Curtin Graduate School of Business

Integrated Supply Chain Model for Sustainable Poultry Production in Bangladesh: A System Dynamics Approach

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This thesis is presented for the Degree of

Doctor of Philosophy

of

Curtin University

DECLARATION

To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Mohammad Shamsuddoha

Date: 14 May 2014

DEDICATION

To My Loving Family

My Mom, Dad (Deceased), Sister, Brother and Parents-in-Law

My Wife: Tasnuba Nasir (Nomi)

My Kids: Fawaaz and Faizaan

"THANKS TO ALL THOSE WHO KEEP ME IN THEIR CONSTANT PRAYERS"

ACKNOWLEDGEMENTS

“In The Name of Allah, The Most Beneficent, The Most Merciful."

First, thanks to my creator Allah to give me honour and opportunity to pursue a PhD under a prestigious business school and scholarship.

My deepest appreciation goes to Professor Mohammed Quaddus, my supervisor. It would not be possible to pursue a PhD using rigorous methodology without receiving his patience, guidance and supervision. I really owe my deepest gratitude to him for his encouragement, guidance and support, especially in the critical stages of my PhD. I also thank Mrs Quaddus for encouraging comments whenever I have had the chance to meet with her. My sincere gratitude also goes to Associate Professor Desmond Klass, my co-supervisor, for his guidance on this journey.

My heartfelt gratefulness goes to the Australian Government and Curtin University for their exclusive IPRS scholarship along with tuition and living expenses. I am also thankful to the University of Chittagong, Bangladesh for allowing me to pursue my PhD under study leave. Special thanks to Associate Professor Therese Jefferson who has motivated me throughout the study. My extended appreciation goes to Associate Professor Jeremy Galbreath, Professor Alma Whiteley, Professor Alison Preston, Professor Al Rainne, Rod McDonald from Rockefeller College, USA for their kind mentoring. In addition, I would like to convey my warmest gratitude to all the CGSB staff and my alumni PhD colleagues.

I am particularly indebted to my parents for their immense contribution to my life to travel to here. My father would have been the happiest person in the world to see my success. As he died in 1994, I will really miss the opportunity to show my success to him. However, my Mom and elder brother and sister will be happy to see my achievements. Without them, it would never have been possible to have the patience to accomplish such a journey.

Foremost, my honest and sincere gratefulness to my caring and loving wife, Tasnuba Nasir, who is beside me to cheer me up at all times although she is also a PhD student. She is used to cooking and managing most of the housework for the sake of allowing me to study. There is no word to convey how much I love her. I have really deprived my kids a little, 11-year-old Fawaaz and 21-month-old Faizaan. They are used to seeing me as the busy father with a laptop all the time. Thanks for their unconditional sacrifice, immense love and patience. My achievements are dedicated to all of you.

Well, the list of people who I need to thank will not fit in a single acknowledgements section. I have just mentioned some people whose contribution is obvious. I may have missed a few names. May Allah give reward to all my relatives, friends, colleagues and staff for their heartfelt assistance.

I love you all!

ABSTRACT

The concepts of sustainability and supply chains are essential elements for modern businesses in facing the immense challenges of competition and in managing economic, social and environmental sustainability. Contemporary literature reveals that, to date, the poultry livestock sub-sector has not received sufficient consideration from academics. This particular industry is suffering from unstructured supply chain processes, lack of awareness of the implications of the sustainability concept and failure to recycle poultry wastes. Structured supply chain processes and the sustainability concept are assumed to be mandatory to achieve additional sustainable benefits. So far, no initiatives have been undertaken by academics to close the research gap. To ensure an integrated sustainable supply chain process, research on this particular industry is worthwhile. Thus, the current study is an attempt to develop an integrated poultry supply chain model based on a case study. This current research has considered both sustainability and supply chain issues in order to incorporate them in the poultry industry in Bangladesh. The integration process model is an extended version derived from real-life scattered processes carried out by different supply chain members. By placing the forward and reverse supply chains in a single framework, existing problems can be resolved to gain economic, social and environmental benefits, which will be more sustainable than present practices.

This research incorporated the theoretical foundations of sustainability and the supply chain to examine possible improvements in the poultry production process along with waste management. This quantitative research also adopted the positivist paradigm and 'design science' methodology with the support of 'system dynamics' and the 'case study' method. Initially, a mental model was developed followed by development of the causal loop diagram based on in-depth interviews, focus group discussion and observation techniques. The causal model helped to understand the linkages between the associated variables for each construct. Finally, the causal loop diagram has been transformed into a stock and flow (quantitative) model, which is one of the prerequisites for a system dynamics (SD)-based model. Various equations and formulae were deployed to construct the complete stock and flow model to replicate real-life relationships in a virtual simulation environment. Moreover, a decision

support system (DSS) tool was used to analyse the complex decision-making process in selecting an accurate extension of the project.

The findings revealed that integration of the supply chain could bring economic, social and environmental sustainability along with a structured production process to support the research objectives and research questions. It is also observed that the poultry industry could apply the model outcomes in their real-life practices with minor adjustment. This present research has both theoretical and practical implications. The proposed model's unique characteristics in mitigating the existing problems, an ideal for farmers, are supported by the literature. As for practical implications, the poultry industry can follow this structure (as directed by the research model) applying their comprehensive policy prior to testing it in the simulation model to see the complete impact. Positive outcomes will provide enough confidence to implement the desired changes within the industry and their supply chain networks. At the same time, associated supply chain members may have the opportunity to use the same model for better efficiency and performance.

PUBLICATIONS FROM THIS DISSERTATION (UNTIL JANUARY 2014)

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CHAPTER 1:

INTRODUCTION

1.1 OVERVIEW

Bangladesh is a developing country which has many difficulties from economic, social and environmental perspectives. Despite such difficulties, Bangladesh is still doing better in various indexes compared to other homogeneous and neighbouring countries. Bangladesh is managing to supply food and other basics to its huge population of 160 million people. It has achieved self-sufficiency in food production, more than doubled per capita income within a decade, reduced the poverty rate by a substantial percentage and controlled the birth rate, as well as many other achievements. In the livestock sector, Bangladesh has maintained the pace of growth rate as per the demand. Among livestock species, poultry chicken meat, which is a great protein source for the human body, is most popular and part and parcel of Bangladeshis' daily consumption. The poultry industry is one of the important sub-sectors in Bangladesh, contributing in endless ways to Bangladesh's society and economy (Alam et al. 2009; Asaduzzaman 2000). This sub-sector has an immense reputation for creating employment opportunities, cheap sources of protein supply, and direct and indirect income sources for millions of people (Das et al. 2008a). Bangladesh has about 120,000-130,000 poultry farms of all sizes – small, medium and large – with a total investment of around US$2 billion (Rahman 2012). In addition, around two billion chickens in Bangladesh generate some 22 million tonnes of poultry litter (mixture of poultry excreta, spilled feed, feathers, and material used as bedding in poultry farming) a year (Rahman 2012; Saleque 2013). However, this industry still has tremendous scope to grow in terms of production and engaging more people for their livelihood.

Unfortunately, this industry has failed to adopt modern concepts, technologies and value addition in poultry product procurement and wastes processing. As a result, this industry fails to take the opportunity of maintaining sustainable growth. Furthermore, the poultry supply chain network in Bangladesh is scattered in nature, and each supply chain member deals with a small fragmented process. Owing to minimum coordination among supply chain players, the cost of production goes up. Moreover, farmers are facing problems in assessing market demands, which often causes over- and under-production. Certainly, over- and under-production lead to an unsustainable situation in the relevant market. Therefore, it is essential that dynamic sustainability and supply chain concepts be practised within the poultry production process and supply chain. Here dynamic sustainability refers as constant learning and problem solving, ongoing adaptation of interventions to concentrate on better adjustments between interferences and existing contexts to expect the superior outcome over time (Chambers, Glasgow, and Stange 2013). It is not likely to get sudden improvement rather progressing it a slow and steady way to achieve sustainable growth. For instance, to improve the Bangladesh poultry situation, the industry needs to practice a dynamic, structured and integrated supply chain process along with sustainability concepts. The logic behind of implementing improvements over the poultry industry due to limited resources (funds, appropriate policy and method). Dynamic system can adopt necessary changes over time to build this industry more sustainable and profitable. This research has placed a special focus on comprehending how supply chain and sustainability practices can be carried out to mitigate socioeconomic challenges.

The Bangladesh poultry supply chain process is also complex in nature because it deals with many uncertainties like different calamities and disasters. Supply-demand imbalance, market price, low productivity, incorrect futuristic assumption, natural disaster like flood, cyclone, seasonal variation are the few names of uncertainties. These uncertainties hinder Bangladesh's poultry industry in achieving sustainable growth. To overcome this situation, the poultry industry needs an appropriate production process, which can be designed through a rigorous supply chain process model, techniques and methodology. The simulation technique in conjunction with system dynamics is a creative tool to support policy analysis and decision making in similar circumstances (Maliapen 2003; Wang et al. 2007). At a corporate level, many industries are interested in reviewing and revising the complex production process through applying suitable methodology, tools and techniques. In practical terms, traditional methods which cannot immediately track problems are used to evaluate strategic decisions involved in maintaining poultry processing. In the past, researchers have rarely offered poultry industry executives a sustainable process and other insights that were easily understandable.

In the supply chain perspective, there are a number of participants at different levels of the poultry forward supply chain process (Barratt 2004). However, they are not coordinated and unaware of what to do with their immediate and preceding supply chain member regarding meeting optimum demand requirements. Each of the members is highly centred on their own process rather investigating the consequences of their ignorance within the process. For example, breeder farmers concentrate on producing more chicks without considering how much supply is needed by the immediate distribution houses. In addition, distribution houses simply sell their chicks with a minimum profit margin and never think about breeder farmers' problems relating to costs, supply and market variability. Similarly, the reverse supply chain along with waste management (Nagurney 2005; Rubio 2008) is never prioritised by farmers and policy makers. They always assume that someone will do the waste management or that it has no additional monetary benefit. However, reverse supply chain concept is using for different electronic wastes in various countries (Nagurney 2005). The same concept can be applied in this current research. Yet, most of the supply chain members never consider the social and environment benefits that are also linked with long-term goodwill. Such a self-centric business attitude destroys their good image with customers (Labus and Stone 2010). Subsequently, customers erupt with several complaints against them, which are related to high pricing, supply vulnerability, low quality and the degraded environment. In seeking to overcome such disorganized circumstances, an integrated forward and reverse supply chain with sustainable practices can ensure economic, social and environmental benefits (Linton, Klassen, and Jayaraman 2007).

Realizing the current situation as discussed above, the poultry industry in Bangladesh needs to reduce the gap between the ideal supply chain and current practices. System dynamics (SD) approach may be a solution for this research as it aims to build an interactive and integrative model where maximum coordination among the supply chain members will be ensured. System dynamics can be offered suitable extended model with simulation results for the complex supply chain system (Jain, Wadhwa, and Deshmukh 2009). At the same time, the SD approach considers the other perspectives of production forecasting, sustainable benefits prediction and benefits from poultry wastes reversal through making by-products. Such dynamic research may consist of designing a revised process model which by examining possible inputs can find out desired outputs. These methods can be key sources for upgrading the existing situation of a particular business process. Later, proper analyses from model testing can be key sources for increasing and improving learning about better decision making or appropriate policy making as policy makers can receive alternative ideas from 'what-if' analyses using the model(s) to compare with reality (Morecroft 1988b).

The necessity of the current research is enormous due to the existing supply–demand gap, opportunities to invent supplementary benefits from the existing operation, and the chances of creating more small and medium enterprises (SMEs), entrepreneurs and employment. In addition, poultry value-added products and by-products from wastes are still a new idea for Bangladesh. Such enormous scope is the instigator of the current study to examine these issues to find out a suitable sustainable poultry process. The study inspects a parent stock (PS) farm renowned in terms of production, experience and process as a case. However, other parts of the industry such as grandparent (GP), broiler and layer farms and individual distribution houses are beyond the scope of the current research.

1.2 BACKGROUND OF THE RESEARCH

The poultry industry in Bangladesh consists of an extended forward supply chain which starts from grandparent (GP) breed rearing and finishes with the final products of chicken eggs and meat (Laughlin and MIBiol 2007). In addition, giant companies are managing their wastes through converting them into valuable by-products (Reinhardt 2000). In fact, they are managing their wastes not for profit but in order to protect their sensitive poultry breed from possible diseases. However, the profit motive is also appropriate if wastes are properly handled and reversed through an appropriate channel. There is an immense opportunity to implement reverse logistics in the poultry industry. Interestingly, a little evidence is found on reversing poultry wastes for the potential and existing market. Again, a number of supply chain members exist within the poultry forward and backward process. With such a supply chain network, the poultry industry has significantly contributed to the society and economy of Bangladesh (Saleque and Mustafa 1997). Unfortunately, the Bangladesh poultry supply chain is not structured enough to obtain its potential maximum benefits.

Furthermore, environmental issues are increasingly important due to huge population pressures, limited land resources, food crises and drastic climate changes (Liverman et al. 1988). Indeed, the current poultry farming process is damaging the environment which creates more burdens for Bangladeshi society. Consequently, strong awareness is mounting in support of implementing environmentally friendly operations for poultry businesses through designing an effective supply chain and introducing the concept of reversing wastes at the national and industry level (Mudgal et al. 2010). Inappropriately, most poultry farmers do not have scientific knowledge on modern poultry and poultry waste management, which results in tonnes of poultry wastes being dumped in the lowlands, rivers and on vacant land (Zavodska 2000). In this situation, it is crucial to implement a proper supply chain and apply sustainability theory to this particular industry and its operations. This research proposes a realistic poultry process model with necessary extension which includes the concept of integrating both forward and reverse supply chains. It is assumed that the use of a reverse supply chain has the potential of removing environmental hazards by utilizing existing poultry wastes (Mbuligwe and Kaseva 2006). In addition, various by-products from poultry wastes are socially, economically and environmentally feasible for home and industrial use. This approach is also beneficial for economic and social gain for the community through creating additional profit, new businesses and entrepreneurs. Therefore, it is justified to conduct a research study in this field to gain maximum benefits towards achieving sustainability. Successful implementation of the current study will add theoretical and practical knowledge to modify the existing poultry process for the sake of gaining sustainable benefits.

1.3 PROBLEM STATEMENT

Sustainability performance and outcomes are the major concern for modern companies to ensure maximum facilities (Siddique and Quaddus 2011; Quaddus and Siddique 2011). Again, sustainable planning should therefore be done to accomplish the targeted goal (Quaddus and Siddique 2004). Moreover, a sustainable process helps to expand the current business operation and extend its supply chain network (Moore and Manring 2009). Obviously, an extended network accommodates many small and medium enterprises (SMEs) as supply chain members and stakeholders. In addition sustainability brings triple bottom line (social, economic and environmental) success to the industry concerned (Savitz 2006; Dyllick and Hockerts 2002; Epstein 2008; Blackburn 2012). Conversely, sustainability cannot be achieved until or unless the supply chain process is smooth and efficient (Lee 2004). An effective supply chain assists a firm to achieve sustainability. In addition, an efficient supply chain contributes to society in terms of employment creation (Porter and Kramer 2011), entrepreneurship development (Ketchen Jr and Hult 2007) and increased firm performance in various aspects of profitability, productivity and optimality (Gunasekaran, Patel, and McGaughey 2004; Beamon 1999). The above-mentioned literature reveals that both sustainability and sustainability concepts help a firm to achieve so many things by incorporating sustainable outcomes. It is assumed from the various literature and observation that the Bangladesh poultry industry is not considering such issues in their operation. To date, the concerned industry is only motivated by the 'produce as much as it can' policy without considering these facts. This study now attempts to relate the above concepts within the research context to address the research questions.

