on the percentage infected chicken meat. Limiting the visits of external people to zero, is only reducing the total visits by a limited bit. While limiting this external people to zero and reducing the farmer visits by half, does reduce the total visits a lot, because normally the farmer will visit the broiler house a few times per day.

6.5 Summary

The focus of the implementation of policy measures is on the on-farm part of the model. The results show one best policy measure, which helps to reduce the percentage of infected chicken meat significantly. This policy measure is the removal of the thinning process in the chicken meat production chain. By implementing this measure, a reduction of about 20 per cent infected chicken meat is visible. However, the uncertainty analysis shows that the exact decrease is not possible to tell. Two other policies which offer a significant effect are stricter farm hygiene and limiting the number of visits entering the broiler house. In chapter 7 policy recommendations are given, which are based on the results.

7

Conclusion

The conclusion chapter is divided into different parts. The first section will highlight the most important conclusions and answer the main research question. The second part will reflect on the scientific and societal relevance of the research. The final part gives recommendations for policies.

7.1 Answering the research questions

The most relevant way to reduce the number of humans that get infected with Campylobacter is by minimizing the number of chicken flocks that are infected with Campylobacter. Different moments within the chicken meat production process can be distinguished in which Campylobacter can infect chickens. These moments are during the time that the chickens are in the broiler houses, after the thinning process, on transport, and in the slaughterhouses. Nevertheless, the farm is the preliminary site of Campylobacter entering the chicken chain production process and therefore this is the focus of this research.

Especially from April to October when insects are in season, they form a threat to infections. Flies can enter broiler houses through the ventilation systems or valves. The ventilation systems will be working more often in summer- than in wintertime. This suggests that flies may be an important vector in summer. Besides flies, also other insects will transmit Campylobacter into the broiler houses. Insects such as beetles are often found in the broiler houses.

Campylobacter often occurs in wild animals, therefore also the vermin living around the farm often host Campylobacters. The defecation of the vermin contains Campylobacters and this can be transmitted by humans and insects into the broiler houses. Campylobacter infections by insects can either happen when flies enter the broiler houses through ventilation systems or the valves, or when humans enter the broiler houses and carry insects with them on their shoe soles.

Human traffic exists of farm staff, but also the broiler houses are regularly visited by several other visitors, such as the veterinarian and the catch crew. Especially after the fifth week, when the thinning process takes place and the catch crew visits the broiler houses, there is a lot of human traffic in and out of the broiler houses. Because visitors can carry Campylobacters with them while entering the broiler houses, the number of visits is related to Campylobacter infection risk.

A peak by the number of chicken flocks infected with Campylobacter can be found from April to October when the temperature in the Netherlands is higher. The reason for this, is that in summer the number of insects increases. Apart for the risk of infection going up because the number of insects is higher in summer, this effect is strengthened by that the ventilation systems will be operational more often in summer- than in wintertime. In this research, a system dynamics model was developed to get more insight into the effects of implementing different biosecurity measures to reduce the introduction of Campylobacter in the chicken meat production process. The objective of this research was to answer the following main research question:

What are the effects of biosecurity measures that can be introduced to reduce the introduction of Campylobacter in chicken meat in the Netherlands?

It is important to minimize contamination of chicken rearing houses from the different sources mentioned earlier. The major intervention should strategies be targeted at farm level. Biosecurity measures should be improved, which prevent Campylobacter transfer from the outside environment entering the various broiler houses. Based on the model, various biosecurity measures showed an effect on the percentage of infected chicken meat over time. The effect of the following measures was the most significant:

- Removal of the thinning process: Removal of the thinning process shows in the model the most significant effect on the percentage of infected chicken meat over time. This could lead to a reduction of about 20 per cent of Campylobacter infected chickens over time.
- Minimizing the number of visitors: No other visitors except for the farmer him/her self will be allowed to enter the broiler houses. Also, the visits of the farmer should be halved. Based on the model could be concluded that, when this measure is implemented, the percentage of Campylobacter infected chickens decreases. The seasonality peak is still visible in summer.
- Stricter following the protocols: Existing biosecurity protocols are generally perceived to be adequate, but the consistency with which they are applied by the farmers and visitors can be variable. For example, routine procedures such as the effective use of hygiene barriers, hand washing, and boot disinfection can easily be performed under normal conditions. For this measure, it is important to warn all other visitors, such as the catch crew. When the protocol is followed more strictly, on the basis of the model outcomes, the percentage of infected chicken meat will decrease.

7.2 Scientific Relevance

This section reflects on the scientific relevance of the research. By means of a literature study, different knowledge gaps were identified that generally identified knowledge was missing about the transmission routes and the survival of Campylobacter in and around the chicken meat production process. In addition, various studies focused on one specific part of the chain but did not present an overview the entire production process. Furthermore, existing research on the Campylobacter problem was mostly qualitative research and did not include dynamics over time. In this research, a multi-actor qualitative approach is combined with a quantitative approach to turn information into data. Therefore, System dynamics is useful in quantifying this problem by identifying trends of the amount of infected chicken meat over time. The system dynamics model developed in this research shows the infection moments of the chickens during the different steps of the production process. To get a deeper understanding of the various infection moments, submodels of these moments are developed. The parameters used in the models are based on qualitative data which was obtained through interviews with people in the field and policymakers. Due to the time restrictions and incomplete knowledge, some of the values used for the parameters are uncertain. This research provides the first building blocks of quantitative research of Campylobacter in chickens, future can continue expanding the model. Despite the model does not accurately represent the actual situation yet, the model helps to understand the entrance of Campylobacter on moments of the chicken meat production process. Different analyses were performed using the model, and with this, it was possible to point out which moments are the most significant for the entrance of Campylobacter. In addition, the implementation of different biosecurity measures was introduced in the system dynamics model and tested. Herewith, the effectivity of the various biosecurity measures could be tested.

7.3 Societal Relevance

Infectious diseases are one of the most significant global challenges in the health world nowadays. One of these infectious diseases is Campylobacteriosis, which is caused by bacteria called Campylobacter. In the Netherlands, it is estimated that Campylobacter species infections represent at least one-third of the disease burden of all intestinal infections. Campylobacter infected chicken meat causes the most significant part of these infections. Reducing this amount of campylobacteriosis cases in the Netherlands would be a major societal contribution to human health. Nevertheless, research on the structure of the chicken meat production process is necessary. The model, developed for this research, indicates the different times of Campylobacter bacteria entering the chicken meat production process. Even more important is the method "Semi-structured interviewing", which is used to develop this model. Using this interviewing method, the opinions and ideas of different actors could be taken into account. In this way, a realistic overview of the activities and behaviour of the different actors in the system can be illustrated. The model helps to identify which moments of Campylobacter infection are the most sensitive and crucial. By implementing the proposed biosecurity measures on the different parts of the process the amount of infected chicken meat can be reduced.

7.4 Recommendations for policies

From the different analyses can be concluded that the policy implementations should be done on the farm level. A first recommendation based on the results of the model, is the removal or changing of the thinning process. The impact on the percentage of infected chicken meat of removing the thinning process is significant, and therefore this policy recommendation can be crucial for the reduction. The thinning is considered as a financial necessity, which can make it hard to implement this policy. However, implementing this policy will not only reduce the Campylobacter problem, but it may also increase the welfare of the chickens. Chickens may experience stress during the thinning process, and this will not be there anymore. Nevertheless, this policy implementation will result in a lower final number of chickens per broiler house, and there with the profit of the farmers will go down. Since this is not attractive for the farmers, compensation or subsidy from the government is needed to stimulate farmers to bring down the number of chickens per broiler house.

A second recommendation based on the analysis of the results is to take care of a higher hygiene level on farms and therefore farmers should be stricter on the visitors, but maybe more critical on their selves. Maintaining such control measures on the farm can be difficult, and it should be reinforced with farmworker education and incentives. Next to that, the farmer should be strict in who is allowed to enter the broiler house. Limiting the number of visits helps to reduce Campylobacter infections. However, some visitors, such as the veterinarian or the catch crew, cannot be avoided. In addition to the hygiene protocols, it is highly crucial that the farmer ensures a clean farm at all times. A clean farm may not have mud or water on the way to the broiler house and no vermin on the farm side. However, it can be not easy to ensure this, because also external factors such as the amount of rainfall and vermin in the surrounding area affect the cleanliness of a farm.

To implement these more so-called "practical" recommendations, various policy recommendations are essential to take into account such as "communicate with each other". Farmers are in this current situation, not aware of the importance of reducing the Campylobacters in chicken meat. Information coming from slaughterhouses about the level of Campylobacter in their chicken meat is essential to raise awareness for the Campylobacter problem. Besides, information about hygiene protocols should be shared between farmers. In this way, they could learn from each other and also see what works best for them. The catching crew should also be informed about the Campylobacter problem and be communicated why it is essential that they adhere to the hygiene protocols of the farmers. Currently, the communication is one-way, namely from farmer to catch crew. In the future, the communication should be bidirectional, since the catching crew could also help the farmer in bringing down the infection risk of Campylobacter. For example, they can tell or remind the farmer they only proceed if they all receive different overalls and footwear.

In conclusion, raising awareness among the different involved actors is essential. All other actors should feel responsible, and only in this way, the number of Campylobacter chickens can be reduced. Policies can help by raising this awareness by setting stricter protocols, monitoring the different processes of the production chain, and offering high-quality information to all other actors. Nevertheless, it should not be forgotten that what is said in theory, is not always applicable in practice. This sentence should be in the minds of all policymakers in this system. Analysing the results, a policy measure such as reducing the number of visits entering the broiler house could be introduced. Or, a policy which implements new hygiene rules such as showering before entering the broiler house. Before entering such policies, first research must be done if these policies work in practice. When introducing a new policy, it is essential to involve everyone in the process. In this way, the practical insights will become visible before the policy is implemented. In this problem, it is from immense importance to always involve the farmers and slaughterhouses when introducing a policy.

8 Discussion and Recommendations

This chapter reflects on the research and gives recommendations for future research, which are based on the limitations.

8.1 Limitations of the research

Limitations help to identify the recommendations for further research, which are revealed in section 8.3. Several assumptions or boundaries used in this research lead to limitations of the study. The assumptions, boundaries and limitations, are discussed in this section to get a critical overview.

In the Netherlands, it is estimated that Campylobacter infections represent at least one-third of all intestinal infections. In this model the choice has been made to focus on the Netherlands and not include other countries in this research. However, a lot of chicken meat is imported and exported to other countries. Since the final objective is to reduce the number of human Campylobacter infections in the Netherlands, it is necessary to have an overview of the infected chickens in other countries that are exported to the Netherlands. Also, it can provide insights into their way of working during the chicken meat production process.

For this research, the assumption is made to only focus on conventional chicken farms due to time limitations. The model which is developed is based on the processes of the conventional chicken meat production process. Alas, no comparison between different concept chickens can be yet made. The process of the free-range chickens is similar for conventional chickens, only the age of the chickens and the thinning process differs.

The most important limitation of this research is the number of parameters that are based on qualitative information. Based on the interviews with different actors from the field and policymakers, assumptions are made for the values of various model parameters. These uncertain parameters lead to uncertain result for the percentage of infected chicken meat. Nevertheless, this will not change the overall behaviour of the graphs over time, which is more critical in this phase of research. Also, when comparing the model with the Norovirus model, built by David Lane, it can be concluded that the uncertain parameters do not form a big problem.

An important assumption which should not be forgotten is the infections between chickens living in one broiler house. In this research, the assumption (based on literature and interviews) is made that when one chicken is infected, the whole broiler house will be infected. In the model and in this research is talked about chickens and not about broiler houses, in doing so, the infection probability of transport and in slaughterhouses can be modelled. These infection rates are for the individual chickens not seen as a flock. At the same time, the infection probabilities in the broiler house and after thinning are in this research seen as a probability for the total flock getting infected.

For this research, the assumption is made that a chicken is either positive or negative. In reality, when a flock of chickens is contaminated with less than 1000 cfu/g, the flock will be called Campylobacter negative. When a flock is infected with more than 1000 cfu/g, the flock is called Campylobacter positive. In this research, more in-depth details about this numbers are not given, and the specific amount of Campylobacter per gram chicken meat is not estimated.

The number of chickens dying during their time in the broiler house is taken into account in the model. A limitation is a fact that the overall percentage of passing chickens per cycle is divided by the six weeks they are staying in the broiler house. So, if 100 chickens start in the broiler house and the rate of dying chickens after one cycle is 12 percent, 12 chickens will be dead after six weeks. However, now it is modelled as 2 percent of the chickens die per week. Which means that in the first week two chickens die, but in the week after only 98 chickens are left, so fewer chickens will die using the 2 percent. Also, it assumed that no chickens die on transport or when they are arriving in the slaughterhouse, while in reality this is not true.

Another limitation of the research is due to the limited objectivity of humans. The model which is developed is mainly based on qualitative information which is obtained by interviewing people from different parts of the field. Each and every farmer has his/her own perspective of the problem, based on their own opinion and habits. In this way, personal information may have been introduced in this research. However, by interviewing so many different people in the field and also people working in Campylobacter research groups, objectivity of the information received for this study is enhanced.

Finally, the model output is dependent on the human behaviour of farmers, the catch crew, transporters, people working in the slaughterhouse and various visitors of the broiler house such as the veterinarians. The way these people behave, act and work depends on their personalities and the environment, which is hard to model. An example which is not modeled, is when chickens are sick because of other infections. This gives a probability that the farmer and the veterinarian will visit the broiler house more often, these kind of behaviour changes are not modelled.

8.2 Reflection

8.2.1 *Reflection on the used method*

The method used for this research is System Dynamics. The choice for this modelling method is based on different reasons. One of these reasons was the stock-flow principle in which chickens are settled as stock in different phases of the process. The initial rationale behind the model was to model every part of the process as a separate stock, namely: broiler house, on transport, thinning phase, in a slaughterhouse and supermarket. Every week a part of the chickens is in the broiler house, thinned and slaughtered. Therefore, the choice was made to only model two stocks which are "Chickens in broiler house" and "Chickens in a slaughterhouse'. Another reason for the choice of System Dynamics is the seasonality peak which is visible in the Campylobacter transmission through the chicken meat production process. The output graphs of the model show a clear peak around summer over time. However, some disadvantages of using SD modelling can also be identified. As already given as a limitation, the transmission of Campylobacter infections between chickens is not taken into account. To model the infections between chickens, an agent-based model approach would be better suited. Also, the chicken chain is modelled as a process which happens continually. However, the time of the specific processes happening during the entire chain is not in specific modelled. Using a discrete modelling technique, this could be better implemented.

8.2.2 *Reflection on the model and its scope*

The model shows a clear overview of the production process of chicken meat and identifies the different moments of the Campylobacters entering the chickens. The different moments that Campylobacter can enter the chicken, are in-depth analyzed and modelled as separate submodels. Various values of the input parameters were uncertain. Nevertheless, the transmission routes of Campylobacter became clear in one model. The uncertain parameters did not have a significant influence on the behaviour of the graphs. Therefore, different policy measures could be tested on the model, which helped to answer the main research question.

For the scope of the model is chosen to model the process from the broiler houses until the slaughtering process. Two important blocks which are not taken into account in this research are the "chicken meat selling" block and the "chicken meat consuming" block. During these two parts of the process, the chicken meat is either Campylobacter positive or Campylobacter negative. The status of the chicken meat cannot be changed. However, in these parts of the process, the number of Campylobaceriosis cases can still be reduced by various measures such as warning the consumers for Campylobacter in chicken meat.

A fundamental mistake in the model is the fact that the inflow and outflow of the Campylobacter negative chickens are not equal to each other. In the appendix E a figure of a table is shown, in which the values for the different flow around this stock are given. The difference between this inflow and outflows is small and therefore has this mistake no significant effect on the outcome of the model.

In the model the assumption is made that all visitors have a similar probability of following the hygiene protocol. This is based on a theory that the farmer is in charge of who can enter the broiler house and what protocol they should follow before they can enter. However, this probability can be different for the various visitors. As a farmer can be looser in following the protocol than a veterinarian.

8.2.3 *Reflection on the validity of the model*

In the validation phase of the modelling process is checked whether the developed model is an accurate representation of Campylobacter transmission in the chicken chain. In this phase, different verification and validation tests are conducted. The most useful tests, which brought valuable insights, were the face validation and the comparison with historical data. However, only historical data on the percentage of infected chickens arriving in the slaughterhouse was available. Therefore, the final portion of infected chicken meat could not be validated with historical data. Nevertheless, the comparison of the arriving chickens from the model with the historical data received from Nepluvi (NEPLUVI, 2019) illustrates similar behaviour patterns and output of the Campylobacter problem. However, the peak of the model graph is some weeks later in time, than the peak of the historical data graph. This can be caused by the weekly time step instead of the monthly time step which is used for the historical data graph. Face validation indicates a well-modelled structure of the situation. Two Campylobacter experts claim that the model structure represents the Campylobacter transmission through the chicken meat production process. Although specific and correct values for the different assumptions were missing, the behaviour of the output was verified with the real situation behaviour by two experts.

8.2.4 *Reflection on the results*

In this section, a reflection on the results and the generalizability of the results is given. The results of this research are based on a system dynamics model that shows the Campylobacter infection moments of chickens during the chicken meat production process. Different policy measures were implemented in the model, and the results showed that all of them were effective. However, the results are very uncertain since the input parameters are uncertain. These parameters are not precisely representing the real numbers, since these are not known. However, based on the qualitative interviews, relations could be made, and therefore the behaviour of the output graphs are representative. The results show that removal of the thinning process gives the most significant reduction of the percentage of infected chicken meat over time. This can be logically explained, since in this part of the process, many people and material enter the broiler house. The model can also be used for other concept chickens or for other countries if the the input parameters are changed.

8.3 Recommendations for future research

This section illustrates various recommendations for future research on the Campylobacter problem based on the limitations and reflection. The first recommendation which can be drawn is verifying the uncertain parameters with real data. For example, valid input data can obtained by a large-scale survey filled out by various farmers and slaughterhouses. The new information on the parameters can be used for optimizing the submodels. Also, more semi-structured interviews with multiple slaughterhouses are needed to get a more in-depth view of the entering of Campylobacter in chicken meat during the slaughtering processes. Further research on the different processes by generating qualitative and quantitative information will help increase the validity of the model.

Furthermore, a second recommendation would be analyzing the Campylobacter transmission throughout the chicken meat production process in other countries than the Netherlands. Consequently, lessons learned about specific measures or habits used in other countries could be applied in the Netherlands. Next to that, the export and import numbers of infected chicken meat could be introduced in the model to create a more realistic image of the size of the Campylobacter problem in the Netherlands. Additionally, adding the other concept chickens such as the free-range chickens and the organic chickens would improve the model and the results. A comparison between the different concepts of chickens can be drawn. The primary model can be reused, and subscripts for each of the concepts should be added. Finally, for further research, it is recommended to implement the transmission between chickens living on the same spot, e.g. chickens who are staying in the same broiler house and chickens who are together on transport. For this in-between Campylobacter transmission is the use of agent-based modelling recommended. When the infections between chickens are modelled, the effects of implementing policies such as limiting the number of chickens can be shown.

Another recommendation for further research is researching the possibility of removing the thinning process. The thinning process is seen as a financial necessity; therefore, it is recommended to research the economic influence for farmers when the thinning process is removed. Also, before thinking about removal, a more detailed research investigating in thinning is recommended. It is important to see in detail what is happening during this process at different farms. Investigating this process at different farms is crucial, because the different catch groups and different farmers will have a different way of working.

Based on the reflection on the scope of this research, it is recommended to investigate the behavior of the supermarkets selling chicken meat and consumers buying and preparing chicken meat. It could be a possibility to do a statistic choice behavior research to see how often people buy chicken, what concept they buy and if consumers are aware of the Campylobacter problem. Also, for supermarkets it is interesting to have data about if consumers are aware of Campylobacter on chicken meat. They could warn the consumers by placing an informing etiquette on the chicken meat packages. The combination of the choices that consumers make and what supermarkets can do to help the consumer, can be recommended as important areas for further research.

9

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Appendices

A

Deeper understanding of the problem

The first appendix shows a deeper understanding of the problem and the actor and their interest. Different figures, tables and charts are developed for understanding the Campylobacter transmission problem.

A.1 The chicken meat production process

In figure A.1 an overview of the total chicken supply chain on aggregated level is shown. Little chicks are transported from the hatcheries to different farmhouses. These chickens are transported by trucks and are unloaded in the farmhouses by the truck driver and the farmer. Depending on what concept the chicken is, they stay in the farmhouse from 42 to 60 days. They are caught by a catch crew and are transported to different slaughterhouses. The chickens will be controlled on different factors by the NVWA and will be slaughtered. The meat will be transported to different supermarkets.

During this process different actors play different roles. In figure A.2, a clear overview of the process is given combined with the actors playing a role in this process. The last figure A.3 shows an overview of the processes on farm in which campylobacter can be transmitted into the broilerhouses.

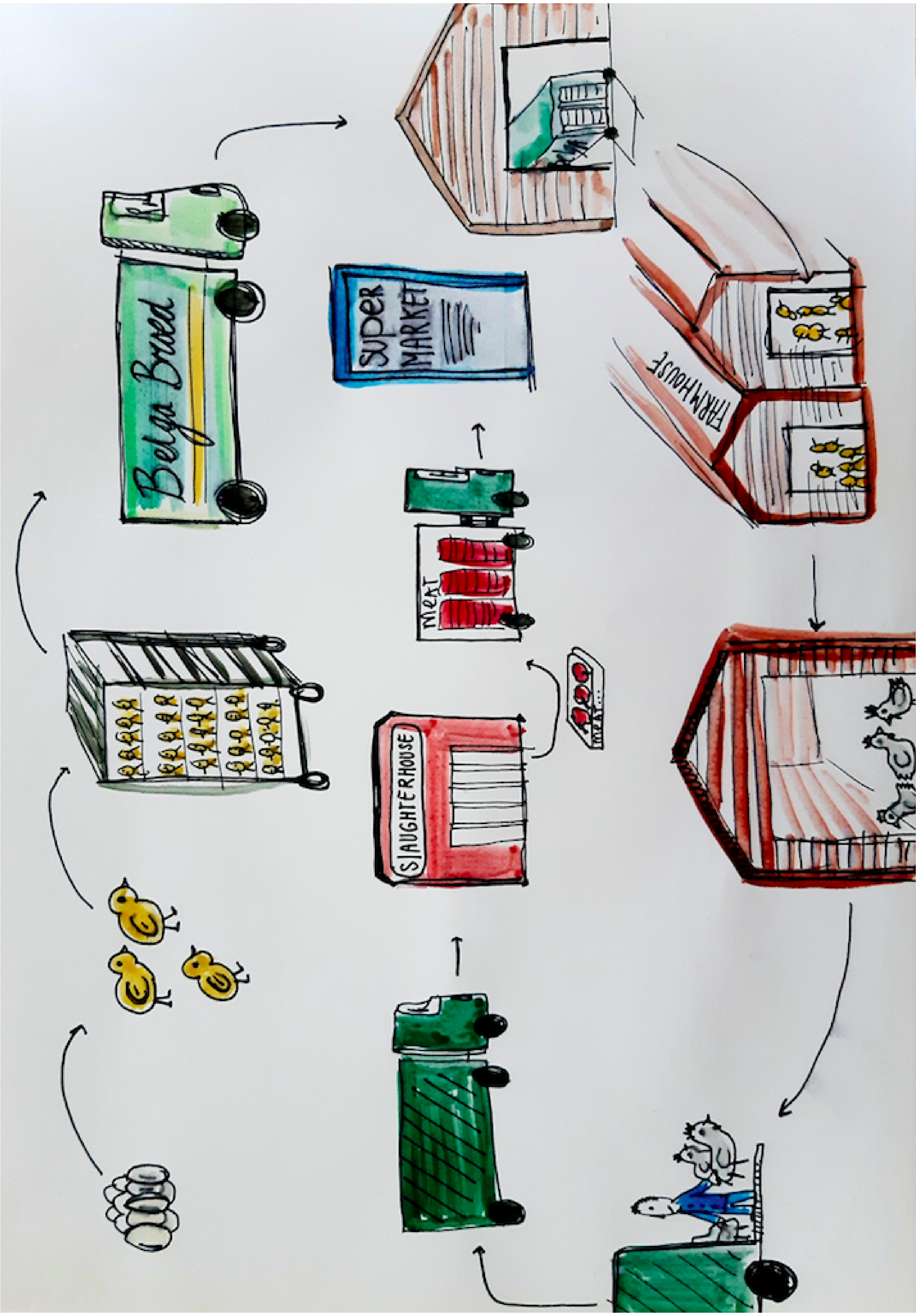


Figure A.1: Chicken Supply Chain at an aggregated level

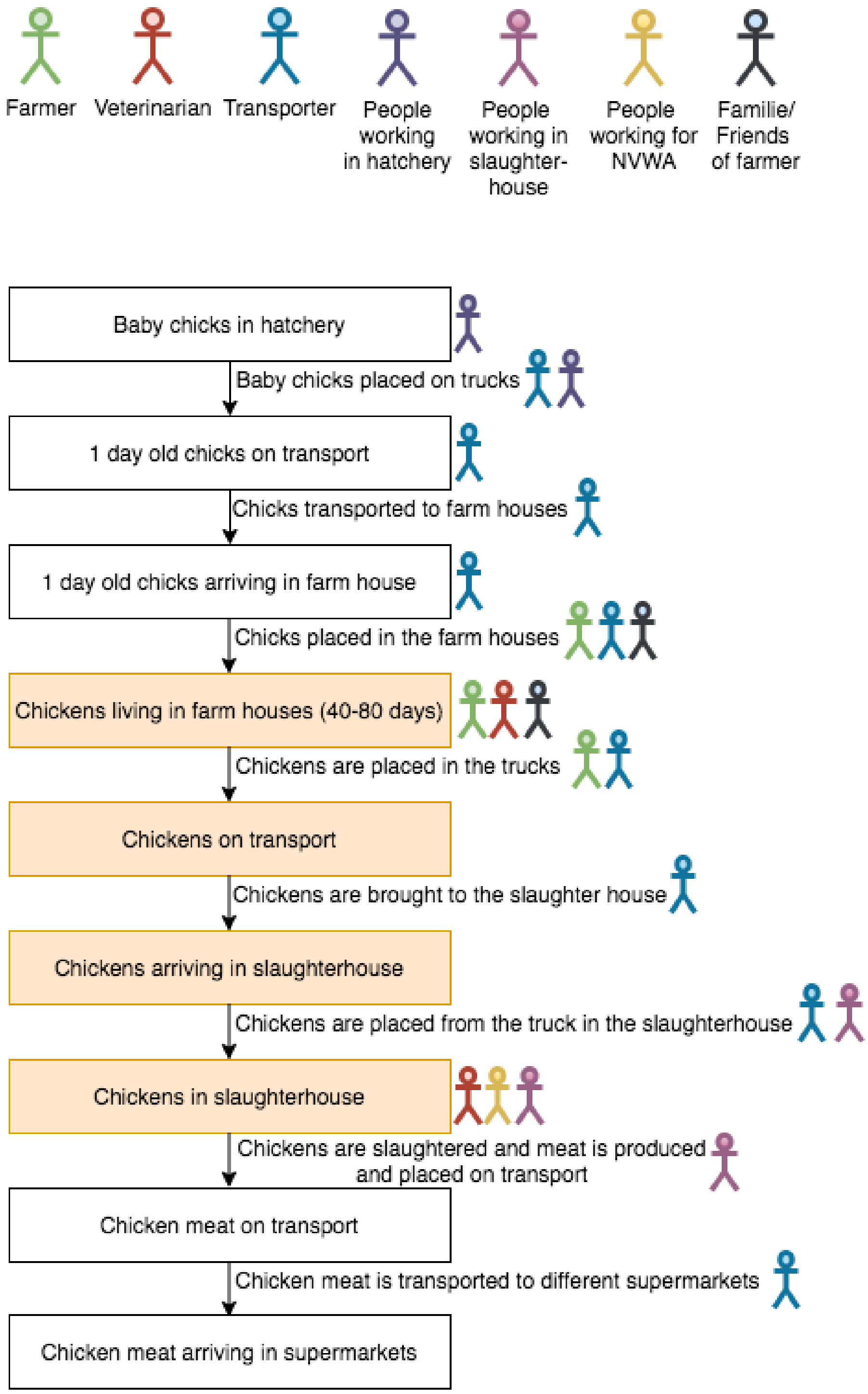


Figure A.2: Chicken chain with actors

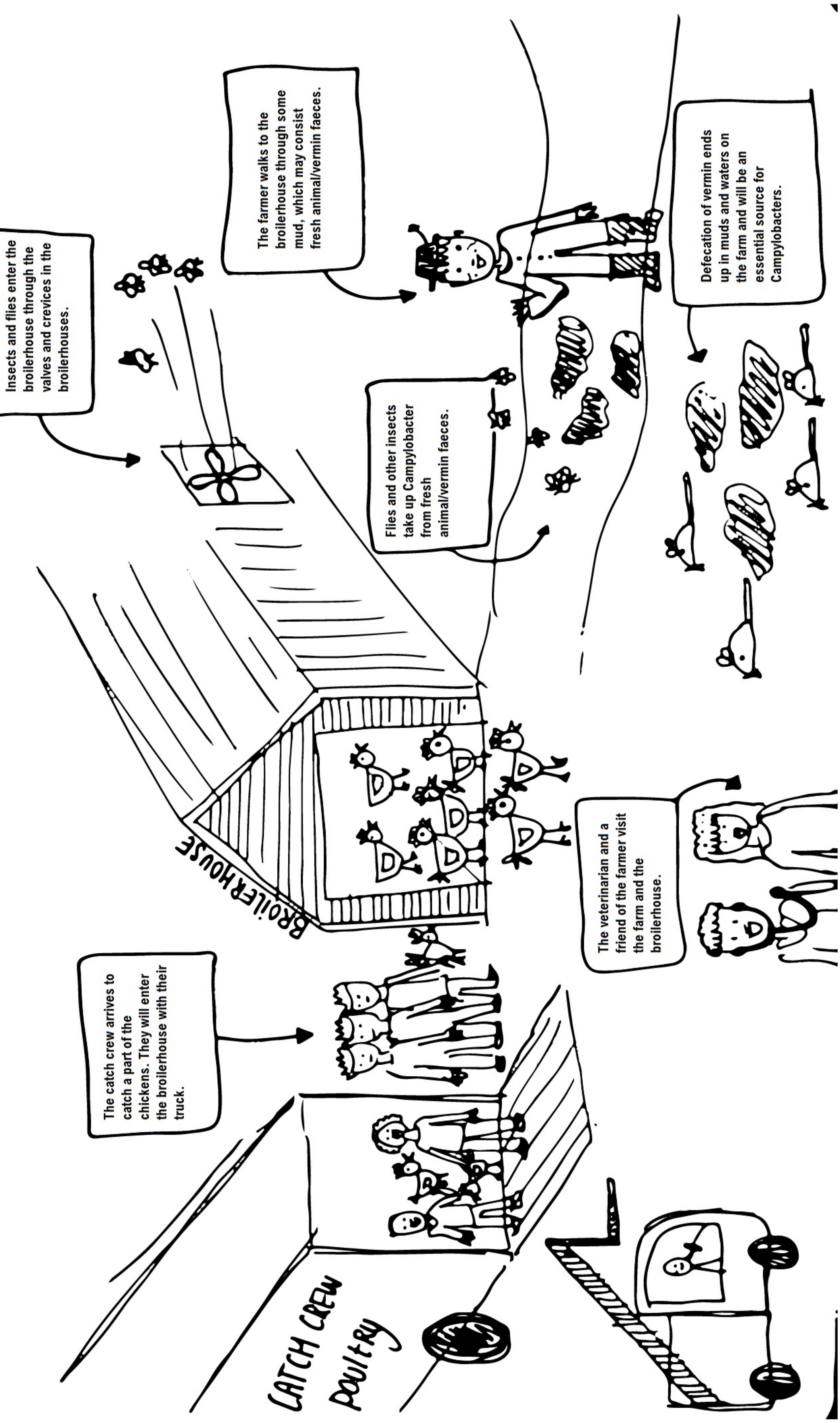


Figure A.3: Routes of transmission for Campylobacter jejune

A.2 The actors, their interests and relations

The figure below shows the formal actor chart of the Campylobacter problem. In the top of the figure the EFSA is shown. This Authority takes care of the rules and guidelines for fresh poultry meat in Europe. It samples the rules for the Dutch Government. The two ministries that are in charge for the Campylobacter problem, are called the Ministry of Agriculture and Fishery and the Ministry of health, welfare and sport. An organisation, called NVWA, which belongs to the Dutch government, controls the farmers and slaughterhouses on Food Safety and Quality. The veterinarians give advise to the farmers and the farmers have a selling-buying relation with the slaughter houses.