Bangladesh is considered to be one of the suitable countries in the world for poultry rearing due to access to cheap labour, easy access to the community, available indigenous items and shortage of supply compared to growing demand. As discussed earlier, such suitability can be justified by reason of employment creation, entrepreneur development, social and economic changes in rural, urban and suburban areas and environmental restoration. However, it is argued that the Bangladesh poultry industry does not have structural and technological facilities to adopt modern concepts in its processes (Jensen and Dolberg 2003). In practice, the poultry industry consists of small farmers who are involved in rearing a couple thousand poultry birds with their modest investment (Dolberg 2001). Several studies have been conducted on areas such as identifying problems and future prospects (Ali and Hossain 2012; Shamsuddoha and Sohel 2004); poultry production and demand projection (Nielsen, Roos, and Thilsted 2003; Dolberg 2004); the relationship among production, efficiency and breed (Sazzad 1992); etc. In addition, other studies have also been conducted on poverty eradication and employment creation through poultry farming, (Fattah 2000; Rahman 2003; Permin, Pedersen, and Riise 2001); poultry farming as alternative income generating activities (AIG) (Shamsuddoha and Sohel 2008); contract farming (Begum 2005); semi-scavenging poultry production (Nielsen, Roos, and Thilsted 2003); poultry disease (Islam et al. 2003); rural development through poultry (Sazzad 1992; Mack, Hoffmann, and Otte 2005); family poultry (Guèye 2002; Jabbar and Seré 2004); etc. Arguably, poultry farmers cannot implement optimum production and maintain sustainable growth without an innovative policy (Jabbar et al. 2005; Jabbar 2005). Thus, innovative policy with sustainable design can make the difference to gain ultimate sustainable success for the industry.

There has been no evidence of research conducted on the poultry supply chain in light of Bangladesh poultry. It is also rare to find academic writings on the global poultry supply chain perspective. Thus, academics have rarely dealt with poultry sustainability and supply chain issues except for a few conceptual studies conducted in recent times. Recent studies have proposed the different important areas of poultry supply chain frameworks, and poultry forward and reverse supply chains (Gwin, Thiboumery, and Stillman 2013; Constance et al. 2013). All these studies have included simplistic models with trivial analyses which is not sufficient for poultry farmers to carry out their own upgrade. These studies have not considered an integrated supply chain model and have failed to deploy a rigorous tool for research reliability in analysing the what-if (policy) circumstances of the poultry industry. Without reliable inferences, it would be very challenging to follow these study recommendations, as companies have invested huge capital that does not support too many experiments. These existing problems with the research gaps have motivated the current study to construct an integrated model for achieving sustainable outcomes.

Since 2010, the integrated supply chain along with forward and reverse networks, poultry wastes, by-products and sustainability have been addressed in several publications published in different journals and presented at conferences. In addition, researchers have also considered the reversal of poultry wastes back to the industry for recycling and reuse to produce by-products thus attaining possible sustainable benefits (Vieira et al. 2012). This approach has the potential of creating new windows for small and medium enterprises (SMEs) that will contribute towards more employment opportunities and reduce poverty. In this research, socioeconomic and environment factors receive priority: the focus is for the industry to reuse its wastes for the sake of solving societal challenges. It is a major concern to conduct research on this burning issue as thousands of small businesses along with millions of people are involved in this industry. The proposed model can be examined virtually to gain insights and a well-thought-of understanding of the implications and benefits of various strategies rather than investigating and overwhelming resources in the real-life situation. This is why carrying out this research is justified to achieve a sustainable industry that might be useful for Bangladeshi society. Notable problems exist in the Bangladesh poultry industry as highlighted in the above paragraphs. It is worth mentioning that developing a sustainable poultry production process is the topmost priority to which no one has yet contributed significant procedures to address. Last but not least, the research gap on forward and reverse supply chains needs to be addressed appropriately through integrating them in one framework.

1.4 RESEARCH QUESTIONS AND OBJECTIVES

The specific purpose of this study is to develop an integrated supply chain model to design a sustainable poultry production process. Simultaneously, forward and reverse supply chains are examined in light of the economic, social and environmental benefits. The model is tested and evaluated to gain more understanding with respect to three research questions and five research objectives. These are mentioned in the section below.

1.4.1 Research Questions

To address the purpose of this study, the following three research questions (RQs) have been developed:

RQ 1: What is the most appropriate sustainable poultry production process for the Bangladesh poultry industry in light of the economic, social and environmental issues?

RQ 2: How can the principles of the reverse supply chain (RSC) be used to recycle poultry wastes effectively?

RQ 3: In what ways can be the poultry forward supply chain (FSC) bring social changes leading to employment generation and, thereby, reducing poverty?

1.4.2 Research Objectives

These three research questions have led to the development of the following research objectives (ROs). The specific objectives of the proposed research are to:

RO 1: Examine the present status of the poultry industry in Bangladesh in relation to its production, process, distribution and consumption of poultry products;

RO 2: Develop a sustainable poultry supply chain model in light of the economic, social and environmental aspects;

RO 3: Assess environmental issues in different stages of the poultry production process;

RO 4: Investigate the implementation of a reverse supply chain (RSC) in recycling and reusing poultry wastes; and,

RO 5: Identify the social impact of a forward supply chain (FSC) in the Bangladesh poultry industry on employment generation.

1.5 FOCUS AND SCOPE OF THE RESEARCH

As mentioned earlier, the focus of this research is to model the poultry process in the simulation environment then integrate and extend it to cover most parts of the supply chains and to utilize all resources effectively. This research considers a case poultry farm, which is one of the top-ranked farms in terms of production in Bangladesh. Several poultry farming systems exist with mainly meat, egg and day-old chick producing farms. This research takes a day-old chick farm (also known as a parent stock farm) as a research case. Therefore, this study does not consider factors at the national or regional level. Likewise, the variables have been considered for building a simulation model in the poultry industry, which may not be applicable at the global, national and regional levels. At the same time, it may not be applicable for another associated industry like poultry feed, marketing or meat and egg producing industries either in the original country or abroad. However, the model can be replicated in the above-mentioned industry if variables are replaced on individual farms. Notably, this study considers only the day-old broiler chick unit from the case parent farm and its associated supply chain up to broiler farm level.

1.6 DEFINITION OF TERMS

Sustainability is commonly defined as utilizing existing resources to meet the needs of the present without compromising the capability of future generations to meet their needs (Daly 1994). Sustainability also focuses on natural balance (e.g. the natural environment) with only inherent acknowledgement of social and economic accountabilities (Jennings and Zandbergen 1995).

Sustainable supply chain management (SSCM) is the management of material, information and capital flow along the supply chain while taking dimensions of sustainable development, that is, economic, social, and environmental into consideration with final consumers' and stakeholders' requirements (Seuring and Muller 2008b). To achieve sustainability, social and environmental matters need to be considered to integrate green/environmental issue within the process (Seuring and Muller 2008b, 2008a).

Forward supply chain (FSC) is a combination of related activities within the supply chain process from converting raw materials to producing finished goods (Cooper, Lambert, and Pagh 1997). Lee and Tang (1997a) and Blackburn, Guide, Van Wassenhove and Souza (2004) introduced the concept of the FSC for substantial financial benefits.

Reverse supply chain (RSC) denotes the sequence of activities essential to retrieve a product from a client and either dispose of it or recover value (Prahinski and Kocabasoglu 2006a). Again, the RSC can reduce the adverse environmental effects of extracting raw materials and waste dumping (Canan, Carol, and Robert 2007).

Parent stock (PS) refers to a mother breed of poultry genetics. Pedigree stock ("pure line") is the highest level of genetics followed by great grandparent (GGP) and grandparent (GP) generations, parent stock (PS), and broiler and layer (AAFC 2012).

Broilers are chickens bred and raised specifically for meat production (Kruchten 2002).

System Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding and discussing complex issues and problems (Radzicki and Taylor 2008). Structurally, system dynamics incorporates feedback information, causality and non-linear relationships between variables of complex systems. The concept of causality in model development has been explained in details in chapter 5. (Williams and Hummelbrunner 2010; Cellier 1991).

1.7 SIGNIFICANCE AND CONTRIBUTION OF THE RESEARCH

The current study contributes to both theoretical and practical aspects of the Bangladesh poultry industry. The present research is undertaken to contribute additional knowledge to the poultry livestock sub-sector and its supply chain. In an attempt to examine the existing Bangladesh poultry process model, this research will propose a revised process model. The proposed poultry process model will address the issues of sustainability, and efficient forward and reverse supply chains. The process model will examine how the social and environmental issues can be dealt with in an integrated way using forward and reverse supply chains. Thus, the proposed research will produce additional knowledge, and contribute significantly on the theoretical aspects of poultry forward and reverse supply chains.

Furthermore, this research seeks to contribute to relevant practices in the Bangladesh poultry industry by developing a sustainable poultry process model based on the simulation tool. The model will be developed to support real-life situations to promote optimal outcomes within limited resources. It is thus expected that the practical application of the study will contribute significantly to the poultry sector of Bangladesh. It will reveal how the issues related to the poultry productivity, namely, efficacy, resource utilization and the environment can be managed by effective use of poultry wastes. Moreover, the revised process model along with the knowledge of sustainability and forward and reverse supply chains will benefit poultry entrepreneurs, executives, stakeholders and workers, the relevant livestock ministry and officials, and the local community. Consequently, this study will significantly contribute to the practical aspects of the Bangladesh poultry industry.

There is no evidence of research conducted on this topic where a poultry supply chain has been analysed based on system dynamics methodology with a simulation tool. This study combines the effectiveness of the theory of system dynamics and simulation modelling to develop true representations of a poultry supply chain for a particular case industry analysing operations and strategic behaviour. In practice, poultry industrialists and policy makers can apply this visual interactive model as a learning tool to improve their decision-making processes. They can also test their intuitive perception by running sensitivity analyses, observing undesirable strategic behaviour, exerting effective policies, visualizing the impacts and modifying the model to include other related issues or scenarios. Such decision-making tools are currently not available in the poultry industry and therefore make a significant contribution to both theory and practice. Thus, this current research is anticipated to contribute to the existing theory, practice and relevant policy.

Theoretical contributions

The theoretical contributions of this research is that it explores and integrates the forward and reverse supply chains taking into consideration the maximization of economic, social and environmental gains. This research explores ways of integrating forward and reverse supply chain products for different groups of customers by considering existing calamities and adopting innovative policies. This particular area adds value to theory which is absent in the Bangladesh context. In addition, this research will improve the current practices of demand and supply measures compared to reality. This study presents a broader picture, if not the complete one, to researchers and educators.

Practical contributions

Poultry producers and stakeholders were looking for such a method from which they could achieve the future behaviour of particular inputs and outputs. Input and output values rely on existing circumstances of capacity, investment, calamities and dynamic policy. Measuring future behaviour in a timely way for various variables is the key to making decisions for better profitability and sustainability. This research model can be implemented in the poultry practices in Bangladesh at different levels of the supply chain of grandparent/parent-broiler farms, suppliers, distributors and retailers.

1.8 ORGANIZATION OF THE THESIS

This thesis is organized and presented in eight chapters. The chapters are intimately related and complementary to each other. The brief outline of the chapters is as follows:

Chapter 1: Introduction

In this current chapter, a brief discussion is provided which reveals the importance of the research and the gap in existing literature. The discussion determines the focus and locus of the research that leads to presentation of the research questions. The research objectives elaborate the research questions concentrating on the very specific areas. This chapter also presents the overall organization of the current thesis.

Chapter 2: Literature Review

This chapter discusses the fundamentals of sustainability, the supply chain, the sustainable supply chain, the poultry supply chain process, the forward and reverse poultry process, integrated process, poultry wastes reversal and various by-products created from poultry wastes. The literature review attempts to relate the current study to the relevant concepts of sustainability and the supply chain. At the same time, the poultry supply chain is discussed in light of sustainability. Finally, the gaps, identified from the literature review, ultimately guide this current study to enrich the present context.

Chapter 3: Bangladesh Poultry Operation and Research Case Description

This chapter consists of an overview of the Bangladesh poultry operation and the poultry case description. Initially, the chapter discusses the Bangladesh poultry industry's operations and includes details about its present status, scope, input–output process, modern technology used in poultry farming, poultry production systems, including poultry genetics, calamities and policy issues in poultry. The study attempts to incorporate most of these issues in the model so that the model can be treated as realistic within a virtual computer screen. The chapter later provides information related to the case industry. The vision, mission, present status, farming process, scope and market share of the research case are discussed in this chapter. Moreover, other areas including farming under the effect of calamities and policy adaptation have been incorporated in this chapter so that the reader will have a good understanding of the case poultry farm and its operations.

Chapter 4: Research Methodology

This chapter presents the methodology supporting this study. The chapter mainly focuses upon discussing and determining the appropriate research approach engaged in carrying out this research. In addition, the research paradigm, research design, research tool, research case, data collection, model construction, a way of quantifying the simulation model, analyses of model output and limitations of the data collection and methodology are also included in this chapter.

Chapter 5: Poultry Supply Chain Model: A System Dynamics Approach

This chapter discusses the process of designing a causal (qualitative) and stock and flow (quantitative) poultry supply chain model under a simulation environment. Initially, the causal model is developed based on observation, focus group discussion, and in-depth interviews. The causal model is designed with all possible interrelated variables using loops. In addition, causes trees for important variables are also discussed in these sections. The stock and flow diagram is later constructed based upon a causal loop diagram by adding appropriate co-variables, data, equations and lookup functions. By adding these variables with equations, the model anticipates working as if it were a practical operation maintained in the case industry. In addition, the length of the loops under a major loop is discussed to acknowledge the complexity of system behaviour. Finally, the integrated stock and flow model is discussed in light of different segments of the simulation model.

Chapter 6: Results of Simulation

This chapter discusses the simulation results for the forward, reverse and integrated poultry supply chains. In the first section, the study discusses the forward supply chain of the poultry industry in Bangladesh. Various rates, variables and equations are described in this section to replicate the forward supply chain. Similarly, this chapter discusses the reverse supply chain of the poultry industry in Bangladesh which is mostly a concern with regard to poultry wastes. This reverse chain considers poultry wastes that are generated in different stages of the poultry process. The model creates a supply chain where all the wastes are collected for reusing or recycling making further by-products to achieve more benefits, including environmental sustainability. In addition, reverse supply chain rates, opportunities for by-product production and sustainable benefits are also discussed. Finally, simulation results for the integrated supply chain process are presented in order to understand its effectiveness.

Chapter 7: Discussion of Results

The results from the simulation analysis are discussed in this chapter. The implications of the research findings are also discussed in this section to realize the practical implementation. More specifically, this chapter presents discussion of the research findings based on theoretical and practical perspectives. Various scenarios are also created to make assurances about the findings of the integrated model.

Chapter 8: Conclusions and Future Research Directions

The final chapter presents the summary of the research and its significant contributions to theory and practice. This chapter acknowledges the limitations of the current research and hence proposes recommendations for future research outlining the possible directions.

1.9 SUMMARY

This chapter provided the background of the current research and established the scope of the current research thesis. It provided an overview of the existing literature gap and outlined how the gap has been addressed through this research. It discussed briefly the existing research in the supply chain and sustainability areas along with the poultry livestock sub-sector. Moreover, the possible research structure using sustainability and supply chain concepts with the help of a system dynamics (SD) research process were also addressed in the above discussion. Furthermore, the research objectives, research questions and key definitions were mentioned in order to understand the direction of the current research. This chapter then presented a brief outline of the organization of this research thesis. To reveal the literature gap, the following chapter discusses relevant research studies.