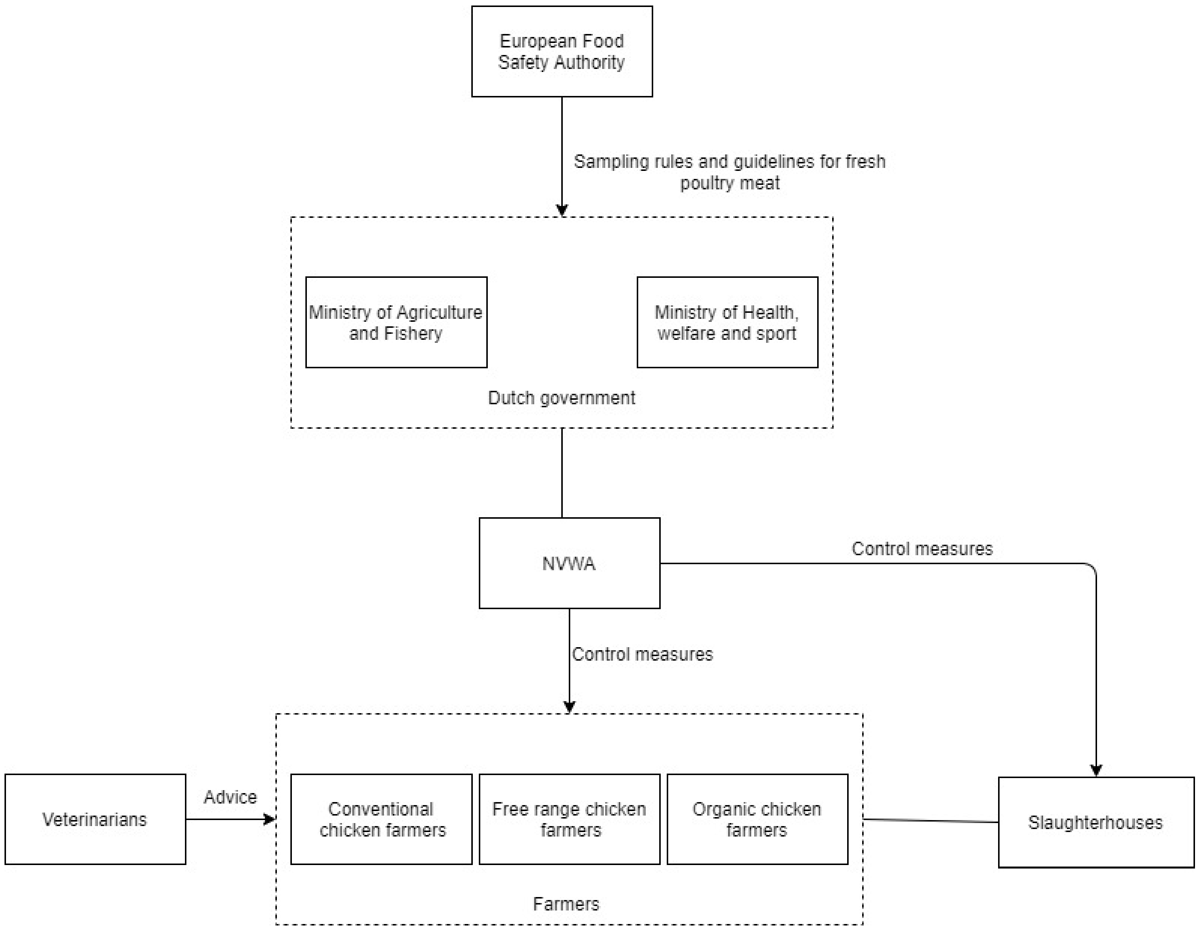


Figure A.4: Formal actor chart

In the table A.1 the different actors and their problem formulations are shown, by giving their desired and existing situation. From the table some important conclusions can be made:

- The farmer actors have to important interest and desired situation, which are linked to each other. They want a good income, which is influenced by healthy happy chickens.
- Except for the farmers, all other actors kind of have the same desired and existing situation. The desired situation is producing Campylobacter negative chicken meat but the existing situation is the

fact that it is still unknown what exactly farmers and/or chicken slaughter houses can do to produce more Campylobacter negative meat.

- This above statement links to the possible causes. Nowadays farmers are not aware of the amount of Campylobacter lives in their chickens. This is not communicated to them, because in the current situation it is not clear what farmers can change in their production chain to reduce the amount of Campylobacter in chicken meat.
- The slaughterhouses are controlled by the NVWA, but also they do not exactly know what they should do to change the amount of Campylobacter.

Table A.1: Actors with their interests, desired situations, gaps, causes and possible solutions

Actor	**Interests**	**Desired situation**	**Existing or Expected situation and gap**	**Causes**	**Possible solutions**
Conventional chicken farmer	Poultry farming, good earnings	Healthy campy-lobacter free chickens, Good income from farming	It is unknown what farmers can do to reduce the amount of Campylobacter infected meat.	No control or biosecurity measures are defined to reduce the amount of Campylobacter in chicken meat. The farmers do not know what amount Campylobacter is in their chickens because this is not communicated to them.	Communication to the farmers about the amount of Campylobacter in their chicken meat. Take care of biosecurity measures that should be implemented by the farmers.
Organic chicken farmer	Poultry farming, good earnings	Healthy campylo-bacter free organic chickens, Good income from farming	It is unknown what farmers can do to reduce the amount of Campylobacter infected meat.	No control or biosecurity measures are defined to reduce the amount of Campylobacter in chicken meat. The farmers do not know what amount Campylobacter is in their chickens because this is not communicated to them.	Communication to the farmers about th amount of Campylobacter in their chicken meat. Take care of biosecurity measures that should be implemented by the farmers.

Free range chicken farmer	Poultry farming, good earning	Healthy campylo-bacter free - free range chickens, Good income from farming	It is unknown what farmers can do to reduce the amount of Campylobacter infected meat.	No control or biosecurity measures are defined to reduce the amount of Campylobacter in chicken meat. The farmers do not know what amount Campylobacter is in their chickens because this is not communicated to them.	Communication to the farmers about the amount of Campylobacter in their chicken meat. Take care of biosecurity measures that should be implemented by the farmers.
Veterinarian	Healthy animal lifes	Healthy Campylo-bacter free chickens on all different farms.	There is no vaccin and it is unknown what exactly should be advised what farmers can do to avoid Campylobacter.	Veterinarians can not really give advises if it is still so unknown what exact measures really help avoiding the Campylobacter.	Know when the Campylobacter affects the chickens and what measures can be taken by the farmer to reduce these moments.
NVWA	Food Safety in the Netherlands	Chickens that are Campylobacter free are slaughtered.	Nowadays nothing is really done with the information if a flock of chickens is contaminated as Campylobacter positive or negative.	It is unknown what kind of measures slaughterhouses and farmers can take to reduce the amount of Campylobacter in Chicken meat.	More research should be done to see what interventions do work to reduce Campylobacter. More control measures are needed to really know and see when Campylobacter enters the chicken (in farms or slaughter houses).

Chicken Slaughter-house	Fresh chicken meat, good earning	Produce Campylobacter free chicken meat.	A big percentage of the produced chicken meat is infected with Campylobacter.	Campylobacter positive chickens are transported to the slaughterhouses. Cross contamination takes place and campy negative chickens can still end up in campy positive chicken meat.	Define the positive and negative flocks before slaughtering the chickens.
Ministry of Health, Welfare and Sport	Human health	Less Campylo-bacter infected chicken meat.	Chicken meat is still infected, because no control or intervention measures are currently done to reduce the amount of Campylobacter.	It is not known where the interventions should be done to reduce the amount of Campylobacter in the chicken chain.	Implement control and biosecurity measures.
Ministry of Agriculture, Nature and Food Quality	Food quality	A reduction of Campylobacter in the chicken chain.	No control or intervention measures are currently done to reduce the amount of Campylobacter.	It is not known where the interventions should be done to reduce the amount of Campylobacter in the chicken chain.	Implement control and biosecurity measures.

European Food Safety Authority	Food quality control	Throughout whole Europe a good food quality and safety. So reduce the amount of Campylobacter in the chicken chain.	All countries should implement the european food safety regulations, while it is unkown what measures help reducing Campylobacter.	It is hard to define regulations for all European countries, because of the seasonality peak.	Start with a minimum rule and make the minimum allowed amount of Campylobacter bigger over the years.

B Interviewing

In the following appendix, the different interview questions and summaries of the interviews are shown. In figure B.1 a copy of the informed consent is shown. Before the interviews were held, informed consents were sent and signed by the different interviewees. Also, after every interview, a summary of the interview was sent to the interviewee, on which they could make comments. These comments are incorporated.

Toestemmingsformulier voor interviews – Master Thesis
Occurrence of Campylobacter in the Chicken Chain

Bij het ondertekenen van onderstaand formulier of het terugmailen van een akkoord, gaat u akkoord met al het onderstaand genoemde:

- Ik heb een samenvatting van het voorstel gelezen of deze is aan mij uitgelegd. Daarnaast was ik vrij om vragen te stellen hierover en werden deze beantwoord.
- Ik doe vrijwillig mee aan deze studie en begrijp dat ik vragen kan weigeren als ik hier geen antwoord op wil geven.
- Ik begrijp dat het interview zal worden opgenomen en dat deze samengevat wordt in tekst. De samenvatting zal toegestuurd worden voor goedkeuring. De opname zal na goedkeuring van de samenvatting verwijderd worden.
- Ik geef toestemming dat de verkregen informatie van het interview zal worden gebruikt voor de master thesis "Campylobacter in de kippenindustrie".
- Persoonlijke informatie (achternamen, telefoonnummers, e-mailadressen etc.) zal niet gedeeld en bewaard worden.
- Ik geef toestemming dat de samenvatting (welke alleen voornamen bevat) gedocumenteerd wordt in het afstudeeronderzoek en op de repository website (van de TU Delft) wordt gedeeld.

Naam participant	Handtekening	Datum
Edien Rommens		
Naam onderzoeker	Handtekening	Datum

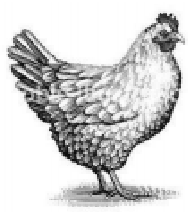


Figure B.1: Informed consent

B.1 Interview questions

B.1.1 *Interview questions farmer*

Purpose of the interview:
Understand the details of the chicken meat production process.

Introduction:
In this research, a computer model will be build look at the introduction of Campylobacter in the chicken chain (from farmer to slaughterhouse). After this, the current (and new) biosecurity measures will be applied and by running simulations can be seen how these measures effect the number of Campylobacter positive chickens.

Questions

1. What kind of concept chickens do you have? (Conventional, free-range, organic)
2. How many days / weeks do the chickens stay until they go to the slaughterhouse?
3. What kind of surface do you use in the stable and why? (Sawdust, straw, etc.)
4. What kind of food do you use and why?
5. Can you describe your farm in terms of environment? Do many other animals live on the farm? Do you suffer from pests? What other products do you produce besides chickens? Is there water nearby? Other farms?
6. Can you describe the chain from the arrival of the chicken until it is picked up by the catch crew to go to the slaughterhouse?
7. Which persons will visit in and around the farmhouse? How long do they stay and how often do they visit?
8. Do you have a hygiene protocol when people want to enter the farmhouse? And if so, what does this protocol entail? Are there situations that this protocol is not used?
9. How often does the vet visit on average in your farmhouse? And what does he do during this visit? Do you make any adjustments before or after the visit?
10. The chickens are caught by a catch crew and then transported to the slaughterhouse. How many people does this catch team consist of? And what does this process look like?
11. How do you clean the chicken house before the new flocks are arriving?
12. Do you have an idea what percentage of your flocks have been infected with Campylobacter?
13. A few years ago the slaughterhouse sent you after the flock was slaughtered, what percentage was infected with Campylobacter. Did you use this data? If so, how? If not, why not?
14. What about Salmonella? What measures do you take to reduce the amount of salmonella?
15. Are there any measures you are taking to reduce the amount of Campylobacter?
16. Would you like to take more measures to reduce the amount of Campylobacter in chicken meat?
17. Do you have an idea of what measures should be taken to reduce the amount of Campylobacter in chicken meat?
18. Are you familiar with the health consequences Campylobacter can have for humans?

B.1.2 *Interview questions slaughterhouse*

Purpose of the interview:
Knowing exactly what is happening in the slaughterhouses and how they deal with the Campylobacter problem.

Introduction:
In this research, a computer model will be build look at the introduction of Campylobacter in the chicken chain (from farmer to slaughterhouse). After this, the current (and new) biosecurity measures will be applied and by running simulations can be seen how these measures effect the number of Campylobacter positive chickens.

Questions

1. Can you describe the different steps of the slaughtering process from the arrival of the chickens?
2. Are the different flocks separated during transport and upon arrival at the slaughterhouse? If so, in what way?
3. When and how often are the trucks used for transporting the flocks, being cleaned?
4. Are you in contact with the catch crew? What do they wear? How often do they visit?
5. Which type of concept chicken contains the most Campylobacter? And why?
6. At what moments is the presence of Campylobacter verified in the slaughterhouse? What is done with this information?
7. What organization controls the slaughterhouses? What are the consequences if you do not meet the European Food safety control measures that have been set?
8. How much Campylobacter is on average per flock? What percentage of the flocks is Campylobacter positive?
9. What measures are currently being taken at slaughterhouses to reduce the number of infected chickens? (prevention or reduce spread)
10. Questions about data from recent years about the amount of Campylobacter positively tested chickens per type of concept.

B.1.3 *Interview questions veterinarian*

Purpose of the interview:
Get more information about Campylobacter itself and how it can infect chickens.

Introduction:
In this research, a computer model will be build look at the introduction of Campylobacter in the chicken chain (from farmer to slaughterhouse). After this, the current (and new) biosecurity measures will be applied and by running simulations can be seen how these measures effect the number of Campylobacter positive chickens.

Questions

1. Why do you think Campylobacter is so unknown for meat consumers compared to Salmonella?
2. How often do you visit the farm houses? How long takes a visit and what does a visit look like?
3. Are tests conducted to check the amount of Campylobacter in the chickens during their lives in the farmhouses? And when, in what seasons? How frequently?
4. In what ways does the Campylobacter enter the chicken? In what ways and at what moments (slaughterhouse / farm)?
5. What is the incubation time of the Campylobacter?
6. How does the bacteria spread in the farmhouse or in slaughterhouses? If 1 chicken Campylobacter is positive, does the entire flock of chickens become Campylobacter positive?
7. How does it spread in the slaughterhouse?
8. If one chicken farm house has been tested positive, will this also be transferred to the other chicken farmhouses?
9. What are current measures that are being taken against the Campylobacter on the chicken farm and slaughterhouses?
10. Are these measures mainly against the first introduction with the Campylobacter or especially against spread/colonization?
11. Is there a vaccine against Campylobacter?
12. Do you see Campylobacter as a threat to human health?
13. Which processes on and around the farm are relevant for the introduction of Campylboacter?
14. According to the literature, Campylobacter is most common in organic chicken and less in conventional chicken. Do you think this is correct?

B.1.4 *Interview questions poultry catch group*

Purpose of the interview:
The purpose of this interview is to receive information about the poultry thinning process.

Introduction:
In this research, a computer model will be build look at the introduction of Campylobacter in the chicken chain (from farmer to slaughterhouse). After this, the current (and new) biosecurity measures will be applied and by running simulations can be seen how these measures effect the number of Campylobacter positive chickens.

Questions

1. What does the thinning/catch process look like from the moment the catch crew arrives until it arrives to leave?
2. How long does the thinning/catching process on average take per broiler house?
3. How many farmers will the catch crew visit in one evening?
4. What is the failure rate during the capture of the chickens and during transport?
5. What is the average transportation time?
6. What hygiene protocol does the catch crew follow?
7. At what times do they change their clothes and footwear? What do they wear during it to catch?
8. Do they change clothes and footwear per broiler house?
9. How often is the “Catch” equipment cleaned? In what way?

B.1.5 *Additional interview questions farmers*

Purpose of the interview:
The purpose of this interview is to receive additional information about on farm details.

Introduction:
In this research, a computer model will be build look at the introduction of Campylobacter in the chicken chain (from farmer to slaughterhouse). After this, the current (and new) biosecurity measures will be applied and by running simulations can be seen how these measures effect the number of Campylobacter positive chickens.

Questions

1. What kind of chickens do you have? Conventional or concept chickens?
2. How many chickens do you have in total? In how many broiler houses do they live?
3. How many weeks do the chickens stay?
4. What failure percentage do you have per flock of chickens?
5. What percentage of chickens is caught during the thinning process? And when is this process?
6. How often do you enter the stable on average per day? And how often do you go into the barn on average when the chickens are sick?
7. How many visits of the veterinarian do you have on average per week?
8. How many other visitors enter the broiler house on average per week?
9. How often do you change your shoes and outfit before entering the broiler house?
10. What does the road look like when you walk to the broiler house(s)?
11. Do you have problems with pests (mices, rats)? And so, do you fight them?
12. How would you describe your hygien level and protocol?
13. How often do you use your fans during the year?
14. Does everyone entering the broiler houses follow the same hygien protocol always?

B.2 Summaries of the different interviews

B.2.1 *Summary of interview with Miriam*

Miriam is a Veterinary Microbiologist at Wageningen University Bioveterinary Research. She is now working on project leader of a project which is called ;The Control of Campylobacter in the Poultry Industry production sector;, a Public Private Partnership with Wageningen Livestock Research, NEPLUVI, LTO-NOP and NOP. Since a few years European Regulation is implemented for Food Safety in the form of a Process Hygiene Criterium (Commission Regulation (EC) No 2073/2005). In the past most of the rules and regulations were created by the sectors and their product boards it selves. The agricultural product boards used money which they obtained from the poultry farmers and they used this budget for research. In this way research was executed. The product boards have been abolished. Nowadays a research in combination with the ministry and the organization Avined is in progress to inspect the Campylobacter problem in the poultry industry. It is already accepted that 100 percent Campylobacter free chicken is not a reachable goal. Therefore the objective set by the European Union is to reduce the prevalence of Campylobacter in chicken meat. Slaughterhouses are obliged by EU regulations to send test every week five neck skin samples from 2 flocks of chickens to the NVWA for Campylobacter enumeration. The samples results of a 10-12 week windows will beare considered, of which only a limited number of the samples may consist contain 1000 Campylobacter bacteria per gram. If the samples consist contain more than the limited number Campylobacter, the slaughterhouses will receive a warning and a so-called "Inspanningsverplichting", which means that they are obliged to show more effort. These European regulations were hard to implement, because the amount of Campylobacter in chicken meat differs a lot between the more northern and southern countries. The reason therefore can be the seasonality peak. It is interesting that Almost nobody isfew people are familiar with the Campylobacter bacteria, while everybody is familiar with Salmonella. The first reason is the number of deaths. Salmonella causes deaths and Campylobacter does not. It is hard to control the Campylobacter bacteria. Thirty years ago a plan of action to control Salmonella and Campylobacter is created, which caused a reduction of salmonella in chicken meat. Unfortunately the presence of Campylobacter in chicken meat remained the same as before. In the Netherlands, summertimeon average 70 percent of the chicken flocks are colonized by Campylobacter in summer time, while. In wintertime only around 30 percent of the chicken flocks are colonized by Campylobacter. Campylobacter enters the chicken is taken up orally and stays in the intestinales walls of the chicken in very high numbers (around 10 8 bacteria per gram in the caeca). In a few days after the first chicken becomes Campylobacter positive, all the chickens from one flock are colonized by Campylobacter. If a farmer has more than 1 farmhouse, there is a high chance of Campylobacter entering in the other farmhouses as well. Campylobacter grows incredibly fast and 1 gram of chicken manure will consist ofmay contain up to 10.000.000 Campylobacter germs. When the Campylobacter arrives in the outside world through excretion of the chicken, the bacteria will die soon. Campylobacter is not resistantsusceptible to drought, not to oxygen, not to UV radiation, and not too freezing. It can only survive in the intestines of various animal species or in aquatic environments. After a flock of chickens is transported to the slaughterhouse, and the farmhouse is cleaned, it is assumed that all of the Campylobacter bacteria are deleted. In the slaughterhouses it is possible to obtain Campylobacter free meatmeet the process hygiene criteria from a Campylobacter positive chicken by working precisely. For instance If the organs are pulled out precisely, there is a chance that the Campylobacter which is in the organs (intestinal packets), will not get the opportunity to stick to the chicken meat. Therefore a difference is proved are differences between slaughterhouses with regard to the amount of Campylobacter positive chicken meat, slaughterhouses they produce. This cannot be attributed to simple differences in slaughterhouse procedures, because of high variations in processing between slaughterhouses as well as considerable variations in uniformity and the percentage of Campylobacter positive flocks they receive. Until 2015, through a national monitoring program for Campylobacter from the product poultry board (Productschappen Vee, Vlees en eieren) Some years ago the broiler farmers were told how much Campylobacter was located in their produced chicken meatif their flocks were Campylobacter positive or not. (However, nowithout consequences were given if your chicken meat consisted too much of the were Campylobacter positive). Hence nowadays the farmer is not informed about the presence of Campylobacter in his/her chicken meat, and because Campylobacter does not lead to health problems in chicken, farmers have no feedback on the Campylobacter status of their flocks. Besides no rules or measures are created yet to reduce Campylobacter so the farmers can not do anything about it little to reduce Campylobacter. The only thing farmers can do and can be aware of is "hygienic/biosecurity measures" to prevent Campylobacter from entering their flocks. The last part of the interview with Miriam was about the difference between the different concepts of chickens. Miriam told me that the biological organic chickens are always usually a hundred percent colonized by the Campylobacter at slaughter (up to 90% of the flocks), because the chickens live in the outside environment. The regular chicken and the slow grower chicken, are in summertime around 70 percent colonized and in wintertime only 30 percent. The difference between these chickens is the fact that the regular chickens are colonized after 30 days, and the slower growers after 36 days. Because age is a risk factor for chicken to become colonized with Campylobacter (every day there is an additional chance of coming into contact with Campylobacter) and slower growing broilers ('kip van morgen'-concepts) are slaughtered at a later age, it was expected that slower growing broilers would be more often Campylobacter positive at slaughter. Interestingly, this is not the case. The percentage of Campylobacter positive flocks of slower growing chickens is similar or perhaps even a bit less compared to regular broiler chickens. Preliminary results from the Campylobacter research program show that on average slower growing birds seem to become colonized later in life (about a week difference was found). Further research is planned to get more insight in these apparent differences between concepts.

B.2.2 *Summary of interview with Veterinarian Maarten*

Maarten is a veterinarian, and he is involved in a Campylobacter project. According to him, the media attention always was focused on salmonella. Therefore, Campylobacter is really unknown by people. However, different people who have had symptoms such as diarrhoea can have had Campylobacteriosis. The point is that they did not go to see a doctor, and the fact that they probably were having Campylobacteriosis was not reported. He also explained to me two ways to measure the influence of Campylobactoriosis on human life.

He explained to me that there is not one number for visiting the different farms. When the chickens are sick, he will go there every week. But if there is no problem he goes there once per new flock chickens is arriving. When he enters a farm, he always put plastic bags around his shoes, and when he comes to the chicken house, he always wears boots of the farm. He explains to me it is essential to keep the chicken houses clean, and it is crucial to separate the dirty and clean part of the farm. Often these two parts cross each other, when for example the new chicks are brought into the chicken farmhouses or when a farmer walks from one chicken house to another chicken house. Some farmers have a room in between the two chicken houses so that they do not have to go outside. This in-between room is called a "feeding room". One farmer, he knows, has specific clothing for each of his farmhouses. Maarten explains to me, this is perfect because, in this way, no bacteria can be transported from one chicken house to another chicken house.

Campylobacter enters the chicken through their beacks and ends up in the intestines of the chickens. How much Campylobacter eventually ends up on the meat depends on the slaughterhouse. The slaughter houses delete the guts from the chickens. When this is done precisely, there is a chance that no bacteria will end up on the chicken meat. Maarten emphasizes that of course, Campylobacter negative flocks will always end up as Campylobacter free chicken meat.

Maarten has seen a lot of different farms and tells me that every farmer takes his biosecurity measures to prevent his/her chickens against diseases. Every farm has its environment. Some chicken farmhouses are close to cattle farmhouses, which attracts flies. In different researches, has turned out Campylobacter can easily be spread through flies. Farms with a lot of mess such as pallets or sewer pipes around the chicken farmhouses will suffer more from pests than farms without mess.

B.2.3 *Summary of interview with Ministry of Agriculture*

Eric is a policymaker for food safety in the Netherlands. He tells me it is essential to take into account the difference between what is told in literature and what is happening in practice. Compared to a lot of other countries, the Campylobacter problem is strictly controlled in the Netherlands. The Netherlands can be seen as a front runner for this problem. The problem is difficult to control, but overall can be told that the hygiene in the farm and slaughterhouse phase is essential for the prevention of Campylobacter bacteria. In general, the assumption can be made that the better the health biosecurity and hygiene is in farmhouses and slaughterhouses, the fewer Campylobacter bacteria will infect the chickens. But as he said; "frankly speaking, it is questionable whether slaughterhouses and farmers really live up to their own standards in daily practice".

The Netherlands started voluntarily with preventing controlling the Campylobacter bacteria in a co-operation of government, science institutes and industry. Since a few years, European rules are developed by the EFSA to control the amount of Campylobacter contaminated chickens. The process hygiene criterium (PHC) is a parameter for the efficacy of the process hygiene control. It is defined as a limit for the amount of Campylobacter on chicken meat. If a slaughterhouse exceeds this criterium, they will have to discuss with the NVWA about their new prevention strategies to reduce the amount of Campylobacter in chicken meat. This limit will become stricter over the years. The slaughterhouses will also communicate with the farmers, and they will impose requirements on farmers.

The process hygiene criterium is not a food safety criteria, which means that infected chickens can still be sold to consumers as fresh chicken meat.

He also tells me that if the slaughter line is infected, all the chickens going along that slaughter line will become infected. This is called cross-contamination. It is essential for as well as slaughterhouses, as well as farmers to work hygienically. If the farmer works in a hygienic way, and the flocks are not infected, it is easier for the slaughterhouses to keep the chickens Campylobacter negative.

Campylobacter free chicken meat is not needed. A few Campylobacter bacteria on chicken meat are essential for the human resistance. On the other hand, research by RIVM has revealed that poultry meat exceeding certain high limits of contamination poses a relatively very high food safety risk to consumers compared to medium or low contaminated meat.

B.2.4 *Summary of interview with Ministry of VWS*

He is a policy maker for foodsafety in the Ministry of Health, Welfare and Sport. He explained me a lot about the rules and regulations which are set by the European Union, based on scientific advice of EFSA. According to him, science and practical application do differ due to differences in farmingsystems and climate across the 27 European Member States. Compared to other countries, the Netherlands reduced the percentage of broilermeat with more than 1000 Campylobacters per gram breast skin from 9.8% in 2006 to 3.9% in 2016.

He tells me about some farmers who almost always produce Campylobacter free chickens. They appear to really take care of their biosecurity measures. Therefore he explains me that the human factor is of big importance in this problem. The problem is that farmers do not know if their chicken meat is Campylobacter positive or negative and if so, what measures they should implement. So for them there is not really an incentive to avoid Campylobacter. He tells me it is important to have a deeper look into the thinning process and into the enviroment around the farm houses, because he thinks these could be important risks. The new method to identify bacteria, Whole Genome Sequencing (WGS), which enables to link food outbreaks to their source, will the coming years probably also stimulate Campylobacter reduction in the entire broiler-meat chain.

For slaughterhouses it is hard to produce Campylobacter free chicken meat, if they receive Campylobacter positive chickens from the different farmers. 1000 Campylobacter bacteria per gram neck skin is the allowed amount in the slaughterhygiene norm. This norm is set by the European Union, to stimulate slaughterhouses to improve their slaughter hygiene measures and how they can reduce the amount of Campylobacter in chicken meat.

If a chicken gets infected, in a few days the whole farm house is infected. Farmers are asked by questionnaires how hygienically they work. In this questionnaires answers are never fully trustable. When a farmer is asked "Do you always change your clothing when entering the farm house" and he knows he is doing this almost always, he probably will answer "Always". When a flock is infected and arrives in the farmhouses, this group can easily transport Campylobacter from one flock to another flock. Besides the farmer and the slaughterhouse, the consumer is also responsible for avoiding cross contamination, while preparing the chicken meat in the kitchen.

It is hard to set strict European rules, because for the southern countries, it is really hard to reduce the amount of Campylobacter (Seasonality peak). The European had to struggle for years to introduce the slaughter hygiene norm. This norm will finally become a food safety standard. This means that when the meat consists more than 1000 Campylobacter/gram, the meat cannot be sold as fresh meat in the supermarkets.

B.2.5 *Summary of interview with Conventional Farmer 1*

The interview started with a question from farmer 1. He asked me after the introduction of the interview why nothing is done with Campylobacter? He told me he thinks the camyplobacter problem is bigger than the salmonella problem.

After 35 days a part of his chickens are getting thinned and after 42 days the left chickens are caught by the catch crew. He tells me pest control helps him against pests and vensims. Therefore he does not have problems with pests anymore. Especially in summer normally pests appaer on the farms.

Only the vetenerian and the food representor are allowed to enter the broilerhouses. He and his sons enter the broilerhouses around 1/2 times per day. They always switch checking broilerhouses (he and his sons), so that they have every time a new view on the broilers.

For every broilerhouse he uses the same overall, however he changes his boots for every specific broilerhouse and he always washes his hands before entering one of the broilerhouses. When he wants to go to his chickens, he first goes to a cantine, where he changes clothing and shoes, than he walks to the broilerhouse, where he enters the so called "voerlokaal", which is a room between the different broilerhouses. He changes his shoes again in here. When he wants to enter a broilerhouse, he changes his shoes again.

He mentions the problem with the thinning process. The poultry catch group always have to wear clothing and shoes provided by him self. When they enter the different broilerhouses they do not change boots, because then you would need 100 different boots he tells me. Besides to that, the equipment they use, also will be transported from one broilerhouse to another broilerhouse, without being cleaned. He agrees that he does think it is weird to so not follow your protocol, but he tells me there is no other option. He is wondering, why not testing the chickens on Campylobacter before starting the thinning process? So then you know which flocks should be caught first.

When I ask Farmer 1 what measures farmer can take to reduce the level of campylobacter, he acknowledges the hygiene level on a farm.

B.2.6 *Summary of interview with Free Range chicken Farmer 2*

Farmer 2 is a free range 1 star chicken farmer. In his farm house around 25 kg chickens live per square metre and they stay for 8 weeks. The chickens can easily go to an outside veranda space, which is 30 percent of the total farmhouse space. This outside room is a cold, closed space, in which grain is scattered every day. The chickens are allowed to go outside, when they are 3 weeks old. Farmer2 was first a conventional chicken farmer, but some years ago he started with the free range chicken farm. He tells me the rules are less strict than we he was having conventional chickens, and the thinning process is not happening for this concept chickens.

In the neighborhood are some other farms but the closed farm is 500 metre away. The closest chicken farmer is 12 km away and a few cow farmers are around 2 km away from his farm. Ninety percent of the space around him is filled with agriculture.

Different people such as the veterinarian, and the food advisor are entering the farm houses. They switch on these moments clothing and shoes and they always wash their hands. He explains that he is really strict on other people entering the farm houses, and to see if they follow his hygiene protocol. He admits that he thinks the farmers should have a look in the mirror and ask themselves if they "Always" follow their own protocol... When the chickens are getting caught and go to the slaughterhouse, they will get slaughtered on a earlier stage than the regular chickens.

He explains me in slaughterhouses flocks infected with salmonella are always slaughtered after salmonella free flocks. He does not understand why this is not implemented for Campylobacter infected flocks.

B.2.7 *Summary of interview with Organic farmer 3*

Farmer 3 is a farmer in the south of the Netherlands, and he has besides slow-growing chickens, around ten different poultry breeds such as guinea fowl or turkey. In total around 1000 animals live on this farm. The chickens are 80 days to 6 months until they get slaughtered. The chickens live the first four weeks separately in small chicken houses, but after this weeks they all live together. After this first four weeks, they are allowed to go outside, and the first chickens will get slaughtered after ten weeks. In 4 weeks a flock of chickens is slaughtered. The slow-growing chickens will end up in their own store, and the unusual chickens will end up in different restaurants.

Farmer 3 told me the consumers who enter the shop, can also enter the garden, where the chickens live. Once every year he cleans the different chicken houses. He tells me that before, he cleaned the farmhouses more often, and the chickens got more often sick. Therefore he is convinced the chickens get more reliable in an environment which is not cleaned every few weeks. According to him, Campylobacter and salmonella only enter a totally bacteria-free chicken house.