CHAPTER 2:

LITERATURE REVIEW[1]

2.1 INTRODUCTION

This chapter presents the literature review relevant to the current study. The literature review is focused on several aspects explaining sustainability, supply chain models, the sustainable supply chain, the sustainable supply chain in the poultry industry and the status of the Bangladesh poultry industry in light of achieving sustainability. Relevant sections highlight the literature gap while presenting the literature review. This chapter finds that there is only a little evidence of research conducted on the existing poultry process model based on system dynamics and simulation. Such studies have not considered the integrated poultry operation for achieving sustainable production. This chapter also finds the research gap in integrating forward and reverse supply chain as a whole and poultry supply chain integration in particular. The rationale of the study emerges from the existing literature helping the reader to understand why it is important for this particular context. Relevant concepts and contexts are discussed throughout this chapter to understand the facts that can be deployed in the current study to fill the research gap. Again, the theoretical basis helps to understand the various concepts that may follow in the relevant practice. Accordingly, the research develops a conceptual framework which helps to construct a poultry process model based on the above concepts and the literature gap for this research context. The

[1] Parts of this chapter have been published in the following publications:

a. Shamsuddoha, Mohammad. 2010. "A Sustainable Supply Chain Process Model for Bangladeshi Poultry Industry." In *Curtin Business School (CBS) HDR Colloquium 2010 Perth, Australia,* edited by Joanne Boycott, 1-7. Curtin University: Curtin Business School.

b. ———. 2011a. "Applying Reverse Supply Chain in the Poultry Industry" Emerging Research Initiatives and Developments in Business: CGSB Research Forum 2011, 71-79, Perth, Australia: Curtin University.

c. ———. 2013a. "Livestock Wastes Reuse: A System Dynamic Approach " In *Curtin Business School (CBS) HDR Colloquium 2013*, *Bentley, Perth, Western Australia,* edited by Fay Rola-Rubzen and Jenny Goodison, 17-24. WA, Australia: Curtin Business School, Curtin University.

d. ———. 2011b. "A Simulation Supply Chain Model for a Sustainable and Environment Friendly Poultry Industry: Insights from Bangladesh." In *Australian and New Zealand Academy of Management (ANZAM)*, *Wellington, New Zealand,* edited by Kevin Voges and Bob Cavana, 1-12. New Zealand

e. Shamsuddoha, Mohammad, Mohammed Quaddus, and Desmond Klass. 2011a. "Incorporating Reverse Supply Chain in the Poultry Process of Bangladesh " In *Australian New Zealand Marketing Academy Conference 2011*, *Perth, Western Australia*, 73-81. ANZMAC.

f. ———. 2013a. "Poultry Supply Chain: A System Approach" 31st International Conference of the System Dynamics Society, 117-125, Cambridge, Massachusetts USA: System Dynamics Society.

g. ———. 2013c. "Sustainable Poultry Production Process to Mitigate Socio-Economic Challenge." Humanomics. (accepted)

h. ———. 2013d. "A System Dynamics Approach for Poultry Operation to Achieve Additional Benefits" Winter Simulation Conference 2013, 35-43, Washington, DC, USA: http://www.wintersim.org/

following section addresses the sustainability issues which can be adopted with the supply chain for better output.

2.2 SUSTAINABILITY

No matter what the operation, almost every industry, institution, country and organization is pursuing the achievement of sustainability. The literature on sustainability is discussed in the following section.

2.2.1 Sustainability: A Brief Review of the Literature

The most popular and cited definition of sustainability is derived from the "Brundtland Report" of the World Commission on Environment and Development (WCED 1987, 1), in which sustainable development means "meeting the needs at the present without compromising the ability of future generations to meet their own needs." With reference to the United States (US) Environmental Protection Agency, sustainability is denoted as reservation or recovery of social conditions and ecological capabilities (Sikdar 2003b; Elkington 1994; Jennings and Zandbergen 1995). The reasons behind the growing interest in sustainability are limited resources (Davis 1990; Wakeford 2012; Daily and Ehrlich 1992); over-population (Davis 1990; Daily and Ehrlich 1992); poverty condition (Rhyne 1998); chaotic industrialization (Barrera-Roldán and Saldıvar-Valdés 2002); dwindling living standards (Munro and Holdgate 1991); polluted natural resources (Tilman et al. 2002); global climate change (Belisle 2011); escalation in the consumption of non-renewable resources (Goodland and Daly 1996); and troubled biodiversity and ecosystems (Tilman, Wedin, and Knops 1996). Such issues are creating problems in achieving optimum growth that are hindering companies' profitability.

As a result, an understanding of the following issues has become a priority for academic scholars in solving these problems: the ecological influence of economic activity (Erlich and Erlich 1991); ensuring food security (Lal et al. 2002); meeting fundamental human needs (Savitz and Weber 2006); and the safeguarding of non-renewable resources (Whiteman and Cooper 2000). Again, Diesendorf (2000) includes the three principles of environmental protection, economic growth and societal equity within sustainability. These are sometimes referred to as the "triple bottom line: social, economic and environmental or people, profit, and planet" (Elkington 2004a; Norman and MacDonald

2004; Peacocka and Shermanb 2010; Elkington 1994). Furthermore, Shrivastava (1995) perceived sustainability as the potential for reducing long-term risks associated with resource depletion, pollution and waste management. Management, supply chain, production process, operations and engineering domains are considered in applying sustainability theory for improved productivity (Bakshi and Fiksel 2003). Yet, in the management literature, sustainability focuses on the natural environment, with implied appreciation of economic and social responsibilities (Starik and Rands 1995; Jennings and Zandbergen 1995). The operation management literature has, likewise, considered sustainability from three perspectives of ecology, society and economy (Sarkis 2001; Hill 2001; Daily and Huang 2001). In the macroeconomic viewpoint of sustainability, this research has also taken short- and long-term viewpoints in defining and incorporating sustainability within the current production process (Starik and Rands 1995). Remarkably, sustainability in the engineering field clearly combines three dimensions of organizational sustainability defining it as "a wise balance between economic development, environmental stewardship, and social equity" (Sikdar 2003b; Go´ncz et al. 2007).

In contrast, Shrivastava (1995) described sustainability as proposing the possible risk reduction of resource depletion, variations in energy costs, product accountabilities, wastes contamination and management (Syahruddin 2013). Overall, sustainability is widely known as three-factor success as discussed in the above sections. This three-factor success is also known as triple bottom line (TBL) success. To attain the same in the poultry industry in Bangladesh, the industry needs to incorporate triple bottom line concepts in their existing production system (Dolberg 2004; Ward 2002; Akter and Farrington 2007, 2008, 2009). To explore these three factors, the following section discusses sustainability and the details of its components to understand the relevant indicators.

2.2.2 Triple Bottom Line Sustainability

Interrelated measurements of profits, people and the planet (triple bottom line/3BL) are the important instrument to support and achieve sustainability aims for livestock business (Bader 2008; Heijungs, Huppes, and Guinée 2010). During the mid-1990s, Elkington (1994) attempted to design a framework for sustainability to measure performances at the corporate level. Later, this framework would be called the triple bottom line (TBL) dealing with economic benefits (profits), investment return and providing value for shareholders to comprise environmental and social measurements (Elkington 1998, 1994). However, Savitz and Weber (2006) expressed the opinion that sustainability was an essential code for smart management. Since then, industries have become determined to implement sustainable concepts for the sake of better outputs at various levels. Thus, sustainable performance depends on the three above-mentioned components of economic, society and environment, which are depicted in Figure 2.1 (Elkington 2004b, 1998).

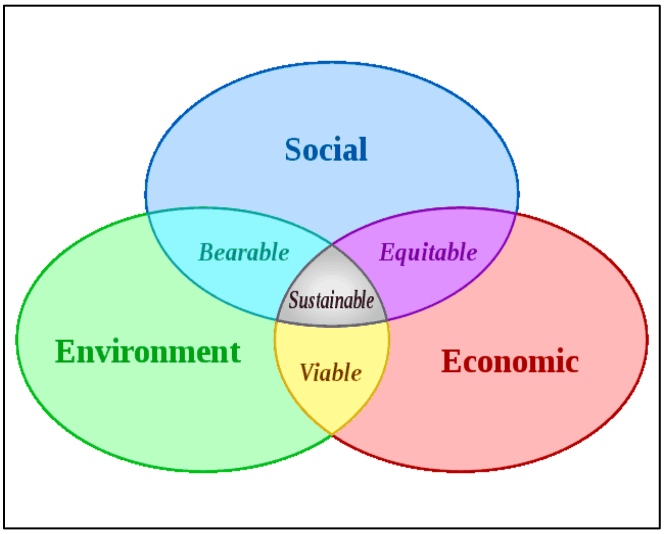

Figure 2.1: Sustainability: The Triple Bottom Line (Carter and Rogers 2008)

Conversely, triple bottom line (TBL) sustainability comprises risk management, transparency, strategy and culture (Hacking and Guthrie 2008; Savitz and Weber 2006; Henriques and Richardson 2004). After that, the effectiveness of applying the triple bottom line to achieve sustainability was examined in the previous literature (Gladwin, Kennelly, and Krause 1995; Hart 1995; Elkington 1998; Henriques and Richardson 2004; Jennings and Zandbergen 1995; Sarkis 2001; Savitz and Weber 2006; Shrivastava 1995; Starik and Rands 1995). As shown on Figure 2.1, Carter and Rogers (2008) argued that any two out of three components can also be treated as 'bearable' (social and environmental), 'equitable' (social and economic) and 'viable' (economic and social). Success in all three factors is called sustainable as discussed above. Hence, the poultry industry in Bangladesh needs to be studied in light of triple bottom line sustainability so that the industry can be managed efficiently to serve the country's people. The economic, social and environmental sustainability matters are discussed in the following sections.

2.2.2.1 Sustainability and Economic Benefits

Sustainable economic performance refers to elements such as employment, profit, value addition and sales which are also the main elements of small business (Venkataraman 2002). Some scholars have argued that employment frequency (turnover) is also logically linked with economic performance. To support this viewpoint, Bjerke (2007) found substantial links between sales, revenues and employment. In addition, many scholars have used profit as an indicator of economic success (Chen et al. 2007; Honig 1998; Davis et al. 2010; Kreiser and Davis 2010). In fact, profit is a fresh blood flow into a business which is necessary to extend and continue the current business. At the same time, the cost of goods sold is a vital component for economic performance which measures ultimate profitability (Zainol and Wan Daud 2011; Laforet 2011; Shrader and Siegel 2007). According to the Global Reporting Initiative (GRI) (GRI 2009), Dow Jones (Knoepfel 2001) and the Institution of Chemical Engineers (IChemE) (Sikdar 2003a) present a number of economic indicators is shown in Table 2.1 which are found to be relevant to the Bangladesh poultry industry. Hence, financial profitability, value addition, sales and cost of goods are the main performance indicators to measure economic factors in achieving economic sustainability.

Table 2.1: Economic Activities Related to the Study

Indicators: Economic Factors	**GRI**	**IChemE**	**Dow Jones**	**Others**
Financial Profitability (Dees 1998)	Y	Y	N	Y
Value Addition (Ahmad and Seymour 2008; Acs and Armington 2004; Cobb et al. 2009)	Y	Y	N	Y
Sales and Cost of Goods (Cobb et al. 2009; GRI 2009)	N	Y	N	Y

Again, the economic issue is the priority for every business, including its own stakeholders' financial performances. The poultry business is no exception to this. The agro-based supply chain targets are a suitable location, supply–demand harmonization and, ultimately, curtailing waste and improving productivity at every stage of a product life cycle are the priorities (Sharma and Patil 2011). Practically, the yields are uncertain, and the available raw material quantities cannot be judged as required with on-time delivery of the final meat products (Mont, Dalhammar, and Jacobsson 2006).

Complaints are directed at the middlemen and retailers who take major shares from the profit or costs as they have been accustomed to playing a powerful role among the stakeholders (Hovelaque, Duvaleix-Tréguer, and Cordier 2009). In fact, middlemen have some limitations relating to cost and to providing the product to their clients. To address this, the sustainable development initiative has evolved for some time to support companies to develop more sustainable products (Maxwell and Vorst 2003). Quality, market stability, technical matters and cost issues are the main considerations for economic sustainability (Maxwell and Vorst 2003).

2.2.2.2 Sustainability and Social Benefits

For social wellbeing, sustainability considers security, a modest lifestyle, comfort and health by maintaining eco-friendly goods and services (McMichael, Butler, and Folke 2003). These can be achieved through employment generation, poverty reduction, entrepreneurship development, facilities for young entrepreneurs, and providing social care (Reynolds et al. 2001; Yunus 2007; Åstebro and Thompson 2011; Dyer and Chu 2003). Ultimately, social benefits reduce the rich–poor divide for that particular society (Butler 2000; McMichael, Butler, and Folke 2003). According to the GRI, Dow Jones and IChemE, a number of social indicators are similar to the current study context. Table 2.2 lists employment creation, poverty reduction, young entrepreneur creation, new venture creation and ensuring social welfare as relevant indicators for social sustainability. The current study has examined how social benefits can be achieved through poultry operations.

2.2.2.3 Sustainability and Environmental Benefits

Currently, profitability, productivity and the environment are receiving more and more focus from manufacturing organizations (Sarkis 2001). Among them, the environment is the burning issue for societies such as Bangladesh. Similarly, it has attracted appropriate attention from academics and practitioners since the 1990s, which shifted classical thoughts from the profit-making goal (Boyazoglu 2002). Obviously, everyone attempts to gain maximum benefits which is also expected of most businesses. It is argued that environmental management can be done for 'not for profit', which will convince and motivate the customer to buy the products from such an eco-friendly operation. Moreover, strong awareness is demonstrated by environmentalist groups to maintain standards for eco-friendly procedures in a production and supply operation.

For example, 90% of US manufacturers have existing environmental strategies and 80% trust their environmentally friendly operations (Boyazoglu 2002; Arbab, Criss, and Miller 1998).

Table 2.2: Social Activities in Poultry Farming

Indicators: Social Factors	GRI	IChemE	Dow Jones	Others
Employment Creation (Reynolds et al. 2001; GRI 2009; Cobb et al. 2009; Knoepfel 2001)	Y	Y	Y	Y
Poverty Reduction (Yunus 2007; Krantz 2001; Coulthard, Johnson, and McGregor 2011; Rhyne 1998)	Y	Y	Y	Y
Create Self-employed Young Entrepreneurs (Wagner 2003; Freytag and Thurik 2010; Lazear 2003; Åstebro and Thompson 2011; Lynch 2004; GRI 2009; Cobb et al. 2009; Knoepfel 2001)	Y	Y	N	Y
Creating New Ventures and Family Business Creation (Stock and Watson 2003; Dyer and Chu 2003; Heck and Stafford 2001)	Y	Y	Y	Y
Social Welfare and Care (Seelos and Mair 2005a; Hall, Daneke, and Lenox 2010; Sundin 2011)	Y	Y	N	Y

Environmental sustainability is also improving our lifestyle and reducing threats to human health, genetic diversity, and habitat alteration associated with modern agriculture (Robert 1997). These days, scientific production faces the challenge of developing a new paradigm which embodies the concept of sustainability (Sands and Podmorea 2000). However, farming needs to take appropriate measures in its surrounding environment to achieve environmentally sustainable production (McRae, Smith, and Gregorich 2000). Simultaneously, environmentally sustainable farming not only improves ecological balance but also protects wildlife habitat, and increases the visual beauty of farmland, efficient nutrient cycling and the optimum storage and filtering of water (McRae, Smith, and Gregorich 2000). Theoretically, scholars have proposed frameworks for evaluating sustainability using various scales (Liverman et al. 1988; Lal 1991; Senanayake and Sustain 1991; Stockle, Martin, and Campbell 1994). Therefore, a combination of various efforts will help to achieve environmental sustainability.