Normally farmer 3 slaughters around 40 chickens per week. He is allowed to slaugther maximum 200 chickens per week and 2000 per year. When he exceeds this minimum amount, the NVWA will come around to control the slaughtering process.

B.2.8 *Summary of interview with Slaughterhouse 2*

Slaughter house 2 is a modern poultry slaughterhouse that supplies chicken products to customers in many different countries. He tells me a lot about the chicken meat production process happening in slaughter houses. When the chickens arrive in the slaughterhouse, they are kept apart from other broiler houses. So two different flocks of chickens originating from two different farmers, staying in one truck, are in the slaughterhouse kept apart and seen as two different flocks of chickens. He tells me that there is one exception for the thinning process. When a part of the chickens is thinned arriving from different broiler houses, but having had the same food, vaccinations and medicines, they can be put one one truck. The chickens are not tested on Campylobacter when they are in the broiler houses. I ask him in what priority the chickens are slaughtered. He tells me the slaughter order depends on the salmonella status. So first the negative salmonella flocks are slaughtered, followed by the salmonella positive flocks. For the salmonella positive flocks a difference is made in the magnitude of danger of the salmonella bacteria. After every ride, the transport cars and crated are totally cleaned and disinfected. He tells me that they are not in contact with the poultry catch group, but the farmer is. In less than 8 hours the chickens always have to be slaughtered after being thinned.

How older the chicken is, how bigger the chance of Campylobacter in the chicken is. In the slaughterhouses once a week, 15 chickens are tested on Campylobacter. So every week on a random and new moment (one week, on Monday morning, but the second week, on Tuesday afternoon), 15 chickens of one specific flock are tested. The time and day is scheduled and is controlled by the NVWA. The schedule is developed so slaughterhouses can not choose to take the sample every week on Monday morning to avoid cross contamination with other flocks. Yearly during the audits, the Campylobacter level is monitored. Measures that can be introduced to reduce the level of Campylobacter in chicken meat by slaughterhouses, is using hot water and use extra disinfection. The requirements set are non-binding requirements and will get stricter every five year. He tells me the slaughterhouses can contribute to the reduction of Campylobacter positive meat by slaughtering really hygienic. This can be done, by using more hot water on the pickers and a tighter adjustment of equipment. The Campylobacter bacteria are settled in the cecum of the chicken.

B.2.9 *Summary of interview with Poultry catch group*

He tells me everything starts at the chicken farmhouse. He tells me about the action plan, which was created to reduce the amount of salmonella in the broiler houses. Samonella was seen as much more critical than Campylobacter. He starts quickly about the feed the chickens eat. It is transported through ships. What if seagulls drop their stool into these ships with chicken food?

I'm asking him about the process of catching and transporting the chickens. He tells me the catching group catches around 1000 chickens per hour. And most of the nights the catching group needs to go to other farmers on one night. They work for about 7 hours per night. When for example, chickens need to be depopulated (thinning), it is standard to visit more farms on one night. However, when all chickens are caught (in week 6), only one farm will be visited. According to the IKB rules, people entering the broiler house always have to shower before entering. This means that the catch crew also should shower before entering. In practice, this is not working. In addition to that, the loader machine comes the broilerhouse. This loader is, of course, cleaned every time it enters a new broilerhouse, but how detailed is it cleaned?

A striking fact he tells me is the differences between the farmers. He says me some of the farmers are following a strict protocol and have, for example, for all catch crew people clothing and shoes. Another part of the farmers cares less.

B.2.10 *Summary of interview with Slaughterhouse 1*

The first question asked to him, was about separating the different flocks arriving from the different farm houses in the slaughterhouse. He tells me that the chickens are not on purpose seperated from each other, but that the chicken meat from the different farmhouses is kept seperated. He says that cross contamination is not applicable for the infection of the Campylobacter. Every time the transport trucks deliver new chicken flocks from a new farm, the transport trucks are getting cleaned, so no bacteria are left behind on the different trucks. The catch group is in contact with the slaughter house and they always switch clothing and shoes when entering the farmhouses. He also tells me that there is a relation between the age of the chickens and the chance of chickens getting infected with Campylobacter. On different moments the chickens are tested on Campylobacter. The NVWA controls the slaughterhouse on the infection rate of campylobacter and other bacteria. When the process hygienium criteria is exceeded, this is communicated to the farmers. He thinks that there is no relation in the hygiene measures of farm houses and the campylobacter infections. The seasonality effect is something which is striking. In winter time around 10 percent of the flocks are infected, while in summer time 70 percent of the flocks are infected. When a campylobacter positive flock arrives in the slaughterhouse, it is not possible to turn this flock into campylobacter negative chicken meat. One of the most important conclusions is that nowadays there is no measure to reduce the campylobacter infections. There are some ideas in literature, but nothing works in practice.

B.2.11 *Summary of interviews with different farmers*

In the table below the information obtained from the interviews with the different farmers is given. The most important conclusions retrieved from these conversations are given below:

- When farmers have to enter the broilerhouse (for example when the chickens are sick), more often, they will not always follow their hygiene protocol anymore.
- In summer time, farmers will also often just enter the broilerhouse, without wearing a overall.
- Overall, for all farmers, the hygiene protocol is strictly. When you want to enter the broilerhouse, you will have to switch your shoes twice (first in the so called "voerlokaal" between broilerhouses, and then in the broilerhouse itself).
- They all tell me in summer they have more problems with pests and vensil.
- In summer they see insects such as beetles in the broiler houses.

Table B.1: Summary of interviews with different farmers

	Farmer 4	**Farmer 5**	**Farmer 6**	**Farmer 7**	**Farmer 8**
Conventional or free range	Conventional	Free range	Conventional	Free range (1 star)	Conventional

Chickens per broiler house	41.000	20.000	30.000	15.000	35.000
Process time	6 weeks (in week 5 thinning)	8 weeks (no thinning)	6 weeks (in week 5 thinning)	8 weeks (no thinning)	6 weeks (in week 5 thinning)
Amount of broiler houses	1	3	2	2	2
Failure percentage per flock	2.5%	1%	2%	less than 1%	1.8 %
Average of entering the broiler house per day	1.5 times per day	1 time per day	1 time per day (entering) and observing 5 times a day.	2 times per day	2 times per day
Visits of veterenarian	1 time per flock	1 time per flock	2 times per flock (1 for blood, 1 for salmonella)	1 time per flock	1 time per flock
Visits of other people	3 times per week (father and food represantive)	0	1 time per week (food advisor), 7 time per week (wife/son)	4 times per flock	food representative 4x per flock
Switching clothing	Yes	No	Started with one overall for every broiler house, but now have 1 for both broiler houses	No	One overall per broiler house
Switching shoes	Two times switching shoes	Yes, switching shoes per broilerhouse	Yes always (two times: one time in the "voerlokaal" and one time in every broilerhouse	Yes always (two times: one time in the "voerlokaal" and one time in every broilerhouse	Yes always (two times: one time in the "voerlokaal" and one time in every broilerhouse

Road to broilerhouses	A paved road to the broiler house	A paved concrete road	A paved concrete road to broiler house	Paved concrete road, but sometimes i walk through the grass	Paved concrete road
Pests	In the broiler house itself no pests, but around the grain barn there are.	Sometimes there are mouses	No	Sometimes	no
Pest control	yes	Yes	Yes	Yes	Yes
Fans	In summer more often than in winter	In summer more often than in winter. And in the beginning when the chickens are small, we don't need them	In summer more often than in winter	In summer more often than in winter. And in the beginning when the chickens are small, we don't need them	In summer more often than in winter. And in the beginning when the chickens are small, we don't need them
Clear hygien protocol	Yes	Yes	Yes	Yes everybody follows the protocol but you should really control it	Yes

C

Details of the Model

In the following appendix the details of the model are showed. For the main stock flow model and the various submodels, tables are created to show the values and number that are used. Also, the tables show the source on which the values and equations are based.

The temperature variable equation is based on the data from figure C.1. The development rate equation is based on the linear equatiom from figure C.2.

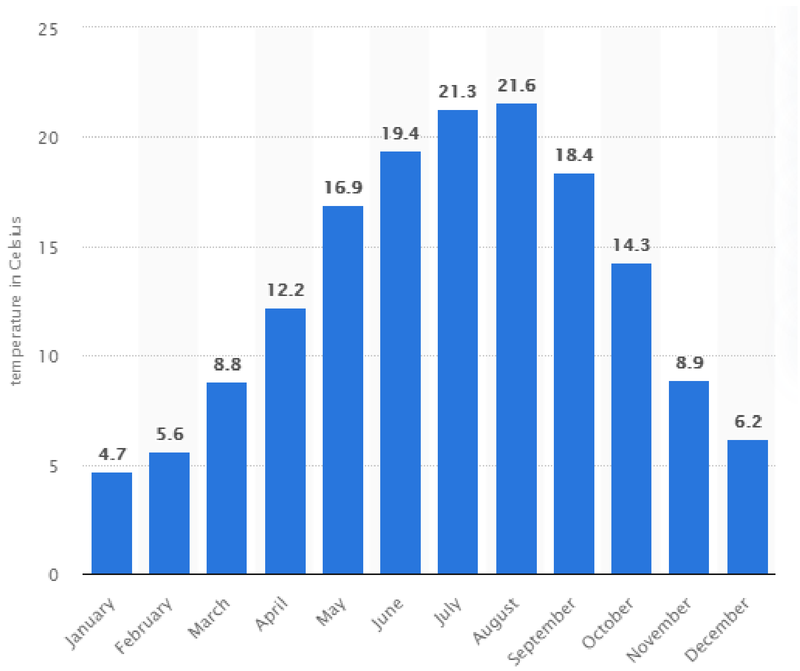


Figure C.1: Maximum average monthly temperature in the Netherlands in 2017 Statista (2017)

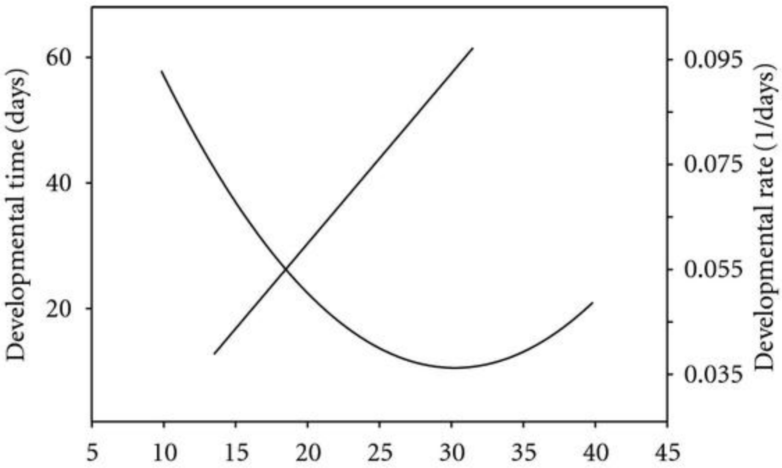


Figure C.2: Development rate of insects over temperature Damos and Savopoulou-Soultani (2012)

In figure C.3 the main stock flow model is shown and in the table below the details of the main stock flow model are shown.

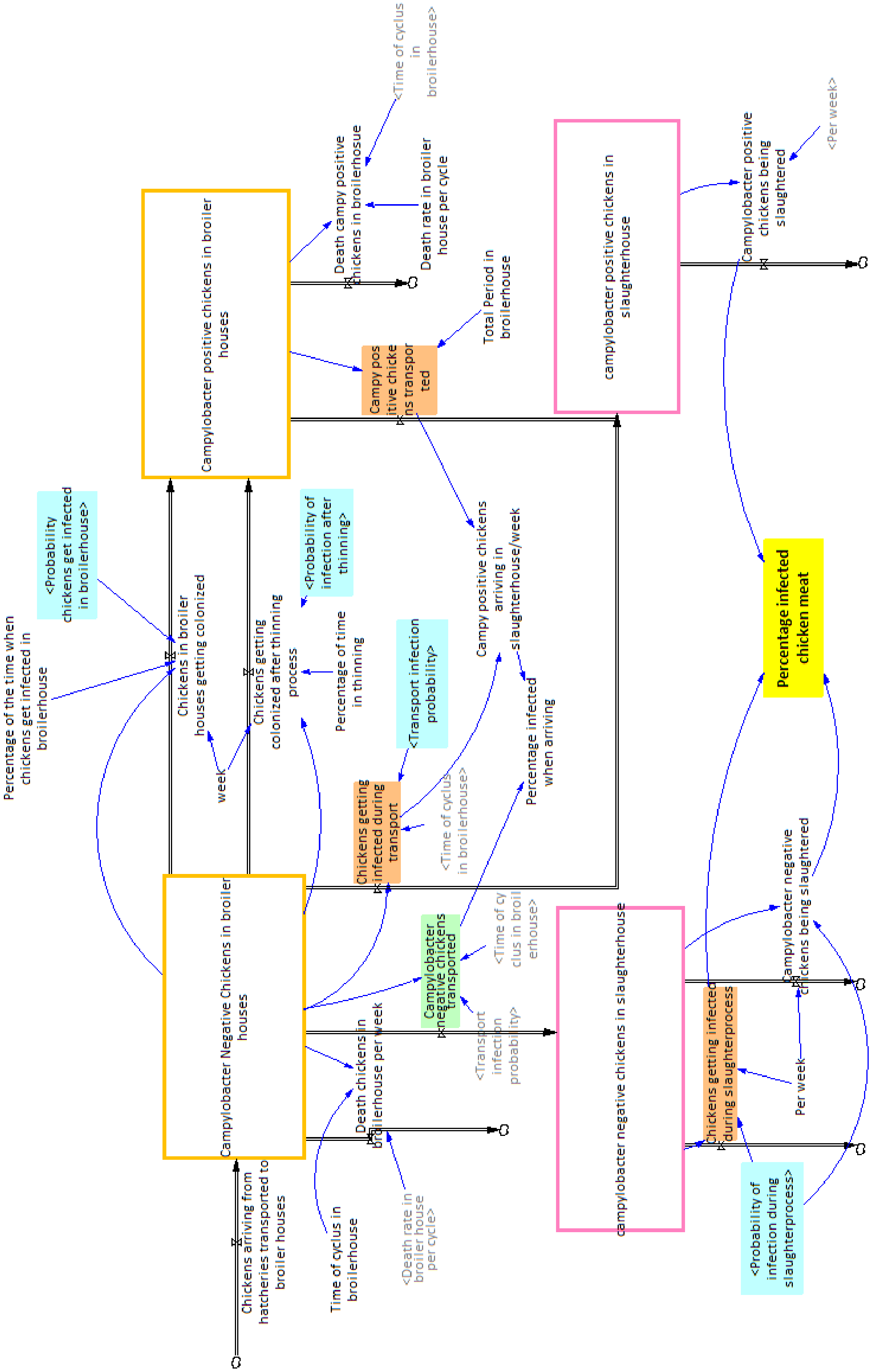


Figure C.3: Conceptual stock flow structure

Table C.1: Details of the stock flow model

Name factor	Units	Initial value	Equation	Source
Time of cyclus in broilerhouse	week	6	x	Interview Farmers
Chickens arriving from hatcheries transported to broiler houses	chickens/ week	x	(4.86843e+07*(6/7))/ Time of cyclus	CBS (2019)
Campy Negative Chickens in broiler houses	chickens	48684314* (6/7)	MIN(Chickens arriving from hatcheries transported to broiler houses-Campylobacter negative chickens not getting infected during slaughtering-Chickens getting colonized after thinning process-Chickens getting infected during slaughterproces-Chickens getting infected during transport-Chickens in broiler houses getting colonized-Chickens not getting infected during transport-Death chickens in broilerhouse per week , ((6/7)*4.86843e+07))	Wageningen University and Research (2020)
Death rate chickens in broiler houses	dmnl		0.02	Interview Farmers
Dead campy negative chickens in broiler houses	chickens/ week	x	(Campylobacter Negative Chickens in broiler houses * Death rate in broiler house per cycle)/ Time of cyclus	x
Chickens in broiler houses getting colonized	chickens/ week	x	(Campylobacter Negative Chickens in broiler houses * Probability of Campylobacter infection in broilerhouse * Possible part of the weeks of getting infected in broilerhouse)/Time of cyclus	x

Table C.1: Details of the stock flow model

Name factor	**Units**	**Initial value**	**Equation**	**Source**
Percentage of Time when chickens can get infected in broiler house	dmnl	4/6	(Campylobacter Negative Chickens in broiler houses * Probability of Campylobacter infection in broilerhouse * Possible weeks of getting infected in broilerhouse)/Time of cyclus	Interview Farmers
Chickens getting colonized after thinning process	chickens/ week	x	(Campylobacter Negative Chickens in broiler houses * Infection rate after thinning)/Time of cyclus	Own interpretation
Percentage of time after thinning	dmnl	1/6		
Campy positive chickens in broiler houses	Chickens	0	MIN(Chicken flocks getting colonized after thinning process+ Chickens in broiler houses getting colonized-"Campy positive chickens getting caught (thinning process)"- Campy positive dead chickens in broiler houses-Left over campy positive chickens getting caught, (6/7)*100000)	Own interpretation
Death Campy positive chickens in broilerhouse	chickens/ week		(Campylobacter positive chickens in broiler houses*Death rate in broiler house per cycle)/Time of cyclus	Own interpretation
Probability chickens get infected in broiler house (submodel)	dmnl	x	Insects infection rate in broilerhouses+ Human infection rate in broiler houses	Own interpretation
Chickens in broiler houses getting colonized	chickens/ week	x	(Campylobacter Negative Chickens in broiler houses * (Probability chickens get infected in broilerhouse)* Percentage of the time when chickens get infected in broilerhouse)/Time of cyclus	Own interpretation
Chickens getting colonized after thinning process	chickens/ week		(Campylobacter Negative Chickens in broiler houses * Infection rate after thinning)/ Time of being in broiler house	Own interpretation
Infection rate after thinning per cyclus	dmnl		"Catchers infection rate (thinning)"+ Material infection rate	Own interpretation

Table C.1: Details of the stock flow model

Name factor	Units	Initial value	Equation	Source
Chickens getting infected during transport	chickens/ week		(Campylobacter Negative Chickens in broiler houses* Transport infection probability)/ Time of being in broiler house	Own interpretation
transport infection probability	dmnl		Material infection rate*Probability chickens stay long on transport and get infected	Own interpretation
campy negative chickens on transport	chickens/ week		DELAY3((Campylobacter Negative Chickens in broiler houses*(1- Transport infection probability))/ Time of cyclus, 0.5)	Own interpretation
Chickens getting infected during slaughterprocess	chickens/ week		(campylobacter negative chickens in slaughterhouse *Probability of campylobacter infection during slaughterprocess)/Per week	Own interpretation
Probability of campylobacter infection during slaughterprocess	dmnl		Probability of carcass contamination +"Probabillity of cross-contimination"	Own interpretation
campy negative chickens being slaughtered	chickens/ week		(Campylobacter Negative Chickens in broiler houses/Time of cyclus)- Chickens getting infected during transport-Chickens getting infected during slaughterproces	Own interpretation
Campylobacter positive chickens being slaughtered	chickens/ week		Campylobacter positive chickens in broiler houses/Per week	Own interpretation
Init neg chickens	chickens		(4.86843e+07)*(1/7)	Own interpretation

The table below shows the details of the first submodel.

Table C.2: Details of submodel 1

Name factor	Units	Initial value	Equation	Source
Time	Week	x	x	Hald et al (2004)
Temperature per week	Degrees	x	13.45 +(8.45 * SIN(((2*3.14)/52)* (Input sinus function* Time-17)))	Statista (2017)

Table C.2: Details of submodel 1

Name factor	Units	Initial value	Equation	Source
Development rate insects	dmnl	x	MAX(0.041 * Temperature*(1/temp)-0.0412, 0.1)	Damos and Savopoulou-Soultani (2010)
Probability ventilator systems working/degree	dmnl/degree		0,042	Interview farmers
Ventilator systems working	dmnl	x	"Probability ventilator system working/degree" * Temperature + 0.04	Interview farmers
Probability insects entering when ventilator system not working	dmnl	x	(1-Ventilator systems working)*0.5	Interview farmers
Probability insects entering the broilerhouse when ventilator is working	dmnl	x	Ventilator systems working*0.9	Interview farmers
Insects infection rate in broiler house	dmnl	x	Development rate insects*(Probability insects entering the broilerhouse when ventilator is working+Probability insects entering when ventilator system not working)*Probability of campylobacter infected vermin on farms	Gilbert and Raworth, 1996
"Probability of camp infected vermin/degree"	dmnl/degree	x	0.03	Assumption
Probability of campylobacter infected vermin on farms	dmnl	x	"Probability of camp infected vermin/degree"* Temperature - 0.05 + Lookup level hygiene (Level hygiene on farm)	Assumption
Level hygiene on farm	dmnl	x		Assumption
Lookup level hygiene on farm	dmnl	x	[(0,0)-(10,10)], (0,0.2),(1,0.18),(2,0.15),(3,0.1),(4,0.05)	Assumption

Table C.2: Details of submodel 1

Name factor	Units	Initial value	Equation	Source
Lookup level hygiene mud	dmnl	x	[(0,0)-(10,10)], (1,0.8),(2,0.6),(3,0.4), (4,0.2)	Assumption
Infection rate in broiler house	dmnl	x	(Insects infection rate in broilerhouses+Human infection rate in broiler houses)	Assumption
Human infection rate in broiler houses	dmnl	x	Probabiltiy of human physically carrying campylobacter*(1-Probability humans following the hygien protocol)	Assumption
Probability of humans physically carrying campylobacter	dmnl	x	Probability of campylobacter infected vermin on farms* "Probability of walking through mud/water before entering broilerhouse"	Assumption
Probability of walking through water/mud before entering broilerhouse	dmnl	x	Lookup level hygiene mud (Level hygiene on farm)	Interview Farmers and own assumption
Visits of veterinarian	visits	x	1,000	Interview Farmers and Vetenerian
Visits of the farmer	visits	x	"Constant visits/degrees"* Temperature+2.8	Interview Farmers and Vetenerian
Visits of other people	visits	x	1,000	Interview Farmers and Vetenerian
Total visits	visits	x	Visits of farmer in broilerhouse +Visits of other people in broilerhouse+Visits of veterenerian	Interview Farmers and Vetenerian
Probability humans following the hygiene protocol	dmnl	x	("Constant of dmnl/visits"* Total visits)+1.16	Interview Farmers and Vetenerian
Constant of dmnl/visits	dmnl/visits	x	-0,029	Assumption
Constant visits/degree	visits/degree	x	0.82	Assumption

The table below shows the details of the second submodel.

Table C.3: details of submodel 2

Name factor	**Units**	**Initial value**	**Equation**	**Source**
Probability of Campylobacter infection after thinning	dmnl	x	("Catchers infection rate (thinning)"+ Material infection probability)	Interview catch group
Material infection probability	dmnl	x	Probability of excretion of feces and pathogens * (1-Probability of cleaning the material strictly)	Interview catch group
Catchers infection rate	dmnl	x	(1-Probability of catcher following the hygien protocol)*(Probability of catchers getting in touch with Campylobacter on the farm+Probability of getting infected by other farmhouse)	Interview catch group
Probability of catchers following the hygiene protocol	dmml	x	Lookup of strictness on catchers(Strictness of catcher on hygiene protocol)* Probability humans following the hygien protocol	Interview catch group and farmers
Lookup of strictness on catchers		x	[(0,0)-(10,10)],(0,0.9),(0.2,0.91),(0.4,0.92),(0.6,0.93),(0.8,0.94),(1,0.95)	Assumption
Strictness of catcher on hygiene protocol	dmnl	x	0.4	Assumption
Probability humans following the hygiene protocol	dmml	x	("Constant of dmnl/visits"* Total visits)+1.16	Interview catch group and farmers
Probability of campylobacter infected vermin on farms	dmml	x	"Probability of camp infected vermin/degree"*Temperature - 0.05 + Lookup level hygiene(Level hygiene on farm)	Interview catch group and farmers
Probability of waking through mud/water before entering broiler house	dmml	x	Lookup level hygiene mud (Level hygiene on farm)	Interview catch group and farmers
Probability of catchers getting in touch with Campylobacter on the farm	dmml	x	Probability of campylobacter infected vermin on farms*" Probability of walking through mud/water before entering broilerhouse"	Interview catch group and farmers
Probability of arriving from other farm	dmml	x	0.8	Interview catch group and farmers

Table C.3: details of submodel 2

Name factor	Units	Initial value	Equation	Source
Infection rate in broiler house	dmml	x	(Insects infection rate in broilerhouses+Human infection rate in broiler houses)	Interview catch group and farmers
Probability of getting infected by other farmhouse	dmml	x	Probability chickens get infected in broilerhouse* Probability of arriving from other farm	Interview catch group and farmers

The table below shows the details of the third submodel.

Table C.4: Details of submodel 3

Name factor	Units	Initial value	Equation	Source
Transport infection probability	dmnl	x	Material infection probability* Probability chickens stay long on transport and get infected	Interview Miriam
Material infection probability	dmnl	x	Probability of excretion of feces and pathogens * (1-Probability of cleaning the material strictly)	Interview Mirian
Probability chickens stay long on transport and get infected	dmnl	x	Lookup transportation time (Transportation time from farm to slaughterhouse)	Interview Catch Crew
Probability of cleaning the material strictly	dmnl	x	0.8	Interview Catch Crew
Probability of normal Feed withdrawel time	dmnl	x	0.2	Interview Catch Crew
Probability of high stress level of the chickens	dmnl	x	0.3	Interview Catch Crew
Transportation time from farm to slaughterhouse	dmnl	x	4	Interview Catch Crew
Lookup transportation time	dmnl	x	[(0,0)-(10,10)],(1,0),(2,0),(3,0.01),(4,0.02),(5,0.03),(6,0.04),(7,0.05),(8,0.06)	Interview Catch Crew

The table below shows the details of the fourth submodel.

Table C.5: Details of submodel 4

Name factor	**Units**	**Initial value**	**Equation**	**Source**
Probability of campylobacter infection during slaughterprocess	dmnl	x	(Probability of carcass contamination+ "Probabillity of cross-contimination")	Interview Slaughterhouse
Probability of carcass contamination	dmnl	x	Probability of contamination during evisceration+Probability of contamination during plucking+Probability of contamination during scalding	Rasschaert et al. (2020)
Probability of contamination during scalding	dmnl	x	-0,04375	Rasschaert et al. (2020)
Probability of contamination during plucking	dmnl	x	0,05	Rasschaert et al. (2020)
Probability of contamination during evisceration	dmnl	x	0,019	Rasschaert et al. (2020)
Probability of cross contamination	dmnl	x	Probability of contamination via the slaughter equipment*Percentage infected when arriving	Rasschaert et al. (2020)
Probability of contamination via slaughter equipment	dmnl	x	Probability of poor cleaning	Interview Slaughterhouse
Percentage infected when arriving	dmnl	x	"Campy positive chickens arriving in slaughterhouse/ week/(""Campy positive chickens arriving in slaughterhouse/week""+ Campylobacter negative chickens transported"	x
Probability of poor cleaning	dmnl	x	(1-Probability of using the right water temperature)* (1-Probability of human working in the slaughterhouse working strictly)	Interview Slaughterhouse
Probability of human working in slaughterhouse working strictly	dmnl	x	0.8	Interview Slaughterhouse
Probability of using the right water temperature	dmnl	x	0.8	Interview Slaughterhouse

D
Model Validation

In the following chapter are the outputs shown of the different verification and validations tests that are conducted for this research.

D.1 Extreme-conditions test

To further test the structure of the model, an extreme-conditions test was performed. As the name suggests, in this test some parameters are set to extreme conditions to evaluate if the model behaves the way it is expected in such conditions. The result of these changes will be evaluated as their impact in the *percentage of chickens Campylobacter positive* variable, as this is one of the KPIs of the system. Due to time constraints, it is not possible to perform this test for every variable. The following figures show the results of the different parameters that are tested. In every figure the influence of the high, low and current value is shown.

Table D.1

	Current value	**Low value**	**High value**
Chickens arriving from hatcheries transported to broiler houses	(4.86843e+07)/7	0	(4.86843e+09)/7
Visits of veterinarian	1	0	100
Probability of arriving from other farm	0.8	0.2	1
Probability of high stress level of the chickens	0.3	0	1
Probability of contamination during plucking	0.05	0	0.5

In the figure below is shown the percentage infected chicken meat over time given the base case and the extreme test of an increased amount of the probability of arriving from other farm (red line) and a reduced Probability of arriving from other farm (blue line). When the probability that a catch crew arrives from another farm it would be logical that the percentage of infected chicken meat is lower, because the chance of infection of Campylobacter will be lower. This is shown in the figure below. The other graph which shows the increased probability gives a higher percentage of infected chicken meat. The behaviour of all three graphs stay similar.

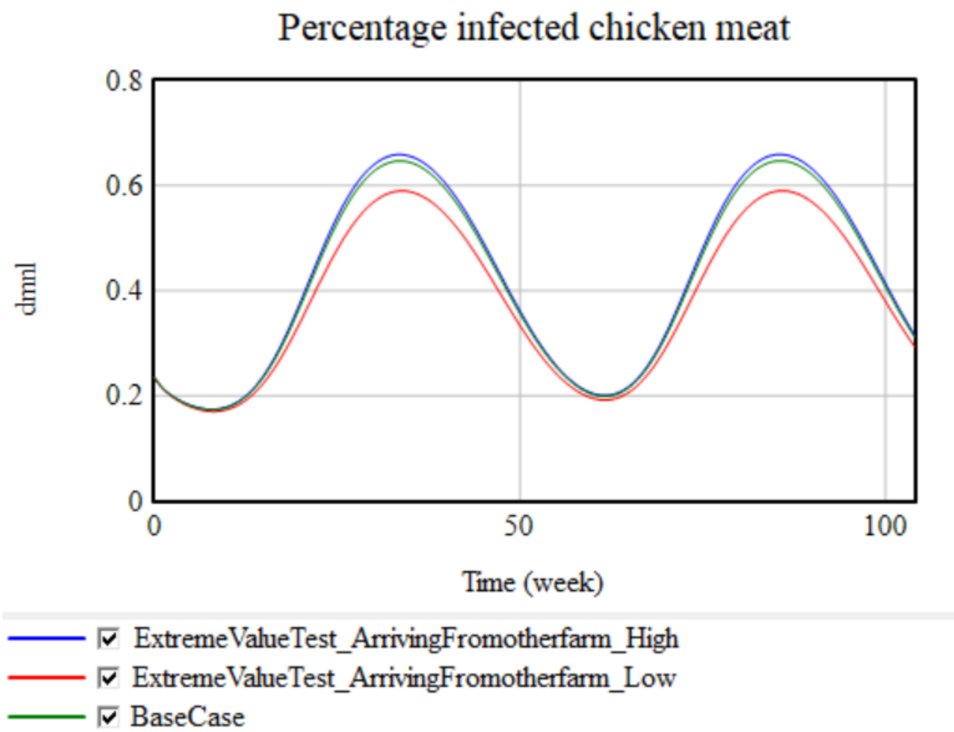


Figure D.1: Percentage infected chicken meat given the base case and the extreme test of increased Probability of arriving from other farm and reduced Probability of arriving from other farm

In the figure below is shown the percentage infected chicken meat over time given the base case and the extreme test of an increased probability of high stress level of chickens (blue line) and a reduced probability of high stress level of chickens (red line). When the probability that a chicken is stressed is higher, the probability of getting infected on transport will increase. This is shown in the figure below. The other graph which shows the increased probability gives a higher percentage of infected chicken meat. The behaviour of all three graphs stay similar.