Arguably, the most serious environmental costs from livestock farming are perhaps experienced from dumping wastes in the natural environment of vacant land, river water and cropland. For livestock welfare, sustainable production needs to be ensured through an appropriate triple bottom line framework (Ostrom 2002; McMichael, Butler, and Folke 2003). Currently, the poultry industry is facing environmental challenges relating to air (odour) (Colletti et al. 2006) and water quality. This degraded air and water quality hampers the poultry industry in terms of spreading disease and maintaining optimum health. Kliebenstein (1998) has suggested that agricultural industries can escape from such disaster through their collective efforts in improving the positive environmental impact of process technologies. To protect from the above disaster, industry needs to follow standard indicators to improve the situation for the present and future. With reference to the GRI, Dow Jones and IChemE, a number of economic indicators match the current study. Table 2.3 lists waste recycling, waste reuse, reducing environmental degradation, biofuel and environmental certification which can help a farm to achieve environmental sustainability.

Table 2.3: Environmental Activities in Poultry Farming

Indicators: Environmental Factors	GRI	IChemE	Dow Jones	Others
Waste Recycling or Reuse (Sikdar 2007; Gertsakis and Lewis 2003; Tipnis 1993; Edwards and Daniel 1992)	N	N	N	Y
Reducing Environmental Degradation (Dean and McMullen 2007)	Y	Y	N	Y
Biofuel (Biogas) (Hill et al. 2006)	N	N	N	Y
Environmental Certification (GRI 2009)	Y	N	N	Y

Alternatively, the widespread and renowned concept of "3R" denoting to reduce, reuse and recycle is predominantly based on production and consumption (Kalk 2012; Srinivas 2007). Policy makers and industrial personnel are trying hard to adjust to such concepts if an enormous amount of waste comes from their industry. Policy makers are increasing their attention towards possible recycling and possible reuse of raw materials and industrial/manufacturing wastes, and overall reduction in resources (Srinivas 2007). Again, reflection on the adoption of the 3R concept is influencing product life cycles, and raw materials use, manufacture, reuse and disposal (Srinivas 2007). Consciousness is growing day by day to implement the reduce, reuse and recycle

(3R) concept everywhere in our everyday life to achieve a sustainable environment (Bushnell et al. 2011; Alahari, Kohli, and Torr 2008). This research context is similar to the 3R concept in seeking to recycle, reduce and reuse poultry wastes for the sake of making valuable by-products for further daily usage.

2.2.3 Findings and Gaps

The above discussion on sustainability has revealed the definition of sustainability and the importance of its implementation in an operation to ensure maximum benefits. Moreover, three components of sustainability have also been discussed. Unfortunately, sustainability continues to be challenging at the corporate level in terms of applying the relevant theory to their operation when diverse stakeholders are involved (Carter and Rogers 2008). They are even struggling to identify the exact extent of present demand and future needs in order to assess resource and technology requirements, and to coordinate accountabilities with the different stakeholders in the supply chain (Hart 1995; Barnett 2007; Peredo and Chrisman 2006). Carter and Rogers (2008) also found that the Brundtland Report's definition on sustainability is far-reaching in seeking to achieve goals for the current and future, and that it is hard to assess the appropriate roles of supply chain members (Shrivastava 1995). For better growth and profitability, industry needs to make the effort to implement sustainability concepts in their business operation. Without such effort, companies may fail to maintain the pace of sustainable growth and profitability to run their business in the long run. Conversely, the poultry industry in Bangladesh is seen to be struggling to implement the sustainability concept in its operation. In fact, the industry does not have sufficient idea about how sustainability would work with the existing operation. In addition, the Bangladesh poultry industry is currently fast reaching actual demand for chicken and chicken products. Farmers do not like spending additional money to achieve sustainability whereas, they could achieve more benefits if they implemented the sustainability concept. Such failure to adopt sustainability is caused by an inappropriate poultry process network, lack of coordination among stakeholders and failure to maximize resource usage. Thus, the current research has found it necessary to implement such a valuable concept in the poultry operation for the sake of economic, social and environmental sustainability. In addition, this study is also focused on such a gap to ensure a sustainable poultry process for maximum benefits. The next section addresses supply chain theory and the model to distinguish the forward and reverse processes.

2.3 REVIEW OF SUPPLY CHAIN THEORY AND MODELS

The supply chain has been a widespread concept for business and academia for the last three decades. A number of definitions and explanations of the supply chain concept are available in various scholars' writings. The supply chain is the process that starts from managing raw materials through to the final consumer associating with the relevant supplier, retailers, other parties that provide services to the customer (Cox, Blackstone, and Spencer 1995) and different points of consumption (Svensson 2007). Fundamentally, the supply chain is a combination of various parties and processes including production, and backward and forward processes within a firm. Once again, the supply chain includes every step towards producing and distributing the ultimate product, on or after the supplier's supplier to the customer's customer (Cooper, Lambert, and Pagh 1997; Council 1999; Ellram and Cooper 1993; Lummus and Vokurka 1999; Lummus and Alber 1997). In addition, the supply chain follows the process of proper planning, sourcing, manufacture and delivery which manages the supply–demand situation, raw materials sourcing, the manufacturing system, warehousing and inventory, order management and distribution heading to consumers (Quinn 1997; Lummus and Vokurka 1999; Cooper, Lambert, and Pagh 1997).

Moreover, Mentzer, et. al. (2002) highlighted the supply chain as a conventional business component for systemic, strategic and tactics coordination with other functions. Supply chain management manages and incorporates all of these activities into a unified process (Tan 2002; Ponomarov and Holcomb 2009). Again, it links within one chain all related stakeholders, including suppliers, carriers, third-party companies, and information systems providers (Carbone and Martino 2003). The supply chain therefore deals with the total process starting from production and ending with consumption. However, dynamic supply chain processes extend beyond the consumption level adding processes such as reverse logistics. The next section discusses managing the supply chain within a process.

2.3.1 Managing an Efficient Supply Chain

Supply chain management (SCM) has received attention since the 1990s, even though the method was introduced in the early 1980s (Oliver and Webber 1982; Svensson 2007). Typically, in SCM, the beginning point is with the suppliers or producers (Carter, Ferrin, and Carter 1995; Ellram and Cooper 1993; Lambert and Cooper 2000; Novack and Simco 1991) while consumption denotes consumers, customers or end-users in a supply chain (Min and Mentzer 2000; Lambert, Cooper, and Pagh 1998; Jones and Riley 1985; Svensson 2007). The term 'supply chain management' has a direct relationship with 'supply chain'. The first literature found on logistics was in the 1980s, as an inventory management tactic with emphasis on the supply of raw material supplies. In the managerial literature, including within the agro sector, SCM links the purchasing function with the corporate planning process as an integral part (Vorst, Silva, and Trienekens 2007; New and Payne 1995; Scott and Westbrook 1991). In the early 1990s, academics used a theoretical stance to explain SCM clarifying how it is identical to traditional supply chain approaches of flowing materials and information (Christopher 1998). Yet again, Tan (2001) and Croom (2000) stated that SCM is a broader strategic approach to materials and distribution management. They also discussed it from various perspectives of purchasing and supply, logistics and transportation, industrial organization, marketing and strategic management. The above matters need to be considered to manage an efficient supply chain in a production process. Such discussions lead to later implementation to efficiently manage supply chain practices. The following section reviews a few supply chain models along with forward and reverse supply chains.

2.3.2 Review of Supply Chain Models

A number of supply chain models have been discussed in the existing literature. The most common and simplified supply chain model starts with product conception and ends with consumption. Figure 2.2 presents a simple supply chain starting with product conception, then raw material collection through to the end of life of a product. Maxwell and van der Vorst (2003) highlighted a simple supply chain model, in which product conception is the starting point of a supply chain network. Later, product conception is followed by raw material collection, a smooth production process, well-managed distribution, consumption and end-of-life procurement. It has been assumed that the model is too simple to implement as the reality is different. In support, Lambert et al. (1998) and Stevenson and Spring (2007) found that managing the entire supply chain is a difficult and challenging task for the concerned industry. Is this because different supply chain members have identical roles to play which are not similar to each other's responsibilities? Only proper coordination among the supply chain members can solve the problems.

In another example, New and Payne (1995) depicted a supply chain network (Figure 2.3) which started from collecting raw materials from the earth followed by converting processed materials; physical distribution; the ultimate manufacturers, traders, retailers and consumers; and recycling products by reversing used materials. In a competitive market, manufacturers continuously update their product offers in order to better satisfy customers' requirements with the purpose being that goods are distributed at the targeted cost, time and quality (Pero et al. 2010). The latter model (Figure 2.3) is little different from the model above (Figure 2.2) as it has given emphasis to physical distribution, warehousing and recycling wastes. At the same time, it is assumed that smooth and efficient physical distribution and warehousing facilities are the key to reaching customers in the quickest way. Moreover, care should be taken with recycling opportunities when these appear as necessity in terms of profitability, protecting the surrounding environment, implementing regulations and customer expectations.

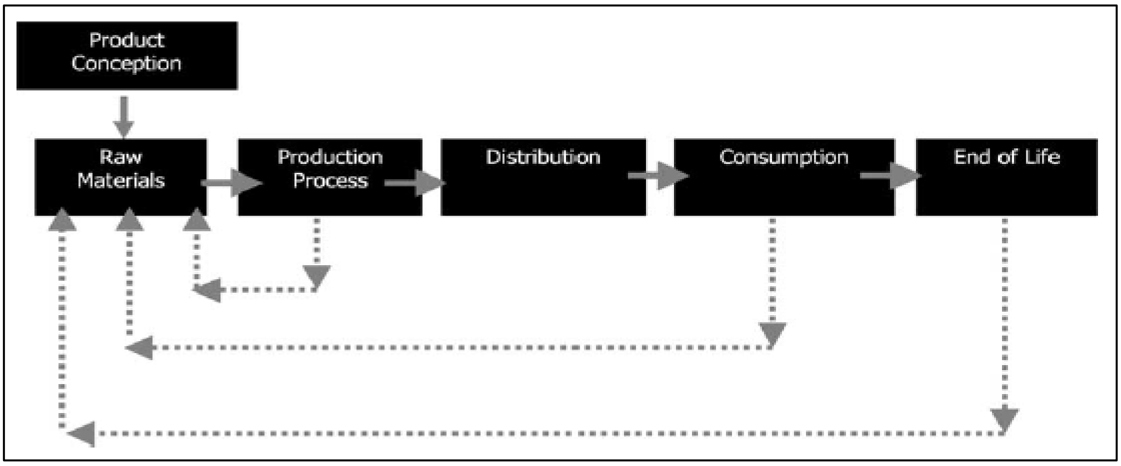

Figure 2.2: Simplified Supply Chain (Maxwell and Vorst 2003)

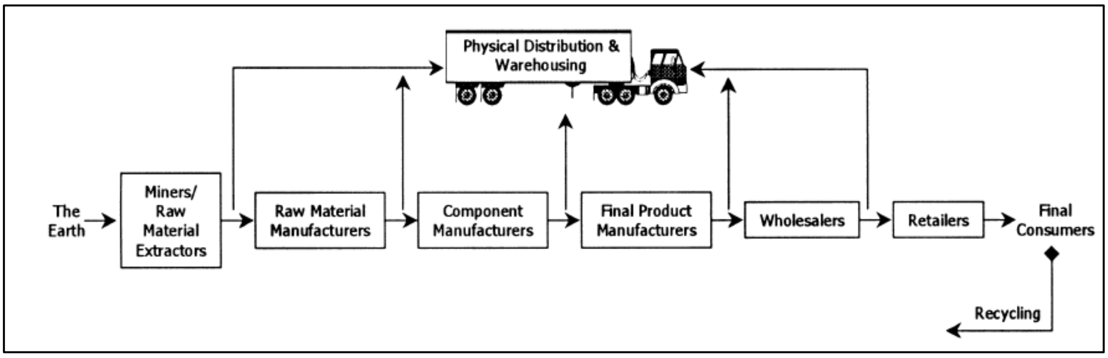

Figure 2.3: Normal Supply Chain with Recycling (New and Payne 1995)

Furthermore, Tsoulfas and Pappis (2006) designed another supply chain model with proper disposal of wastes and recycling, which is depicted in Figure 2.4. In this particular model, raw material suppliers, production process, distribution, wholesaling, retailing followed by end-of-life activities, disposal, recycling, etc. are involved in a supply chain to maintain a standard operation. It is observed from this model that communication with suppliers and selection of materials and processes are vital in an effective supply chain. This model also deals with end-of-life products. It emphasises that proper disposal, recycling, disassembly, refurbishment, repair and direct reuse can add more value to the industry to maximize its profits. Such practices not only maintain better quality products and services but also ensure better environmental and societal sustainability. The concept of this model is used in this current study to build a poultry process model with the above-mentioned facilities to ensure a structured production process.

Even continuously changing products often cannot satisfy customers who instead demand a new product line with assorted products (Hoek and Chapman 2007, 2006). For these frequent changes, SCM needs to be involved with product design, organizing and executing all the activities from planning to distribution along the entire value chain, including the network of suppliers, manufacturers and distributors (Childerhouse, Aitken, and Towill 2002; Vonderembse et al. 2006). The poultry industry can include new lines of products such as different breeds with production capabilities, longer life cycles, etc. The next section addresses the forward supply chain aspect.

2.3.3 Forward Supply Chain (FSC)

The normal supply chain process concept is similarly applied to define the forward supply chain process that starts and ends with raw materials and customers, respectively (Cox, Blackstone, and Spencer 1995; Rogers et al. 2002; Poirier and Reiter 1996; Bowersox 2011). It also links the internal and external partners of suppliers, carriers, investors, policy makers and intermediaries. Briefly, the forward supply chain (FSC) is the step-by-step process of converting raw materials to finished goods (Kocabasoglu, Prahinski, and Klassen 2007). In the same way, the poultry forward supply chain starts with collecting the parent stock breed followed by collecting hatchable eggs from the parent breeder, hatching the eggs in the hatchery, distributing the chicks to farmers through middlemen, rearing them for a certain time by farmers and selling meat and eggs to the ultimate customers. The steadier this supply flow, the more benefits occur in relation to achieving sustainability.