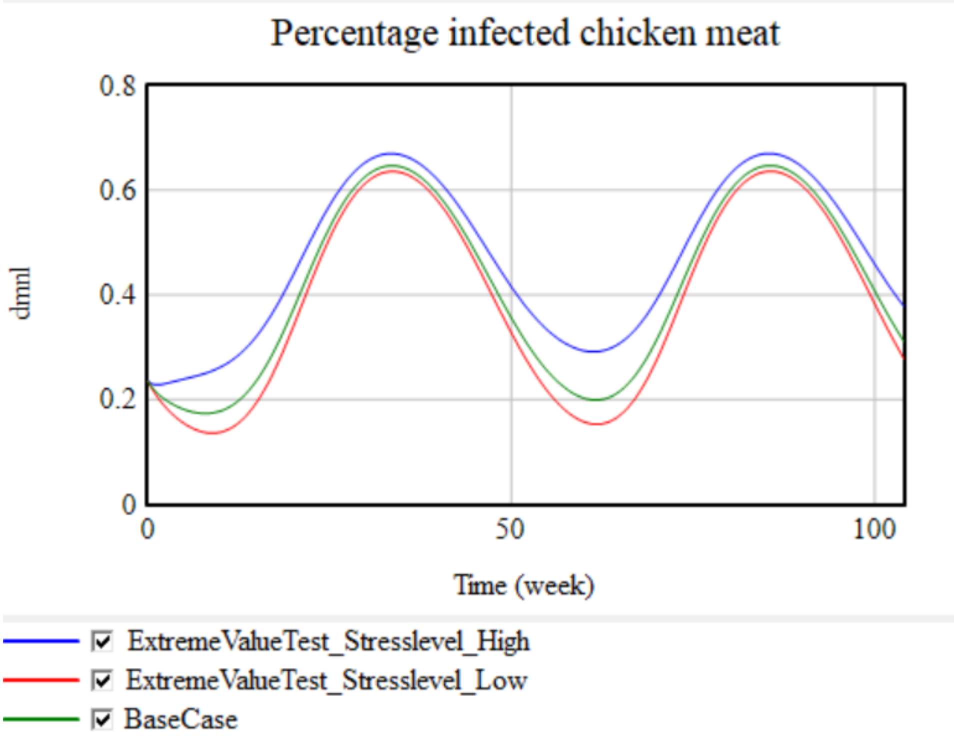


Figure D.2: Percentage infected chicken meat given the base case and the extreme test of increased Probability of high stress level of chickens and reduced Probability of high stress level of chickens

In the figure below is shown the percentage infected chicken meat over time given the base case and the extreme test of an increased amount of the probability of contamination during plucking and a reduced probability of contamination during plucking. As can be seen in the figure below, the increased probability of 1 gives an output of closely 100 percent infected chickens.

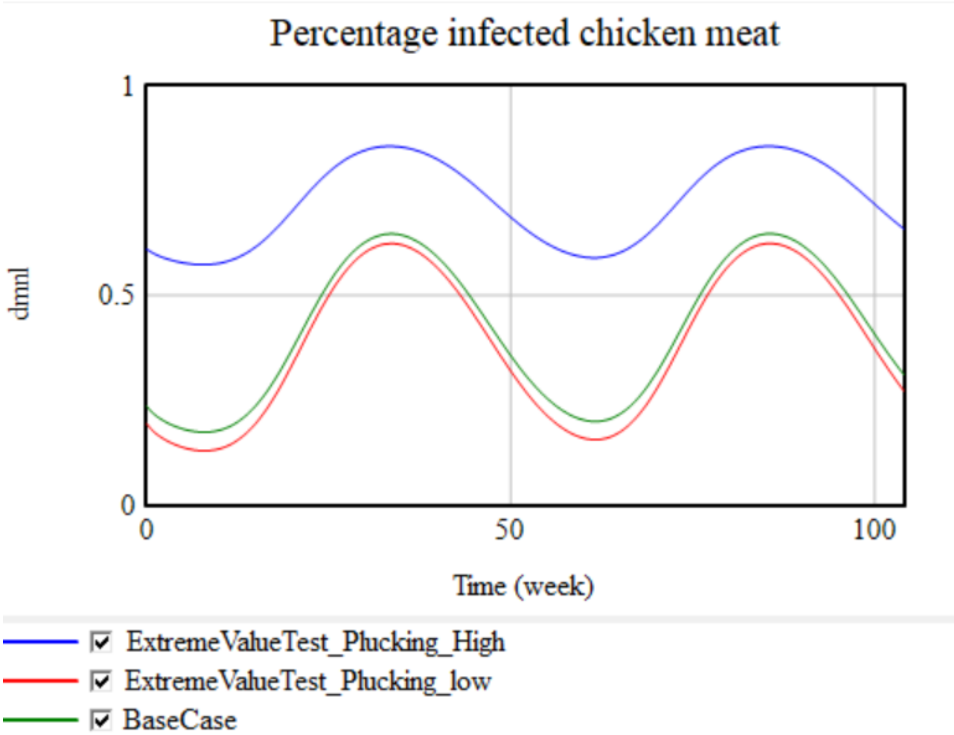


Figure D.3: Percentage infected chicken meat given the base case and the extreme test of increased Probability of high stress level of chickens and reduced Probability of high stress level of chickens

D.2 Sensitivity Analysis

As the model is built resorting to several assumptions and estimates, it is necessary to test how different values in some parameters influence the outcome of the overall model and, hence, cover for the uncertainty inherent to these values. This test is done using the Sensitivity built-in function of Vensim. Using this tool, some parameters are assigned a maximum and a minimum (+- 10% of their value in the model). Then, these parameters vary between these values along a random distribution to see their impact on the model behaviour (in specific, on the KPIs). This was done using an univariate testing - where the value of one parameter is varied while maintaining the others constant.

D.2.1 *Sensitivity analysis infection probability broiler house*

In the figure below the sensitivity analysis is shown for the KPI *probability chickens get infected in broiler-house*, which is visible in the first submodel. Different values of parameters are changed and in figure D.11 it is visible that all graphs have the same behavior, but that the graph in which the parameter *infected vermin on farm* is changed, is the most sensitive. This impact is shown in figure D.5.

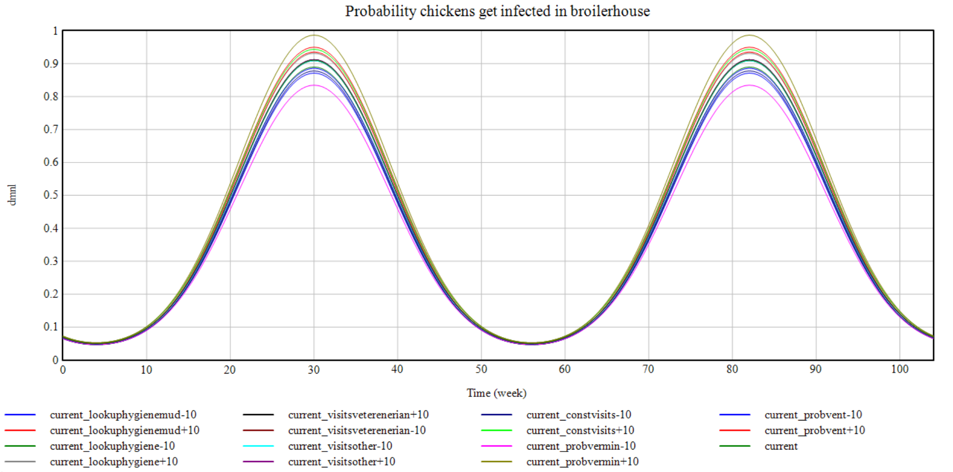


Figure D.4: Probability chickens get infected in broilerhouse given the base case and the sensitivity analysis of 7 different parameters

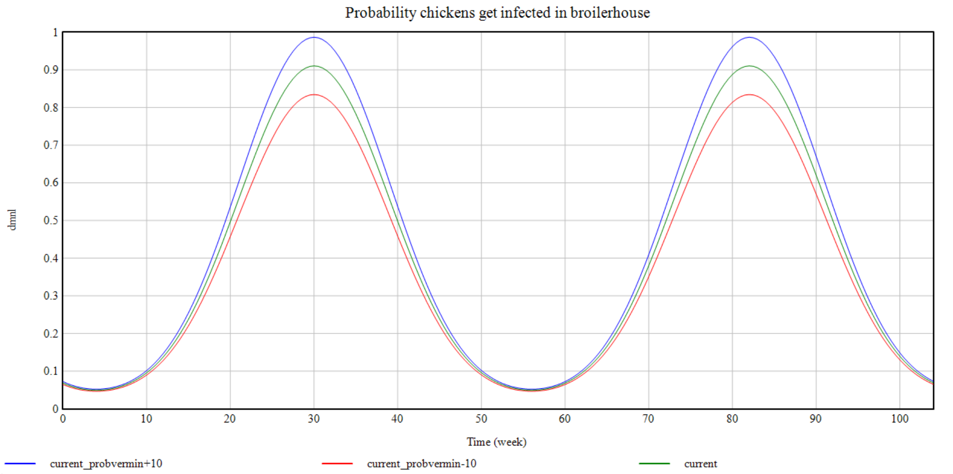


Figure D.5: Percentage infected chicken meat given the base case and the sensitivity analysis of the infected vermin on farm parameter

D.2.2 *Sensitivity analysis infection probability after thinning*

In the following figure an overview is shown of the impact of different changed parameter values on the infection probability after thinning. As can be seen, is the behavior of the different graphs similar as the base case graph (current graph). The most sensitive parameter is the strictness of the catch crew. This graph shows the biggest difference with the base case graph.

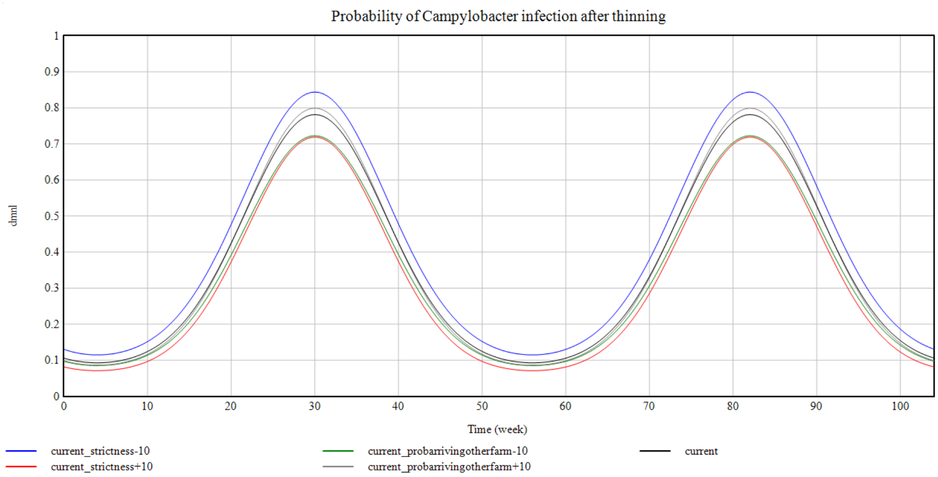


Figure D.6: Percentage infected chicken meat given the base case and the sensitivity analysis of 7 different parameters

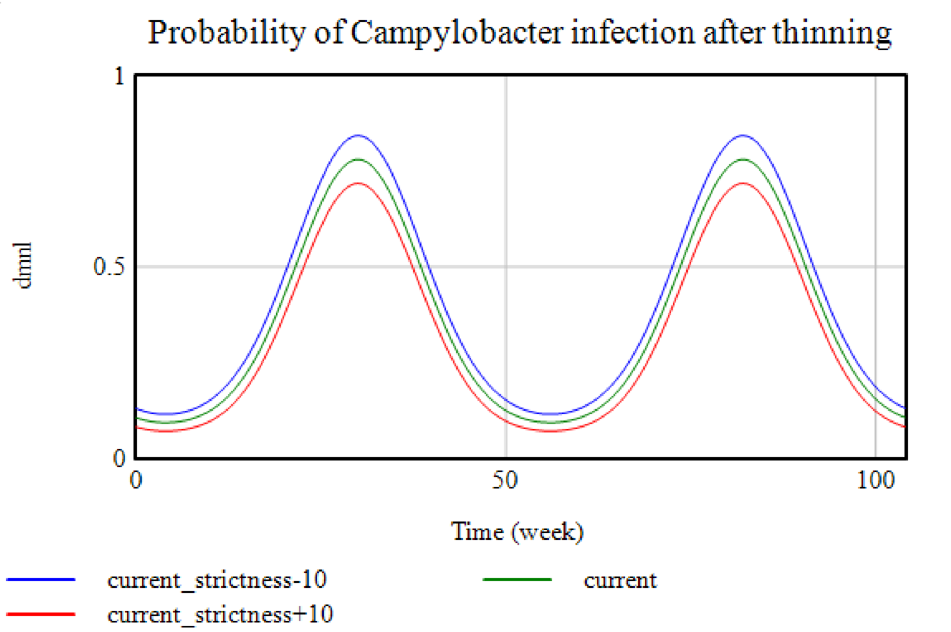


Figure D.7: Percentage infected chicken meat given the base case and the sensitivity analysis of the infected vermin on farm parameter

D.2.3 *Sensitivity analysis infection probability during transport*

As is shown in the figure below, the behavior of the graphs is still stable as one horizontal line of the probability during transport over time. The transport infection probability is really small. The changed parameter of cleaning the transport material strictly shows the biggest impact on the transport infection probability.

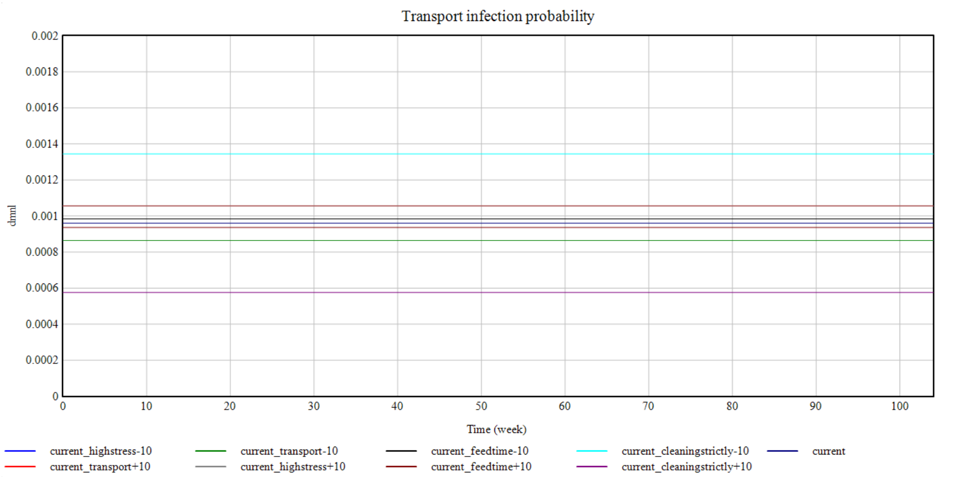


Figure D.8: Percentage infected chicken meat given the base case and the sensitivity analysis of 7 different parameters

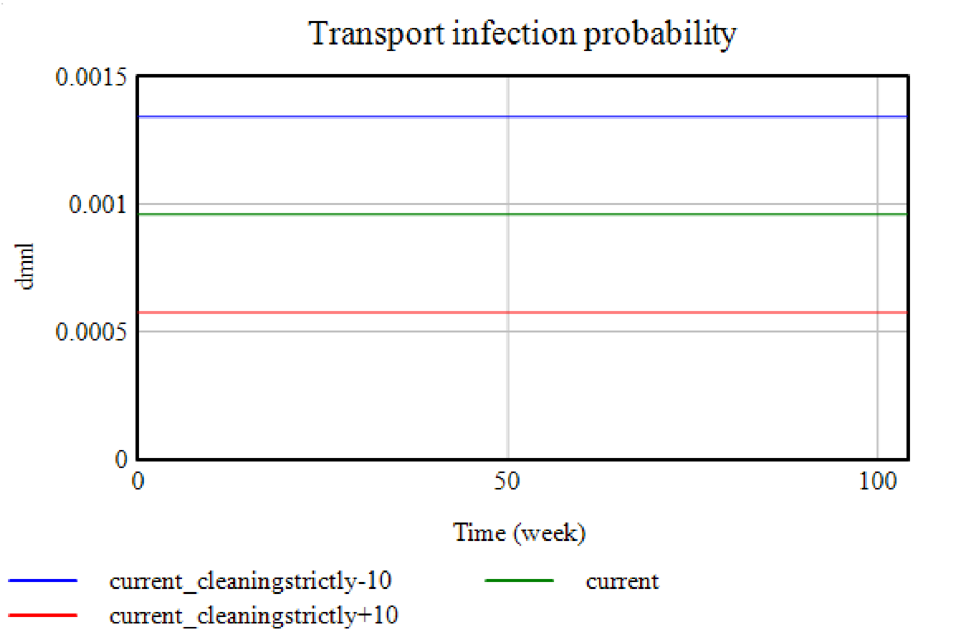


Figure D.9: Percentage infected chicken meat given the base case and the sensitivity analysis of the infected vermin on farm parameter

D.2.4 *Sensitivity analysis probability during slaughtering*

In the figure below the impact of different changed values of parameters is shown on the infection probability during the slaughter process. As is visible, the water temperature and the way the human are working in the slaughterhouse are the most sensitive parameters.