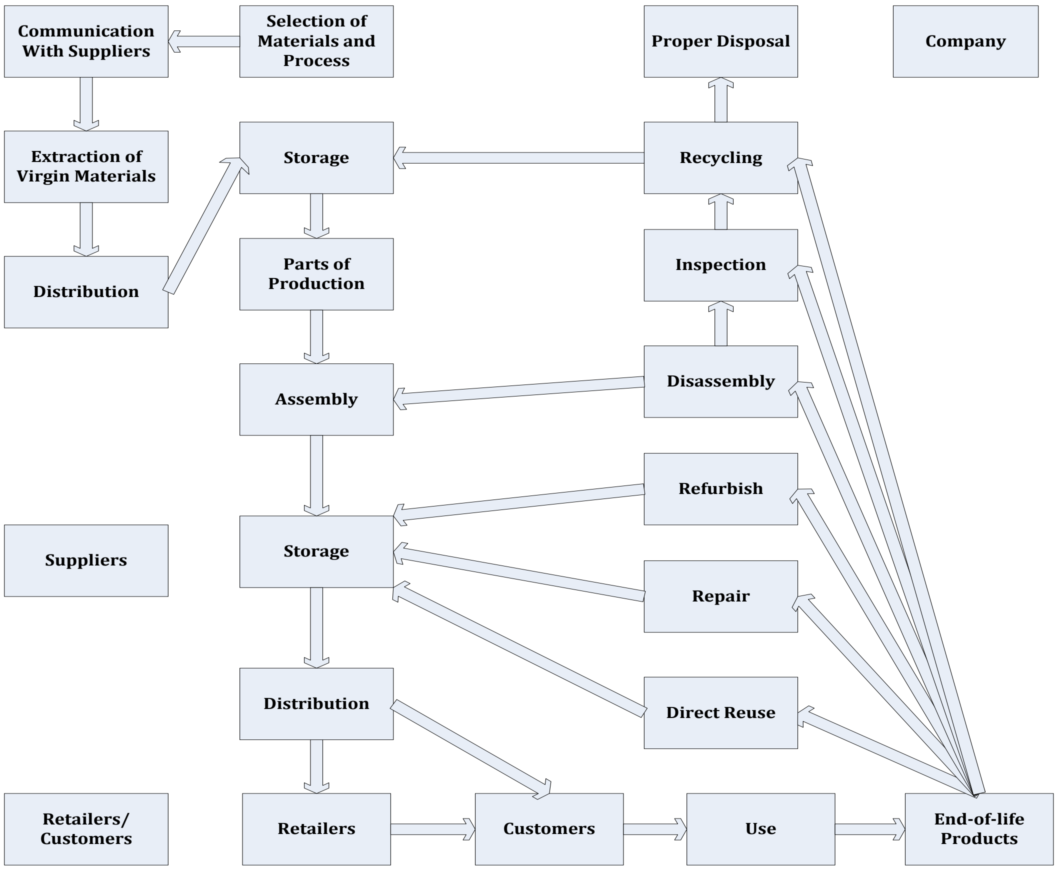

Figure 2.4: Materials Flow (Tsoulfas and Pappis 2006)

Recently, businesses have shifted towards creating a market rather than waiting to receive demand from customers. Most businesses need a good supply chain network so they can simultaneously serve their own company's purpose and customer needs. To reach the customer quickly, the company needs to have an effective and efficient supply chain. Structured supply chains not only help to reach customers but also to receive prompt product return and deliveries from suppliers. The collective and supportive relationships throughout the forward supply chain are needed to increase the degree of integration, to receive maximum benefits, to create a strategic position and to secure desired profits ahead of their competitors (Fuente, Ros, and Ortiz 2010). Nevertheless, various authors such as Monczka and Morgan (1997), Lambert et al. (1998), Rushton, Croucher and Baker (2010), Chandra and Kumar (2001), and Rudberg and Olhager (Rudberg and Olhager) identified the following characteristics for forward supply chain management:

- ✓ Fragmented chain (each supply chain member is focused on its own fragmented processes),
- ✓ Integration of decisions and processes between suppliers and clients, and
- ✓ Information systems connecting the different members of the chain.

The above characteristics can also be treated as limitations for the forward supply chain (FSC) due to the defined features. Arguably, these characteristics can achieve expertise for the individual parties of the FSC. Furthermore, the FSC is the main channel through which a product travels from producers to consumers. In addition, the FSC needs to adapt to continuous changes in the adjacent members' circumstances. Larson (2008) designed a framework (Figure 2.5) in which the FSC is linked with the reverse supply chain, regulatory requirements and sustainability issues. At the same time, Larson emphasised designing an environmentally friendly and stable product life cycle. Therefore, the FSC is concerned with producing products from quality raw materials and efficiently supplying them to customers with adequate feedback. The next section discusses reverse logistics, and the reverse supply chain and its process.

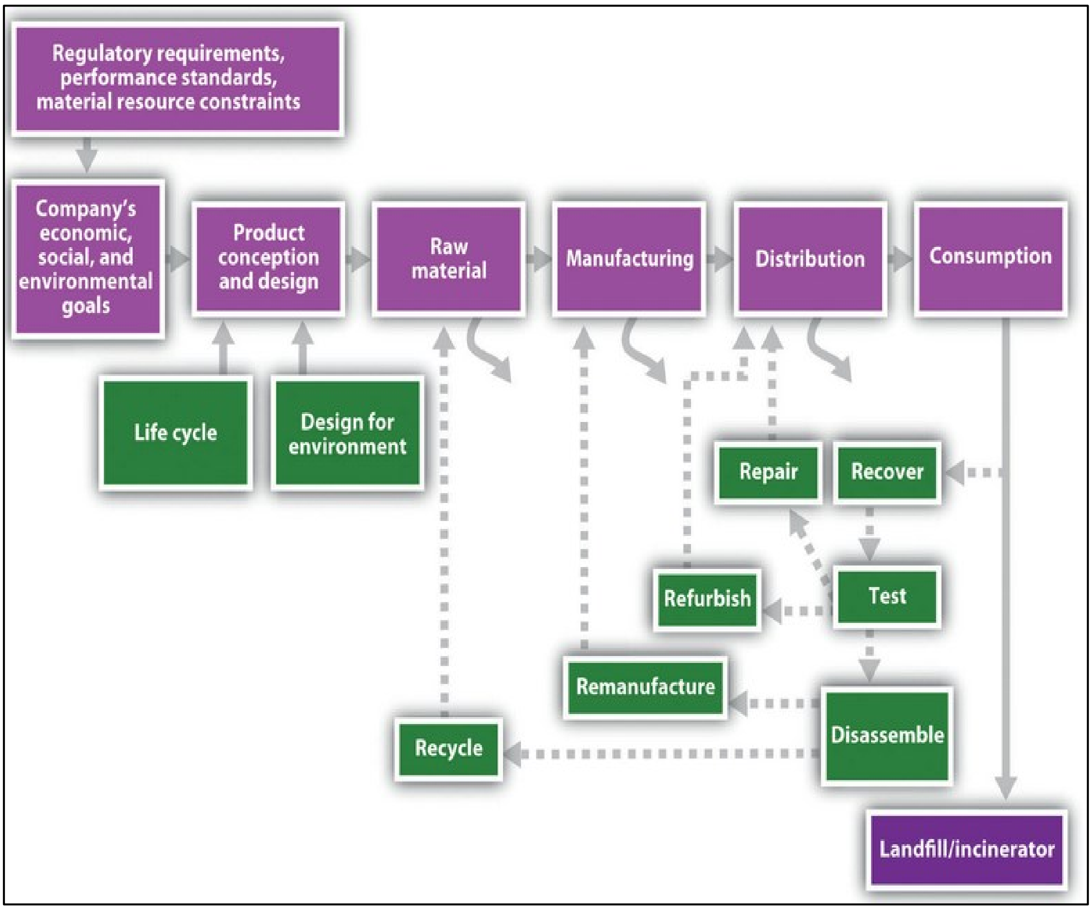

Figure 2.5: FSC With Eco-friendly Process (Larson 2008)

2.3.4 Reverse Logistics (RL) and Reverse Supply Chain (RSC)

The current study proposed the use of reverse supply chain (RSC) concepts for poultry waste management. Poultry waste management endeavours to find a suitable way to recover value from unused wastes to assure additional benefits. The following sections discuss reverse logistics, the reverse supply chain, managing the reverse supply chain, reverse processes and components, and the relationship between the reverse supply chain and the environment.

2.3.4.1 Reverse Logistics (RL)

Reverse logistics (RL) is "the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption at the point of origin in the purpose of recapturing value or proper disposal" (Hawks 2006). It is now believed that RL as a field is "unique enough to undergo specialized research" (Tibben-Lembke and Rogers 2002). This particular area has started contributing to the economy more substantially than expected. Reverse flow is increasing day by day and covers a wide range of industries (Li and Olorunniwo 2008) due to growing consensus and pressure from environmental activists (Dekker et al. 2004). For example, the RL market in the United States (USA) was worth approximately US$58 billion in 2004, comprising 10.7% of the US economy (RLEC 2007).

In further examples, car manufacturing companies are using auto parts from recalled and end-of-life cars, electronics companies (e.g. Apple, Dell and Sony) collect lead and mercury from scrapped and reject products (Li and Olorunniwo 2008; Williams et al. 2008). On the other hand, retailers are unhappy with a higher rate of returns of between 5% to 50% from customers (Rogers and Tibben-Lembke 1999). Sometimes, return policy increases the costing averaging twice to thrice the value of the product due to liberal return policies for intense competition (Guide and Van Wassenhove 2003; Biederman 2006; Rogers et al. 2002; Rogers and Tibben-Lembke 1999). To prevent this, companies need to have a good policy which will protect them from economic losses (Dekker et al. 2004). Modern companies need to undertake vigorous study to learn how to design the reverse supply chain as a profitable network (Biederman 2006; Guide and Van Wassenhove 2003; Richey 2005)

Furthermore, environmental benefits can be achieved along with business profit when firms consider recycling and recovery of valuable resources from products at the end of the product life cycle or used products (Giudini 1996; Fleischmann et al. 1997). In particular, recovery of products aims to improve the exploitation of used products, or their parts, through recycling and remanufacturing (Ayres 1995). The new activities of recycling or improving used products can create new products with a different market niche reducing environmental degradation (Lee, O'Callaghan, and Alien 1995; Daniel, Pappis, and Voutsinas 2003). Then again, industry needs to consider creating market demand while measuring price-sensitiveness for durable end-of-life products that have been further processed for recovery (Karakayali, Emir-Farinas, and Akcali 2007). Ultimately, the recovery process can be done through a different channel: it may create a new product line for a segment of existing customers as well as new customers earning additional profitability and achieving environmental sustainability. The next section discusses how to practise the reverse supply chain operationally.

2.3.4.2 Practising Reverse Supply Chain

It is regulatory in some regions (countries) that the surrounding environment cannot be damaged by production processes producing finished products or parts of products (Hart 2008). Environment preservation and its related rules and regulations with return policies are being adopted throughout the world (Toffel 2003). For example, the automotive industry in Japan, Taiwan and the European Union has endorsed relevant regulation on the collection and re-processing of after-life vehicles (Lee and Tang 1997b; Johnson and Wang 2002; RecyclingTodayOnline 2004; Hart 2008). Owing to increasing popularity of reverse production and networks, academic studies on product recovery have grown significantly. A few studies have also been conducted on network design, organization of channel operations and reverse logistics (Dekker et al. 2004; Dyckhoff 2004).

In practice, the European Union (EU) and the USA are leading in environmental legislation which is related to societal concern about the environment (Dennis and Kambil 2003). Their legislation is includes a mix of waste prevention, material recycling, energy recovery, and disposal options (Dennis and Kambil 2003). The recovery of end-of-life products is starting to be perceived as a business opportunity providing several benefits (Guide and Van Wassenhove 2006). Therefore, designing an effective reverse supply chain along with the existing forward supply chain is required to manage after-use of products and wastes (Fleischmann et al. 2001). The above-mentioned literature presents ways in which to introduce and design reverse supply chain practices along with existing forward chains to maximize the facilities. The next section discusses how to manage the reverse supply chain in a complex operation.

2.3.4.3 Managing Reverse Supply Chain

Reverse supply chain management (RSCM) is defined as "the effective and efficient management of the series of activities required to retrieve a product from a customer in order to either dispose of it or recover value" (Prahinski and Kocabasoglu 2006b; Defee, Esper, and Mollenkopf 2009). In addition, Fleischmann et al. (2000) emphasised RSCM for leftover products (used or wastes) and extended it to include manufacturer responsibilities (Erol et al. 2010; Prahinski and Kocabasoglu 2006b). For instance, a study was conducted on automotive, electronics and other industries in Turkey to reveal the RSCM operational infrastructure and found many inconsistencies as none revealed systematic RSC practices (Murphy and Poist 2003; Sahay, Gupta, and Mohan 2006; Lee 2008; Zhu, Sarkis, and Lai 2007; Zhu and Sarkis 2006). The same study attempted to explore the motivation behind implementing RSC in an industry operation. In contrast, a number of studies explored the difficulties in implementing reverse supply chain strategies due to economic and other concerns (Rogers and Tibben-Lembke 2001; Fawcett, Magnan, and McCarter 2008; Wycherley 1999). They also argued in favour of keeping multiple sources of reverse facilities rather than attempting from maiden sources, a strategy which may not be profitable.

The initiative and motivation for RSCM and RSC practices vary depending on individual industry's motives, enforcement, practices, skills, etc. (Connelly and Limpaphayom 2007; Zhu, Sarkis, and Lai 2007). Zhu and Sarkis (2006) also investigated various Chinese companies' differing motives and practices in a green supply chain to explore vertical to virtual integration of reverse logistics with the mainstream channel. It was found that vertical integration requires substantial financial investment, which is also complex in nature. The outsourcing issue has been involved in a few studies regarding successfully maintaining the reverse process through third parties (Göl and Çatay 2007; McIvor 2000). Factors relating to outsourcing to third parties to maintain reverse supply chain operations were also discussed (Meade 2002). Companies either need to maintain a strong supply chain network to manage RSC activities or can hand over such responsibilities to a third party company. The next section presents the RSC process in order to understand how to implement RSC practice in an operation.

2.3.4.4 Reverse Supply Chain Process

Studies conducted on supply chain management (SCM) have identified greater concentration on the forward chain rather than the reverse flow (Prahinski and Kocabasoglu 2006b). Used products and waste material flow from the ultimate customers to reverse processors has received much less consideration by academics and industry policy makers (Rogers and Tibben-Lembke 2001; Stock, Speh, and Shear 2002). According to Guide and Van Wassenhove (2002), a reverse supply chain (RSC) process requires the retrieval of a used or unused product from a customer and either disposing, reusing or reselling it. Reverse processes also include aspects such as a prompt product return policy (Daugherty, Autry, and Ellinger 2001); information support (Daugherty, Myers, and Richey 2002); supplier performance (Daugherty et al. 2005); innovation (Richey, Genchev, and Daugherty 2005); dynamic reverse logistics process (Starkowsky, Spicer, and Riddell 2009); and proper recycling (Ritchie et al. 2000).

Figure 2.6 presents a reverse process pyramid where recovery is not the consideration but the collection process, direct recovery, reuse, remanufacturing, recycling and incineration also need to be considered (Starkowsky, Spicer, and Riddell 2009; Brito and Dekker 2004). Figure 2.6 presents the flow opposite to that shown in Figure 2.7. Nevertheless, both models use reverse processes for various products and wastes to recover value from them. The ultimate destination for the RSC process is to find a market for recovered products. Without a suitable market for by-products, it would be challenging to sustain this process due to the costs involved. Many companies have accepted these challenges through creating potential markets by using pricing strategies. In the poultry context, it is possible to make valuable by-products from unused products (eggs, feathers, intestines) and wastes (litter, feed). Such by-products can be sold in different market segments to gain extra profit which also helps with reinvestment in reverse management.

In support of the above statement, Figure 2.6 highlights the collection of used and unused material for further value recovery with finding suitable markets to sell the recovered products. Figure 2.7 is modelled based on used products returned by final customers and finding appropriate ways to reuse them to partly recover value. For the current study, it is important to use a similar reverse process in the poultry industry to recover value. Prahinski and Kocabasoglu (2006b) mentioned several key steps for the RSC process as discussed below:

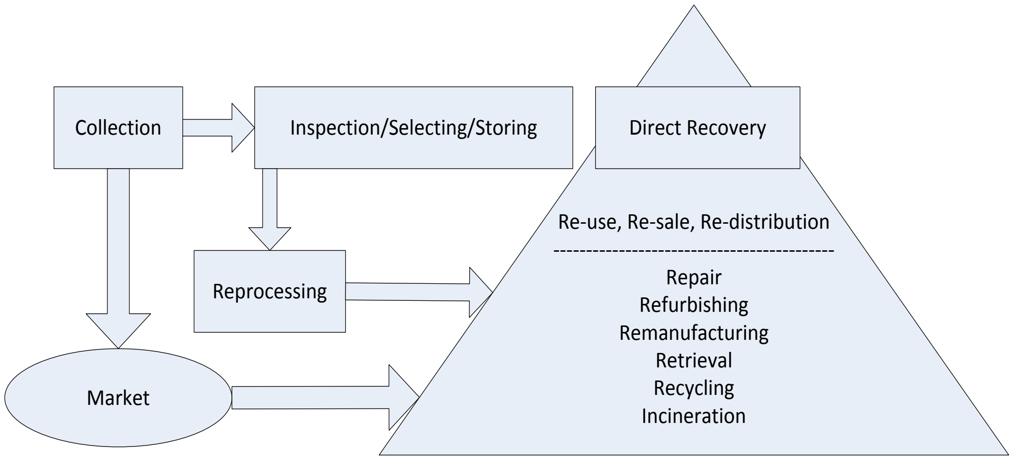

Figure 2.6: Reverse Process (Brito and Dekker 2004)

a) **Acquisition**

The acquisition concept can be used in this study to utilize unused resources of the poultry industry. Acquisition is a procedure by which a product is returned, whether it is used, unused, defective, damaged or wastes (Rogers and Tibben-Lembke 2001; Guide and Wassenhove 2001). The products for recovery basically come from the forward supply chain but can maintain an alternative reverse flow through junkmen, scavengers, dealers, brokers and non-OEM (original equipment manufacturer) remanufacturing (Ginter and Starling 1978). Importantly, waste streams can either be used for landfill or diverted to reuse to gain recoverable value (Wojanowski, Verter, and Boyaci 2007). The acquisition concept can reuse poultry wastes to generate valuable by-products. Obviously, valuable by-products will provide opportunities to achieve economic, social and environmental sustainability.

b) **Reverse logistics**

As with acquisition, reverse logistics is the process of recovering appropriate value from and disposal of products at the end of the product life cycle (Bayles and Bhatia 2000). Activities include distribution, location (Fleischmann et al. 2001), storage and transportation of reusable items (Rosenau et al. 1996) and minimizing the retrieval cost to gain financial benefits (Bloomberg, LeMay, and Hanna 2002). This concept emphasises the distribution, storage and transportation of reusable wastes. Such a concept can be used in the poultry supply chain for waste management.

c) **Inspection**

The quality of recovered products should go through a standard inspection with the objective being to gain customer acceptability (Carter and Ellram 1998; Johnson 1998). Inspection is an important phase for waste management as quality wastes produce quality by-products for further recovery. For example, poultry litter needs to be examined (the ingredients checked) before making plans for reprocessing.

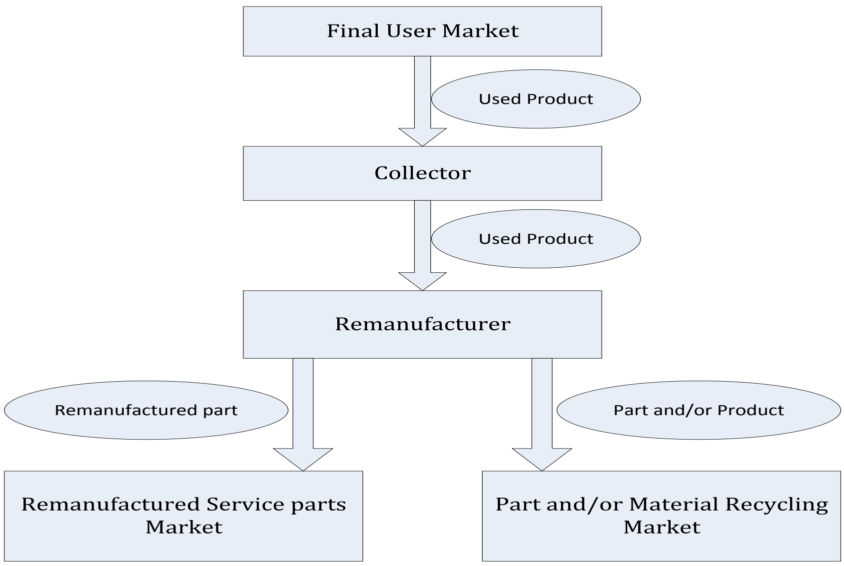

Figure 2.7: Supply Chain Process (Karakayali, Emir-Farinas, and Akcali 2007)

d) **Reconditioning**

Product improvement and recovery options are determined through the disposition strategy and reconditioning process, such as refurbishing, remanufacturing or recycling (Penev and RON 1996; Scheuring, Bras, and Lee 1994). Recycling is the key concept in this study, as it is more appropriate than other concepts for waste management for the poultry industry.

2.3.4.5 Reverse Logistics Theory and Poultry Reverse Supply Chain

It can be argued that the reverse supply chain (RSC) and reverse logistics (RL) have nothing to do with the poultry industry. Reviewing the above literature, reverse logistics happen when used products and materials flow back to the producer or third party for further processing. Poultry products are perishable and there is almost no chance of the reversal of waste chicken meat other than for it to be appropriately dumped. Even so, this research would like to argue that the poultry industry can maintain reverse logistics. The logic behind this view is as follows.

Firstly, a number of studies have mentioned recycling, reusing and recovering value from wastes is part of reverse supply chain (Alahari, Kohli, and Torr 2008; Gadde, Rabinovich, and Chase 1997; King et al. 2006; Brodin and Anderson 1998; Field and Sroufe 2007). In the poultry industry, wastes are recycled and reused to recover value through making substantial by-products for further consumption.

Secondly, the reverse supply chain is also defined as the structured management of the retrieval of used products or parts of products from customers for the sake of disposal or value recovery (Prahinski and Kocabasoglu 2006b; Defee, Esper, and Mollenkopf 2009). In the poultry industry, chicken and eggs are the final products while intestines, feathers, unhatched eggs and eggshells remain after products are consumed. Such wastes help the industry to produce valuable by-products to recover value. Obviously, this process follows reverse logistics theory, thus convincing this study to declare the presence of reverse logistics in the poultry supply chain.

Thirdly, the reverse supply chain also emphasises agreements on excess products and extended producer responsibilities in light of end-of-life and product-return opportunities and laws (Erol et al. 2010; Prahinski and Kocabasoglu 2006b). For instance, poultry feed is consumed by poultry birds that generate litter (excreta). The poultry litter is then used for recycling. Poultry litter then makes biogas, fertilizers, animal feed and fish feed. Wastes from biogas production can be later used as fertilizer and artificial charcoal. Thus, a long reverse supply chain exists within an integrated poultry supply chain.

Fourthly, a reverse logistics system also addresses the retrieval of all possible products and waste materials to gain extra economic value with products' return (Ferrer and

Clay Whybark 2000; Ferrer and Whybark 2001; Guide 2006; Guide and Van Wassenhove 2003; Fuente, Ros, and Ortiz 2010; Fuente, Rosa, and Cardos 2008). In practice, most poultry by-products such as biogas, fertilizer, reject eggs and intestines provide an additional monetary gain: feathers sold in the market also have an economic gain.

The above discussion reveals details of the reverse supply chain and its associated issues. The reverse supply chain is found to be a concept for dealing with used products and wastes to recover value. Such an operation creates more opportunities to make additional profits along with substantial societal and environmental impacts. The next section highlights the literature gap based on the above discussion.

2.3.5 Findings and Gaps

Supply chain theory along with supply chain management and models have been described in the previous sections. This study thus found that efficient supply chain management can maximize the benefits which include on-time delivery of products, efficient logistics and transportation, steady consumption, coordinated networks and reverse logistics. Furthermore, supply chain models highlight structured connectivity between supply chain channel members, smooth physical distribution and warehousing, recycling wastes and managing end-of-life products. Such processes are matched with the forward supply chain process which emphasises converting raw materials into final products. Moreover, each fragmented chain accomplishes particular processes efficiently. Conversely, the reverse supply chain concerns an efficient process for recapturing value through proper disposal, reconditioning and recycling. Only a few studies have discussed the integration of forward and reverse processes to ensure more benefits. It was found that no study has been undertaken combining the poultry livestock sub-sector and an integrated supply chain. Thus, the current study is focused on the integration of these two supply chain networks to maintain sustainable production processes. To continue the above discussion, the following sections address the sustainable supply chain issue in relation to the research context.

2.4 SUSTAINABLE SUPPLY CHAIN

The study of sustainable supply chain management has increased considerably in recent years in academic and business arenas. Seuring and Muller (2008b) reviewed

191 journal and conference papers, published between 1994 and 2007, to excavate the view of sustainable supply chain management. They disclosed two strategies: supplier management for risks and performance and supply chain management for sustainable products. Again, the economic dimension dominated most of the reviewed research with only minor attention on social and environmental issues (Seuring and Muller 2008a). In addition, integrated social and environmental aspects also did not receive much attention in the past literature (Seuring and Muller 2008b). In reviewing previous studies by Seuring and Muller (2008b), Drumwright (1994), Carter and co-authors (Carter and Jennings 2002a; Carter 2000a, 2000b, 2004, 2005; Carter and Jennings 2002b, 2004); found that 140 papers discussed green topics/the environment; 49 dealt with the environment and social issues; only 20 papers focused on the social aspect, and 31 papers was classified as discussing sustainability. To achieve sustainability, integration of two or three dimensions start appearing from 2002 (New 1997; New and Payne 1995). Later, Kärnä and Heiskanen (1998) and Sarkis (2001) published a few leading papers to integrate sustainable dimensions. Thus, integrating various dimensions is important to gain aggregate sustainability for the industry, society and the surrounding environment. The next section discusses sustainable supply chain management frameworks to understand how a sustainable supply chain can be achieved.

2.4.1 Frameworks for Sustainable Supply Chain Management (SSCM)

Lambert et. al. (2006) indicated that SSCM is the integration of key business processes through to the end-user adding value for customers and other stakeholders whereas other research has defined it as risk management, transparency, strategy and culture (Carter and Rogers 2008). Importantly, the firm's economic goals should be shielded by addressing social and environmental matters (Carter and Jennings 2002a, 2002b), and organizations should not treat the supply chain carelessly to achieve sustainability (Porter and Kramer 2002). Carter and Rogers (2008) developed a SSCM framework (Figure 2.8) in which the success of the three factors of sustainability was discussed based on their match with each other. For instance, the combination of 'social and environmental' performances was treated as 'good' (although questioned due to zero economic benefits); 'economic and social', and 'economic and environmental' performances were considered 'better'; and all three combinations were viewed as 'best'. This means that the best possible results are driven through three-factor sustainability. The following section addresses the sustainable supply chain process to find the similarity of sustainable practices within the present context.

2.4.2 Sustainable Supply Chain Process

The supply chain is the procedure that starts from the early raw materials through to the finished product linking suppliers and end-users; and existing both within and external to a company (Maxwell and Vorst 2003; Croom, Romano, and Giannakis 2000). Supply chains also create relationships among internal and external partners, third-party agents, information systems providers and carriers. Kocabasoglu et al. (2007) recommended the integration of the supply chain with issues of disposal, recycling, reconditioning and remanufacturing of used and reject products. Similarly, the consideration of by-product design and process as well as the production of by-products, product life expansion, retrieval of products and recovery processes at the end of the product life cycle have been highlighted in the supply chain process (Linton, Klassen, and Jayaraman 2007). This is the area on which the researcher has focused in the Bangladesh poultry industry. Typically, Bangladesh poultry mainstream forward and reverse supply chains deal with importers, suppliers, processors, distributors and consumers. If appropriate supply chain techniques are applied, the poultry supply chain process can become more sustainable in order to handle socioeconomic issues.

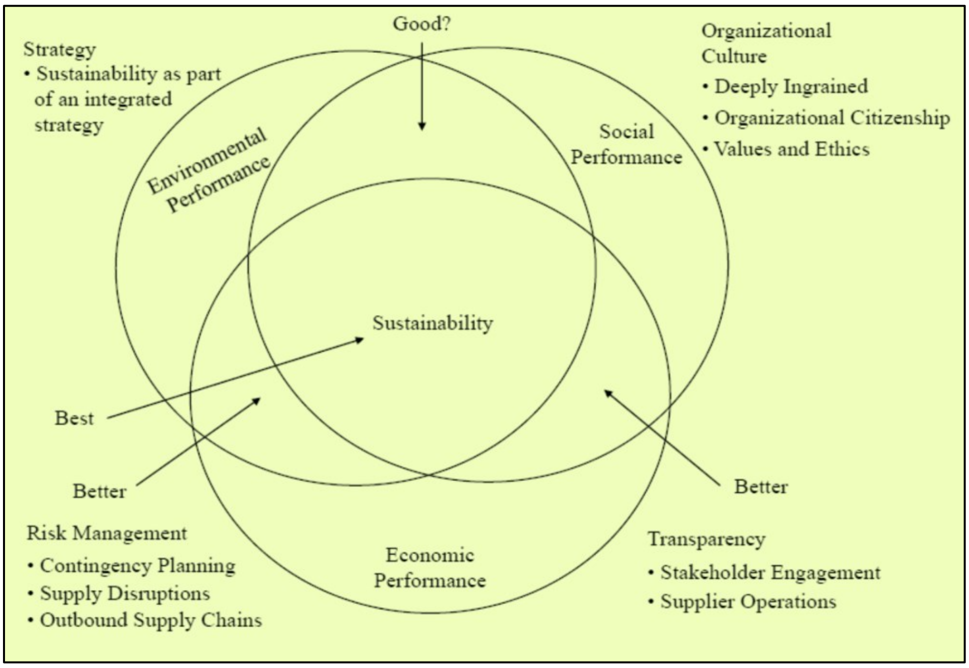

Figure 2.8: Sustainable Supply Chain Management (Carter and Rogers 2008)

When sustainability practices have been absent, company management has attempted to establish the triple bottom line concept in order to achieve in the environmental, economic and social dimensions of sustainability (Dyllick and Hockerts 2002; Elkington 1998). According to Svensson (2007), there are a number of views that attempt to address features of sustainable business operation and philosophy, for example:

a) Sustainable supply network management (Young and Kielkiewicz-Young 2001);
b) Supply chain environmental management (Lippman 1999);
c) Sustainability labelling schemes (Boer 2003),
d) Environmental purchasing (Zsidisin and Siferd 2001);
e) Green purchasing strategies (Min and Galle 1997);
f) Environmental product differentiation (Reinhardt 1999),
g) Corporate social responsibility (Dyllick and Hockerts 2002).
h) Environmental marketing (Sheth and Parvatiyar 1995; Peattie 1995)
i) Green marketing (Crane 2000);
j) Environmental management (Hoffman 2000); and
k) Life cycle assessment (Welford 1999),
l) Reverse logistics (Zikmund and Stanton 1971);
m) product returns; source reduction; recycling; material substitution; reuse of materials; waste disposal; refurbishing; repair; and remanufacturing (Stock 1998).

The above-mentioned features are important to any business operation. However, it is assumed that it is not possible to adopt all these features; instead, attempts are made to incorporate them step-by-step. The implementation of such features may be easy for large companies whereas small organizations will struggle to do so. Different types of industry are known to have their own processes, operation and capability which may not be similar to other industries' processes. It is therefore challenging to integrate these features in the context of the current study which is the main objective of this research.

A significant number of recent research publications have focused on environmentally linked supply chains with the major challenge being to transform them into sustainable businesses (EC 2006, 2011; Dewick, Foster, and Green 2007; Zhu, Geng, and Lai 2011).

Vachon and Mao (Vachon and Mao 2008) found a positive statistical association between the supply chain, suppliers and environmental performance while recycling wastes. Similarly, Seuring (2004) concluded that supply chain sustainability requires consideration of business fluctuations through integrated supply chain management. Concentration on the environment and sustainable operations are to be considered in the entire supply chain process during the production, consumption and post-disposal disposition of products (Linton, Klassen, and Jayaraman 2007). However, the interaction between supply chains and sustainability is the important consideration for operations and the environment (Corbett and Kleindorfer 2003) and for operations and sustainability (Kleindorfer, Singhal, and Van Wassenhove 2005). In addition, optimizing operations is important to achieve a sustainable supply chain, which ensures the greatest value of products or services at the lowest possible cost (Handfield 1999; Leenders and Blenkhorn 1988). The latest consensus on the sustainable supply chain is that it should integrate with product strategy, engineering by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life (Quariguasi Frota Neto et al. 2010; Linton, Klassen, and Jayaraman 2007; Büyüközkan and Berkol 2011; Fabbe-Costes, Roussat, and Colin 2011). To manage an effective reverse chain, the following discussion is the key for a business operation in maintaining waste recycling, reuse and reconditioning.