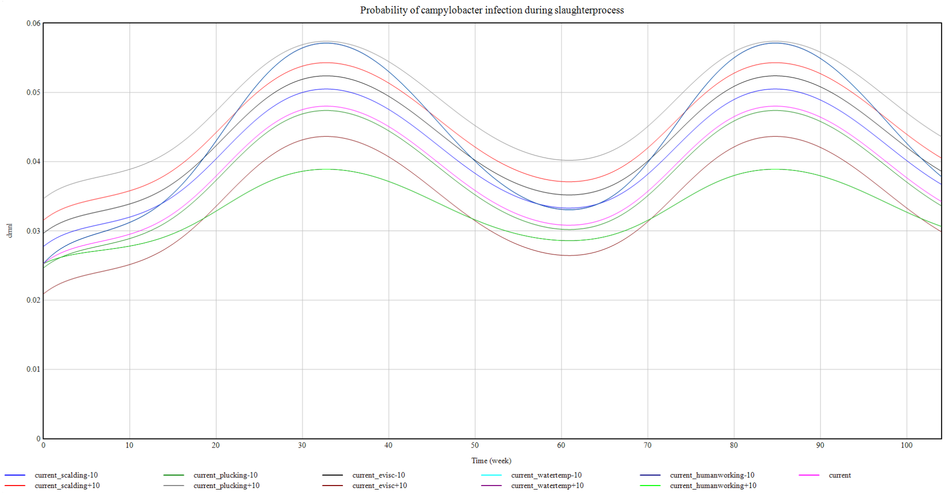


Figure D.10: Percentage infected chicken meat given the base case and the sensitivity analysis of 7 different parameters

Most sensitive parameter

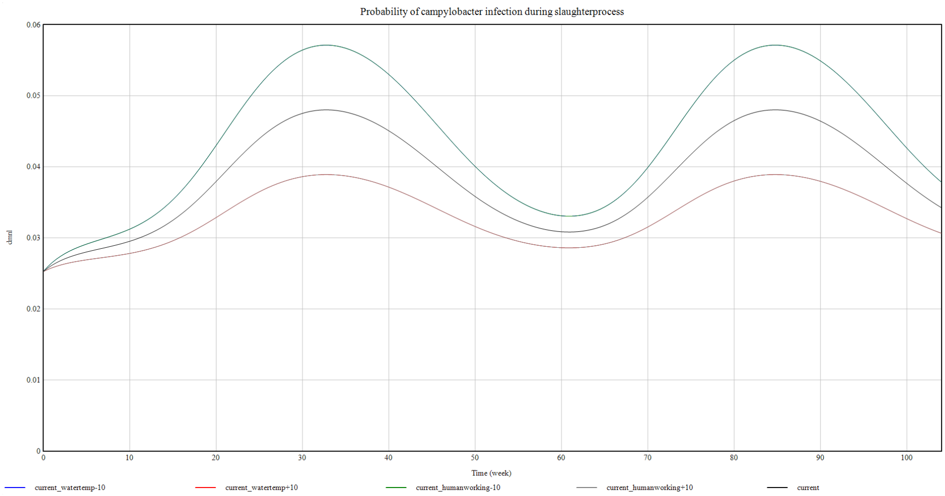


Figure D.11: Percentage infected chicken meat given the base case and the sensitivity analysis of the infected vermin on farm parameter

E

Results

In the following appendix first the various uncertainty analysis graphs are shown. The second part shows two important base case graphs.

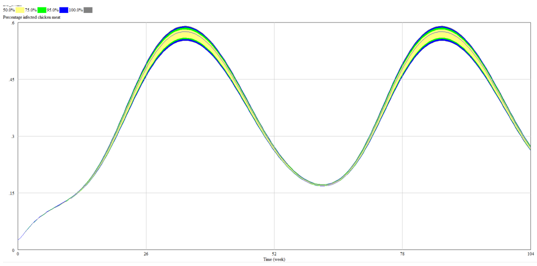
E.1 Uncertainties

A lower and higher value for the uncertain parameters in table E.1, are chosen. Various sensitivity analyses are conducted to see how sensitive these parameters are. As can be seen in the figures below, three different uncertain parameters show the biggest effect on the percentage infected chicken meat. These are the following three:

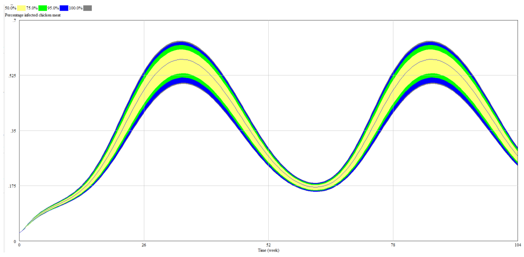
- Probability of Campylobacter infected vermin/degree; This parameter gives the probability of Campylobacter infected vermin per degree on a farm. This parameter is used to estimate the probability of intected vermin on a farm, which is related to the temperature. When the temperature increases, more vermin will be on the farm.
- Probability humans following the hygiene protocol/visit; This parameter gives the probability of humans following the hygiene protocol per visit. This constant is used to estimate the probability that a person follows the protocol based on the number of visits.
- Probability of a high-stress level of the chickens: this parameter shows the probability of chickens having a high-stress level.

Table E.1: Lower and higher value for various uncertain parameters

Uncertain parameters	*Current value*	*Lower value*	*Higher value*
Probability ventilator system working/degree	0,042	0,030	0,050
Probability of camp infected vermin/degree	0,030	0,020	0,040
Constant of dmnl/visits	-0,029	-0,050	-0,010
Probability of arriving from other farm	0,800	0,400	1,000
Probability of high stress level of chickens	0,300	0,100	0,900
Probability of normal feed withdrawel time	0,2	0,000	0,900
Probability of contamination during plucking	0,05000	0,04000	0,06000
Probability of contamination during evisceration	-0,04375	-0,06000	-0,03000
Probability of contamination during scalding	0,01900	0,01000	0,03000

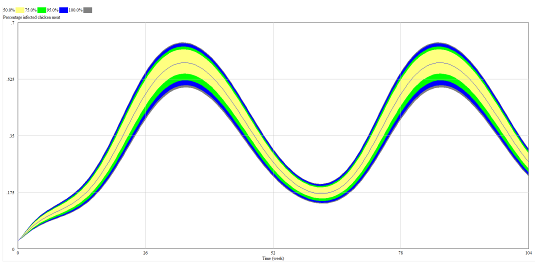


(a) Probability of ventilator systems working

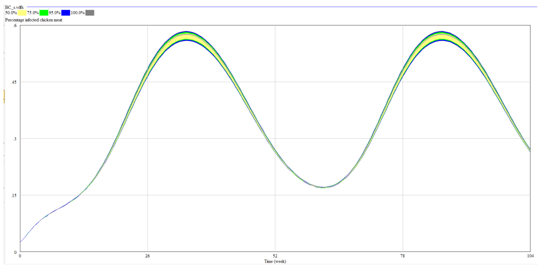


(b) Probability of camp infected vermin/degree

Figure E.1: Sensitivity graphs for different uncertain parameters 1

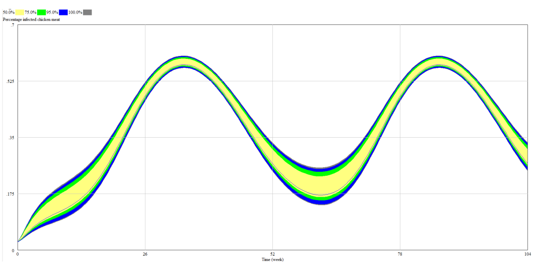


(a) Constant of dmnl/visits

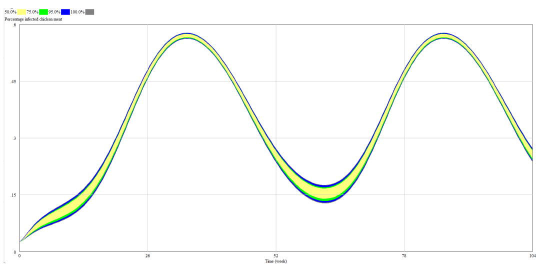


(b) Probability of arriving from other farm

Figure E.2: Sensitivity graphs for different uncertain parameters 2

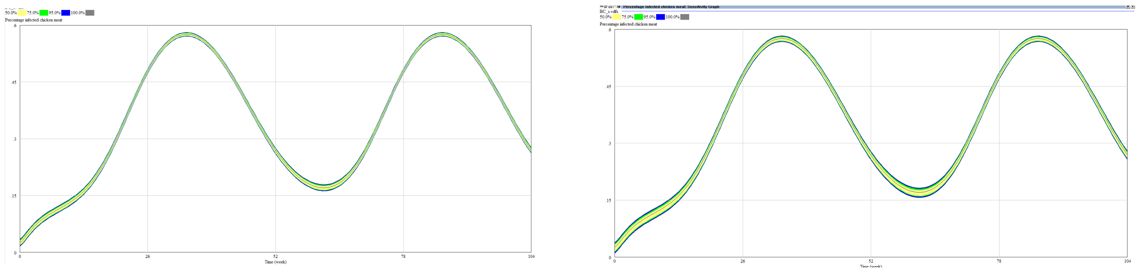


(a) High stress level probability



(b) Probability of normal feed withdrawel time

Figure E.3: Sensitivity graphs for different uncertain parameters 3



(a) Plucking (b) Evisceration

Figure E.4: Sensitivity graphs for different uncertain parameters 4

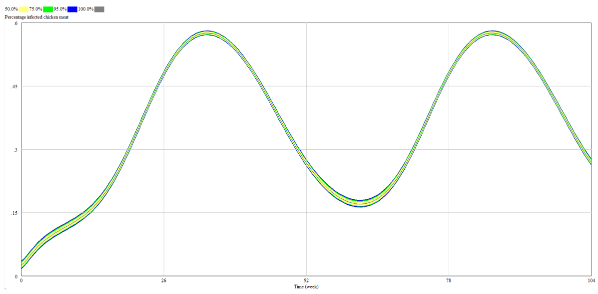


Figure E.5: Sensitivity graph for Scalding

E.2 Base Case Results

Figure E.6 gives the four graphs of the number of campylobacter positive chickens when the various "broilerhouse" policies are implemented. The "Hygiene on farm" policy shows the most positive effect. Figure E.7 gives the graphs of the number of Campylobacter positive chickens when various "Thinning" policies are implemented. The "bye thinning" policy shows the most positive effect.

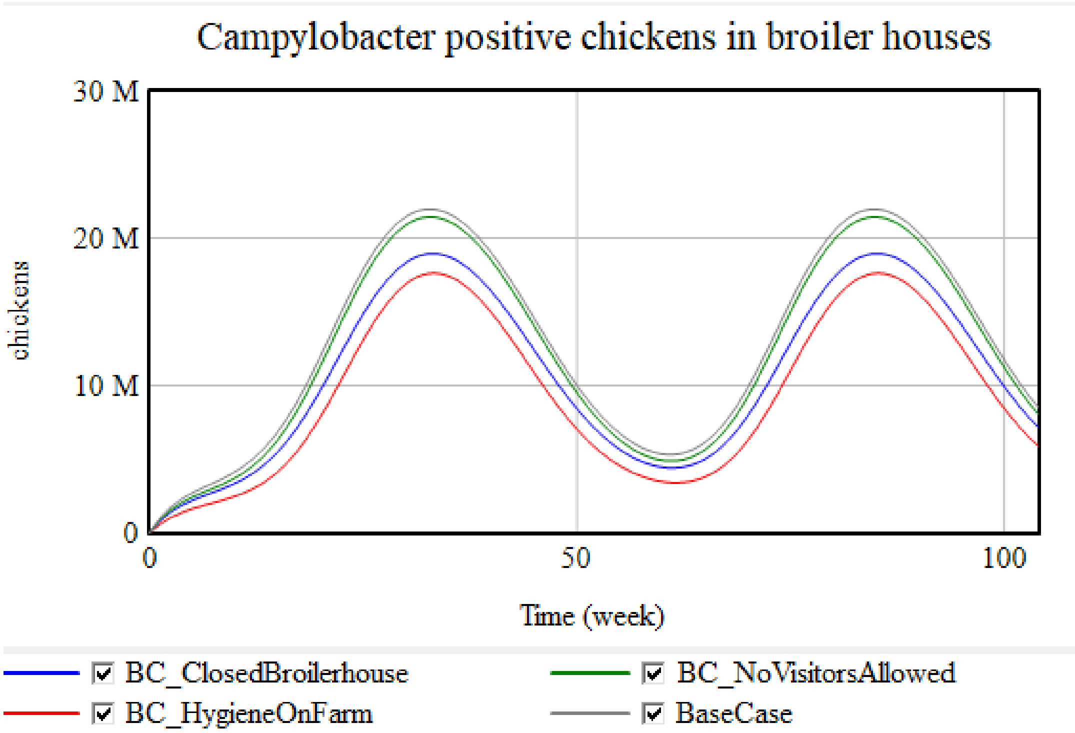


Figure E.6: Campylobacter positive chickens in broilerhouse when various broilerhouse policies are implemented on the base case

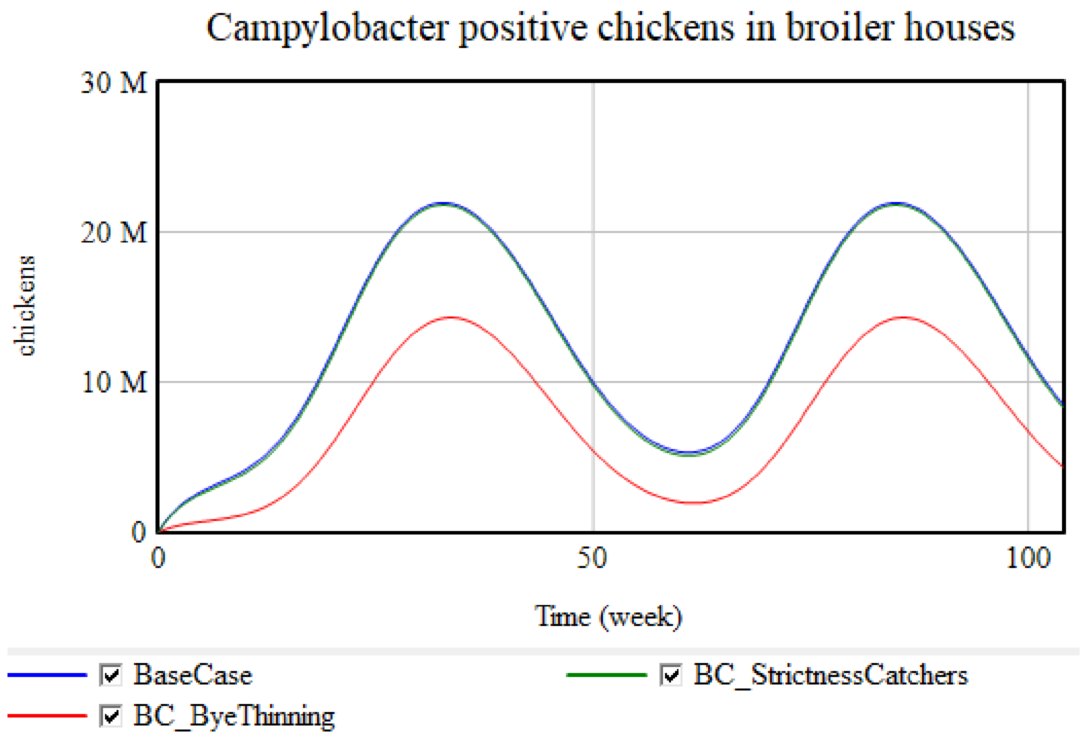


Figure E.7: Campylobacter positive chickens in broilerhouse when various thinning policies are implemented on the base case

Table E.8 gives an overview of the chickens in the system at the in and outflows of the stock Campylobacter negative chickens, at three different time steps.

Time (week)	60	60.5	61
Campylobacter negative chickens transported : BaseCase	5.92145 M	5.92638 M	5.9276 M
Chickens arriving from hatcheries transported to broiler houses : BaseCase	6.9549 M	6.9549 M	6.9549 M
Chickens getting colonized after thinning process : BaseCase	599419	618894	640808
Chickens getting infected during transport : BaseCase	5690.06	5694.79	5695.96
Chickens in broiler houses getting colonized : BaseCase	228923	248162	270219
Death chickens in broilerhouse per week : BaseCase	118543	118641	118666

Figure E.8: Table inflow outflow