2.4.2.1 Product Design

Product design needs to be considered for customer preference and suitability prior to conversion to a by-product. Without considering customer preference, a newly designed product may fail to create appeal for further consumption. Moreover, environmental impact over the new product's life cycle and afterwards is also considered in terms of maintaining ecological sustainability (Rebitzer et al. 2004; Wilkins et al. 2006; Karna and Heiskanen 1998). For example, environmentally friendly poultry slats (beds) are used in commercial farms to ensure their reuse for the next flock.

2.4.2.2 Manufacturing By-products

By-product production from different poultry wastes is dominant in the current research. This involves the reduction and elimination of poultry wastes through cleaner process technologies (Kemp 1994; Clift 1995); quality production techniques (Zink 2007; Zhu, Sarkis, and Lai 2008; King and Lenox 2001); and use of waste to produce new by-products (Frosch and Gallopoulos 1989). For instance, poultry wastes can be recycled to make a number of useful by-products.

2.4.2.3 By-products during Product Use

It would be worthwhile if the poultry industry could convert its wastes into valuable by-products during product use. By doing so, the waste storage issue could be solved due to immediate use of wastes. Economic benefits would be recognized through extended producer involvement and responsibility, provision of products (Michaelis and Coates 1994) and manufacturers who could provide support for original product sales (Wise and Baumgartner 1999). For example, poultry farming is a continuous process in which it is possible to make by-products during the ongoing production and rearing of different sizes of poultry flock. This appropriate concept is useful for Bangladesh context where farmers can access additional benefits from diverting wastes into valuable by-products.

2.4.2.4 Product Life Extension

Product life extension is another important issue in which a product can be used for longer than expected. A number of methods are used to collect and extend the life of after-use products (Linton and Jayaraman 2005). Intelligent manufacturers never miss opportunities for product life extension (Guide and Van Wassenhove 2003; Linton and Johnston 2000) and vibrant highly profitable remanufacturing businesses (Arndt 2005; Lund et al. 1982; Lund and Mundial 1984). At the practical level, approximately 20% of eggs remain unhatched and are excluded. Poultry owners supply these eggs to small and medium bakeries as cheap raw materials. Poultry entrepreneurs are extending eggs' life to customers and thus are saved from immediate dumping.

2.4.3 Environment Friendly Supply Chain

Environmental success is an integral part of integrated sustainability. Environment has to be taken care through production process and supply chain activities. 'The Limits to Growth' (Meadows et al. 1972) and 'Beyond the Limits: Global Collapse or a Sustainable Future' (Meadows and Randers 1992) were the two leading books in which authors justified their logic about the limitation of Earth's resources. Definitely, the Earth has a limited capacity for growing raw materials and consistently supplying it to human beings (Karlsson 1999). At the same time, it is impossible for humans to stop consuming resources to fulfil their own needs. Thus, sustainable development involves consideration of the reduced potential for depletion of resources while consuming a product (Tsoulfas and Pappis 2006). Therefore, the recovery of used products, in particular, is also named as a closed-loop supply chain (Cooper, Browne, and Peters 1991). Closed-loop and reverse logistics are the effective process and control of recovering value for competitive advantage (Porter 1985; Fleischmann 2000; Fleischmann et al. 2005). Chen and Paulraj (2004) developed a framework of supply chain management where supplier and buyer performance linked with strategic purchasing are based on the buyer-supplier relationship in terms of supply network structure and logistics integration. At the same time, they considered environmental inconsistencies or uncertainties among all the relationships. Without considering the environment, no supply chain network can be effective enough to achieve sustainability.

According to poultry farm owners, a strong relationship exists between the existing supply chain, disease outbreak frequency and present environmental conditions of excess rainfall, summer heat exhaustion, humidity, floods, cyclones and contamination from pollution (Rahman 2013c; Chowan 2013; Mannan 2013). Recent studies (Van de Vorst, Beulens, and Van Beek 2000; Riddalls, Bennett, and Tipi 2000; Chang and Makatsoris 2001; Higuchi and Troutt 2004; Erkoc, Iakovou, and Spaulding 2005; Son and Venkateswaran 2007) have emphasised supply chain behaviour under catastrophes and uncertainties. Researchers have used operational research that helps to reduce the problem complexity while simulation has focused on internal and external uncertainties and actions in response (Vo and Thiel 2011). Poultry has a relatively low environmental impact compared to other animal production due to efficient feed utilization (Vries and Boer 2010). Waste feed can create hygiene problems for the farm. In addition, poultry dust, zoonotic diseases (avian influenza, *Salmonella*, *Campylobacter*), and bacteria are risky for human health (PVE 2010). The economic viability of the poultry meat and egg sectors is also under pressure. Thus, care should be taken of the environment to protect against such damage. The next section discusses the feasibility of forward and reverse supply chain integration.

2.4.4 Integrated Poultry Forward and Reverse Supply Chain

It has been reviewed in earlier discussions (see sections 2.3.3 and 2.3.4) that both the forward and reverse supply chain processes are important for any business operation. To gain more benefits, it is essential for a collaborative effort rather than approaching it in a fragmented way (Fuente, Rosa, and Cardos 2008). Such collaborative effort can bring more sustainable results in light of obtaining higher economic benefits and a strategic position among competitors (Fuente, Rosa, and Cardos 2008). To do so, a company needs to redesign its collaborative model involving its various stakeholders. Min and Zhou (2002) gave priority to analysing the supplier–client relationship before designing an integrated relationship whereas Kaihara (2003) placed emphasis on examining the inter-company scenario to find out the feasibility of integrating the supply chain processes. The integrated model for supply chain management (IMSCM) not only considers the traditional flow of the supply chain from raw materials to products to the client, but also envisions reverse supply chain operations (Fuente, Rosa, and Cardos 2008). At the same time, a reverse logistics system helps a firm to collect and recycle products and wastes exploring how to achieve possible economic value (Rogers and Tibben-Lembke 1999; Ferrer and Clay Whybark 2000; Ferrer and Whybark 2001). Thus, an integrated supply chain can provide more benefits to the industry and society. The current study has also considered an integrated poultry supply chain for the sake of maximizing economic, social and environmental benefits. Thus, it is a matter of analysing and examining the consequences of integrating various supply chain processes. In most cases, it is assumed that sustainable outcomes are ensured through an integration process.

The Bangladesh poultry forward supply chain starts from rearing the grandparent breed followed by the parent stock farm or breeder farm, hatchery, distributor, broiler/layer farms (day-old chick consumers), wholesaler, retailer and processor. Day-old broiler chicks (DOCs) are supplied to distributors to distribute to the ultimate farmers who produce meat and eggs for the general public. Then, mature chickens are grown from DOCs which are ready to flow towards the open market, restaurants, processing units, etc. (Schwartz 1991). In this process, issues such as economic, social and environmental issues can be covered. Each of these issues covers a number of concerns, for example, employment generation is addressed as a social issue.

On the other hand, the reverse supply chain is a relatively new concept dealing with product return, recycle and reuse to keep the environment intact by using industry wastes (Papageorgiou 2009; Dowlatshahi 2000). Realistically, the poultry industry has no chance of product retrieval, return or reconditioning due to the perishable nature of its product. However, there is plenty of scope to recycle or reuse poultry wastes. It is also evident from the in-depth interviews that various poultry wastes are generated in the poultry production process namely litter, feed waste, feathers, broken eggs, rejected eggs and intestines. By reusing poultry wastes, industries can make valuable products such as fertilizers, biogas, pillows, charcoal and bakery items. It is likely that someone may argue that no reverse logistics exists in the poultry industry. Traditionally, reverse logistics deals with the end-of-life product. Logically, this study argues that a reverse supply chain is present within the poultry supply chain. For example, poultry birds consume feed which is supplied from the feed mill as a final product. This feed consumption generates poultry litter (excreta) which can be reversed to recycle into by-products. Again, chicken meat is a final product which is reared at farm level. Intestines and feathers can be collected from the final product of chicken meat when it is slaughtered in a processing centre. In this way, poultry wastes flow back to the same industry or a third party industry for value recovery. Such practices are similar to the reverse logistics theory. Therefore, forward and reverse supply chains can be integrated in the poultry industry to maximize the benefits. Following sections will discuss the sustainable supply chain concept for the Bangladesh poultry industry.

2.4.5 Literature and Gaps

The above section has discussed sustainable supply chain theory with a comprehensive model. It was found that such a supply chain could be achieved to ensure economic, social and environmental benefits. The model (Figure 2.5) discussed above presents the options of achieving two-component sustainability (among social, economic and environmental dimensions) if it is not possible to incorporate three factors at once. The systematic progress of adopting various sustainable strategies is emphasised. In contrast, the Bangladesh poultry industry is yet to consider the above issues in their operation to attain maximum benefits. Therefore, the current study is focused on achieving sustainable success for the existing poultry process through adopting the above model. The proposed integrated poultry model takes into consideration the above literature to gain sustainable success in the poultry supply chain. To continue the above discussion; the next section discusses sustainable supply chain issues within the poultry industry in various countries.

2.5 SUSTAINABLE SUPPLY CHAIN IN THE POULTRY INDUSTRY

Modern agriculture now feeds 6,000 million people around the world through the blessings of science and technology (McRae, Smith, and Gregorich 2000). At the same time, an efficient supply chain helps an industry to serve its customers on time. For example, global animal meat production has doubled in the past couple of decades, mainly from better yields resulting from effective supply chain management and superior technologies along with artificial feed (Tilman et al. 2002; Tilman et al. 2001). The sustainability supply chain is becoming a major focus for the poultry industry worldwide, as resources, including raw materials, become limited and expensive in meeting the growing demand (Harris 2013). To design a sustainable poultry industry, an effective supply chain network is needed to maintain optimum demand and supply. In fact, the poultry supply chain is a complex process involving a number of parties such as suppliers, farmers, distributors, agents, sub-agents, meat processors, etc. The Victorian (Australia) chicken meat industry is designed as a vertically integrated supply chain (Figure 2.9) which includes quarantine facilities, breeding farms, feed mills, hatcheries, grow-out/broiler farms and processing plants (DEPI 2013). The complexity of the poultry supply chain depends on the context (location), skills, maintaining the safety process, quality control and financial capabilities to invest (Gwin, Thiboumery, and Stillman 2013).

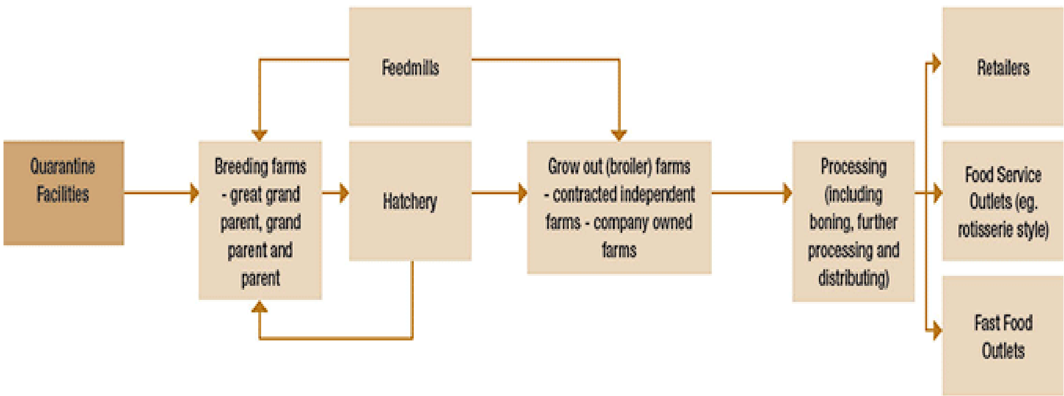

Figure 2.9: Australian Chicken Meat Industry Supply Chain (DEPI 2013)

It is observed from above figure 2.9 and Table 2.4 (DEPI 2013) that the poultry supply chain in Australia is classified into four major stages: quarantine (mother breed rearing), breeding farms, broiler grow out farms and processing units. Each stage has a variety of tasks to accomplish: for example, the breeding unit has to maintain its own feed mill and hatchery units to supply feed and hatch the day-old chicks (DOCs) for further supply. Even a feed mill has many tasks such as steadily supplying feed to the farm units. It is noted that chicken growth and genetics will be hampered if feed supply is interrupted. Similarly, quarantine facilities, broiler farms and chicken feed processors have their individual processes to complete to achieve proper production. Figure 2.10 presents the vertical poultry supply chain in the USA. Moreover, the USA is the leading chicken meat producing country in the world followed by Brazil and China (Mundi 2011). This standard supply chain starts with primary breeding companies and ends with processing units followed by final consumption by consumers. This particular supply chain network has been designed by the National Chicken Council of USA. The difference between the Australian and US supply chain is regarding procurement of by-products from processing plants through further processing units (see Figure 2.10). The US poultry industry is highly concerned to ensure the quality and to maintain sustainable growth through market demand analysis.

Table 2.4: Major Stages of Poultry Supply Chain in Australia

Stages	Descriptions
Quarantine Facilities	Eggs are imported from US and UK suppliers of genetically highbred chickens. The eggs are hatched and raised for nine weeks in quarantine facilities. The hatched birds are known as great grandparent (GGP) birds.
Breeding Farms	The great grandparent (GGP) birds are bred out for several generations. The offspring of the parent birds are then raised for meat production.
Broiler Grow Out Farms	The day-old chicks hatched from the parent generation are delivered by the processing company to its own farms or contracted farms. They are grown out for between 30-65 days.
Processing	The processing company selectively collects chickens of varying sizes from broiler farms depending on its needs. The chickens are then processed into a range of fresh, chilled, frozen and value-added products.

Different countries use diverse poultry supply chain models selecting the model which most suits their environmental context. In Australia, poultry farmers are guided by the Poultry Cooperative Research Centre (CRC) on how to maintain sustainable production and other related matters (Poultryhub 2013). For example, Poultry CRC emphasises the following issues to achieve sustainability:

a) Maintaining poultry health and welfare

b) Improving resource utilization and reducing environmental impacts of poultry production

c) Controlling poultry product-associated food safety issues and enhancing egg quality for consumers

The CRC helpline is always interactive for farmers and their stakeholders to assist them in achieving sustainable production and supply to the ultimate destinations. This practice is one of the effective interactive processes between researchers, farmers and the country's policy makers. Scientific information relating to disease management, rearing procedures and feed ingredient use updates are important issues for relevant stakeholders. It is assumed that such information flows can be useful for the current study's context.

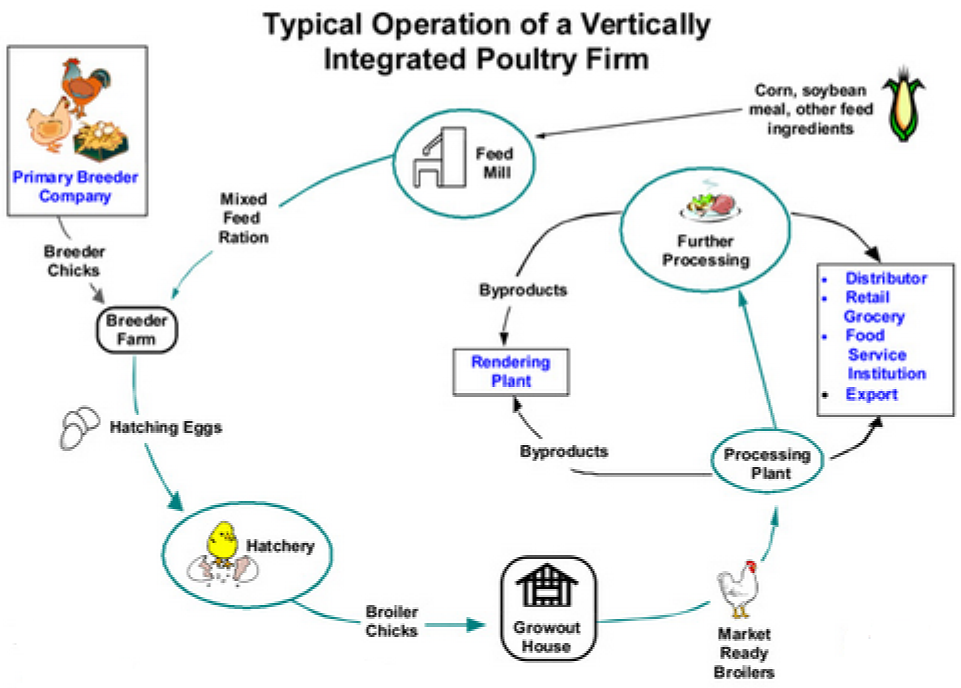

Figure 2.10: Poultry Supply Chain in USA (NCC 2012)

In contrast, the US poultry industry mostly maintains a vertically integrated supply chain with an efficient production system which is demand responsive (Hinrichs and Welsh 2003). The US poultry industry has several unique characteristics: integrated ownership, geographically concentrated production and identical marketing systems to maintain sustainability (Kandel and Parrado 2005; Constance et al. 2013). Moreover, most US consumers are habituated to processed chicken consumption and 90% of their poultry industry is directly linked to processing (Hinrichs and Welsh 2003; Smith 2001). This linkage with processing units enables them to be informed of the exact demand status from food manufacturers to meet the ultimate customers' needs (Welsh and Hubbell 1999; Hinrichs and Welsh 2003). Brazil, China, France, Malaysia and Thailand poultry supply chains are also coordinated with the same stakeholders. They have incorporated sustainability concepts to meet present and future demands of their products. Large poultry meat producing countries are meeting increasing customer demand through maintaining sustainable growth in their current operation.

On the other hand, Boyazoglu (2002) stated that improved and scientific waste management are needed to optimize resource utilization and reduce the accumulation of nutrients in air, soil and water. In addition, more research is required to improve intensive farming systems in the animal excretion of nutrients whilst maintaining production levels (Malechek and Scottsdale 1982). A number of frameworks have been developed by various researchers living in different parts of the world based on different locations and market potential. One renowned framework named the 'Farm System Simulator' (FSSIM) offers a generic structure enabling the assumption of situations and supply response (Janssen et al. 2010). For example, farmers in the European Union (EU) are forced to consider not only economic aspects but also environmental and social consequences (Janssen et al. 2010). In this situation, bio-economic farm models can be used for assessing agricultural emissions on the environment (Falconer and Hodge 2001; Ittersum and Rabbinge 1997; Wossink, Lansink, and Struik 2001) and biodiversity effects from agriculture (Meyer-Aurich et al. 1998; Oglethorpe and Sanderson 1999; Schuler and Kachele 2003).

On the other hand, the German model MODAM has been applied to gain benefits from reusing wastes since the 1980s (Meyer-Aurich et al. 1998; Kachele and Dabbert 2002; Uthes et al. 2008; Zander and Ka¨chele 1999). Simultaneously, the MIDAS model (Kingwell and Pannell 1987; Morrison et al. 1986) was used on sheep farms in South-West Australia (Gibson, Kingwell, and Doole 2008; Kingwell et al. 1995; Kopke, Young, and Kingwell 2008). Furthermore, the CropSyst model (Stockle, Martin, and Campbell 1994) has been applied to different environments (Confalonieri and Bocchi 2005; Pala, Stockle, and Harris 1996; Wang et al. 2006). Another model named the Global Trade and Analysis Project (GTAP) is frequently used for different policy and trade questions (Hertel 1999). Likewise, the CLUE (Conversion of Land Use and its Effects) model (Veldkamp and Fresco 1996) was applied to many different locations at spatial scales. The above models have been used in different agro-based industries linked with various livestock and crop farming and effective supply chain processes in developed countries. The current research has studied the above models to adopt suitable concepts and design in order to develop an integrated supply chain process model for the Bangladesh poultry industry. The next section deals with Bangladesh poultry supply chain and sustainability.

2.6 BANGLADESH POULTRY SUPPLY CHAIN AND SUSTAINABILITY

A very few literatures were found on Bangladesh poultry and sustainability issues which dealt with an existing supply chain model. The current research has developed a simple supply chain model based on commercial poultry farming. This was based on the study's in-depth and focus group interviews with people with poultry expertise. It was found that the Bangladesh poultry supply chain consists of various levels of poultry breed rearing, procuring and processing units such as grandparent (GP) and parent stock (PS), broiler/layer, feed mill, processing centre and waste procurement unit. Figure 2.11 (developed for this research) depicts the existing supply chain network in the poultry industry in Bangladesh. The Bangladesh poultry supply chain starts with GP bird rearing followed by PS, broiler/layer, hatching of eggs in the hatchery, production of day-old chicks (DOCs) through to feed processing in the feed mill, making value-added chicken products in a processing centre, etc. Figure 2.11 also shows the waste management centre which procures various valuable by-products for further consumption.

Table 2.5 shows various stages of existing poultry operations in the Bangladesh context. These stages are named as grandparent (GP) farms, parent stock (PS) farms, hatchery unit, feed mill, broiler farm, slaughtering plants (open market), processing centre, distribution house and consumption. In Bangladesh, people are still accustomed to consuming chicken bought live from the open market which hinders grow up processing plants for further value-added products. Gradually, people have started consuming processed chicken due to the chores of their busy daily lives (Rahman 2013c). Unfortunately, the Bangladesh poultry supply chain is suffering from lack of coordination between different key stakeholders. Each supply chain member is assumed to be responsible for their part of the fragmented process without coordination between succeeding and preceding processes. This unorganized chain hinders the achievement of optimum growth for meat and egg distribution to the Bangladesh society. This is the particular area of the research gap which needs to be filled through designing an effective supply chain process. This study has attempted to propose such a coordinated supply chain network so maximum benefits can be ensured for stakeholders. The next section briefly discusses the different stages of the poultry supply chain.

It has been mentioned that there is no evidence in the previous literature of research conducted in Bangladesh on the sustainable poultry supply chain. The only model (see appendix A) found in the literature is focused on small-scale poultry rearing through the help of the Department of Livestock Service (DLS). This poultry supply chain existed from the 1980s to 1990s. At that time, the Government of Bangladesh directly assisted farmers to supply day-old chicks (DOCs). The total perspective later changed due to the need to manage increasing demands which were handled by commercial poultry farmers and large investors working together to mitigate the supply–demand situation. Recently, private owners have been managing breeding facilities, farm management and supply chain networks themselves rather than expecting to receive help from the government agency. According to Vo and Thiel (2011) and in-depth field study, the most recent poultry supply chain process is often composed of the following stages (see Table 2.5).

2.6.1 Grandparent (GP) to Parent Stock (PS)

The Bangladesh poultry supply chain starts with day-old GP chicks, imported from highbred genetics companies of the USA, France and China. These breeds are sophisticated and sensitive and should be reared in a quarantined and hygienic environment. The eggs produced from the GP are then hatched to produce PS day-old chicks. Later, PS are grown to maturity and produce eggs for further hatching of day-old broiler and layer chicks. The next step is to rear day-old chicks for a certain time to grow them into mature birds for final consumption.

2.6.2 Day-old Chicks (DOCs) to Mature Chicken

The ultimate farmers rear day-old chicks (DOCs) for 25 to 65 days to grow them to mature chickens. However, Bangladesh poultry farmers rear DOCs for a maximum of 45 days having an expectation of 2.5 kilogram (kg) weight for an individual broiler bird. In contrast, poultry meat consumers prefer to buy a chicken weighing around 1.25 kg to 1.75 kg. To grow a chick to this weight, farmers need to be rear them for an average of 30 days. The mature chickens are then supplied to the open market and processing centres for direct sales and making value-added products, respectively.

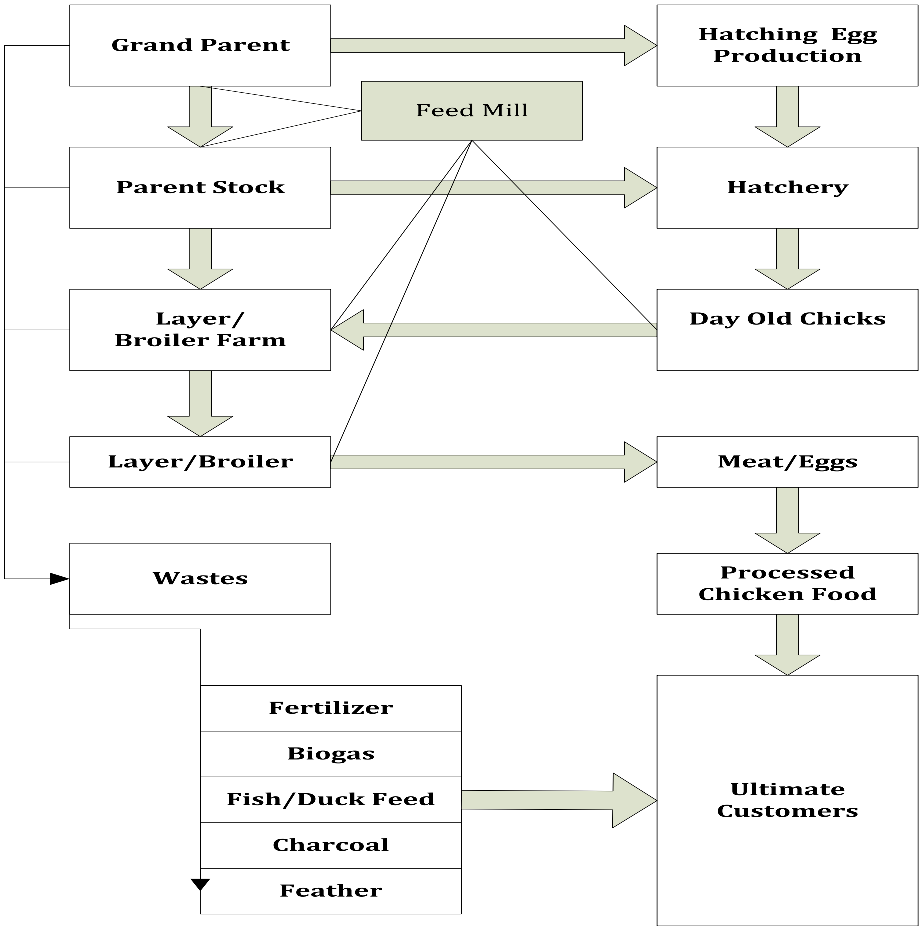

Figure 2.11: Poultry Supply Chain for Bangladesh Poultry

2.6.3 Hatchery and Feed Mill

The hatchery and feed mill are a necessary part of GP and PS farms. It is better to maintain individual feed mills to procure feed for the sensitive birds for quality reasons. Feed ingredients are an important factor for producing healthy optimum numbers of eggs and quality meat. Feed mill operation can be extended for day-old chick, layer and broiler farms. On the other hand, a hatchery is used to hatch eggs to produce the succeeding breed's day-old chicks. Hatchery establishment in a poultry operation is expensive. The necessity of incorporating this operation within a poultry supply chain depends on the production capacity of the mother breed farm. From the opinion of poultry experts, it is expected that a hatchery unit needs to be maintained if weekly production is approximately 50,000. The next section deals with the poultry waste processing unit.

Table 2.5: Different Stages of Poultry Supply Chain

Stage	Tasks to Accomplish
Grandparent Farm	Grandparent (GP) breed produces healthy hatchable eggs for producing day-old parent stock (PS) chicks.
Parent Farm	Parent stock breed produces healthy hatchable eggs for producing day-old broiler/layer chicks.
Hatchery Unit	Hatchery unit takes 21 days to hatch the eggs for GP and PS breeds.
Feed Mill	Feed mill procures consistent feed for GP, PS, broiler and layer birds as per standard requirements.
Broiler Farm	The chickens are grown up to 2.2 kg in 40 days. On a given day, fully-grown mature chickens are transported to the open market and slaughtering plants for direct sales and further processing.
Open Market	Mature chickens and consumable eggs are sold in the open market.
Slaughtering Plants	This stage involves the slaughtering of chickens, de-feathering, evisceration, chilling, maturation, cutting and packaging as well as the pricing for products from the entire chicken. In Bangladesh, the general public are accustomed to consuming chickens bought live from an open market rather than dressed or processed chicken.
Processing Centre	This stage is where value is added to the chickens (pre-cooking, adding spices, etc.) and where chickens are mostly used as an ingredient for the preparation of chilled food (ready meals, sandwiches, etc.). A lower percentage of people are accustomed to consuming processed chicken or different parts of the chicken such as thigh, drumstick, wings and pieces.
Waste Processing Unit	The waste processing centre produces different valuable by-products for household or small industry consumption.
Distribution	Processed chicken products are collected from the processing centre, and then delivered to wholesalers and retailers.
Consumption	This refers to the commercialisation of the product among wholesalers, retailers and markets, i.e. household purchasing, storage, cooking, catering, consuming and disposing of food.

2.6.4 Waste Processing Centre

Poultry genetics produce a huge quantity of different kinds of wastes which can be used for making further by-products. The valuable by-products are then sold to different segments of the market. Some by-products can even be used within the poultry industry. For example, biogas from wastes can be used on the same farm to operate heating systems. At the same time, fertilizers, unused eggs and some other wastes can be resold to different groups of small industries to make other types of products.

2.6.5 Processing Plant and Final Consumption

The last stage of the poultry supply chain in Bangladesh is the final consumption of produced chicken, eggs and various by-products produced from wastes. The poultry supply chain provides fresh meat, eggs and value-added meat products which are produced in various types of processing plants and transmitted to customers with the help of distribution companies. The following paragraph describes a few models which are used in different countries to upgrade agro-based farming.

2.6.6 Literature Gap and Research Model

The literature review in the previous sections has proposed that there is a strong relationship between achieving sustainability and having a structured supply chain. This connection between sustainability and the supply chain may be suitable for the economy, society and the surrounding environment. In addition, the above literature review also discussed the sustainable supply chain, the poultry supply chain around the world and recent poultry supply chain practices. From the literature, the study has achieved an understanding about the literature gap on integrating sustainable supply chains. Consequently, the study has developing an integrated model for a structured poultry supply chain which will contribute in a much better way to Bangladesh society, the economy and the environment. However, gaps still remain in implementing this theory in practical fields, the particular industry or specific operations which might implement this sustainable production process. At this point, the researcher has taken the Bangladesh poultry industry as a research area in which to implement sustainability and the structured supply chain through developing effective forward and reverse supply chain integration.

The above literature failed to disclose a single integrated model which had followed sustainability and pragmatic supply chain concepts to improve the process. It is noted that the literature search was confined to the above-mentioned concepts and the poultry supply chain. In these circumstances, this study is taking the initiative to develop an integrated model where forward and reverse supply chains will act together to make the business more sustainable. To develop an integrated model, the study followed the components of sustainability (economic, social and environmental) and supply chain integration strategy. Firstly, the process in the case industry was modelled (see chapter 5); then the necessary extension was undertaken restructuring the supply chain players to achieve smooth mobility of products. In addition, a few fragmented poultry processes were added to the case industry supply chain process; for example, third party companies normally deal with various aspects of waste processing. The current research tries to adopt these aspects as much as possible to maximize the benefits for stakeholders and customers. Moreover, time variations, policy difficulties, profit goal, time taken in making input decisions and a few other ratios were also incorporated into the model to build a realistic poultry process. Furthermore, the model is run over six years with the four-year output treated as forecasted future productions. Such facilities will help poultry owners to understand what could happen in the future. Finally, the model contains a number of constant inputs: these can be experimented with by changing values to see possible changes that could occur in reality. The final section of this chapter includes a summary of the above discussions.

2.7 SUMMARY

This chapter offered the literature review of this current study. The appropriate details of theoretical concepts from sustainability, supply chain, forward and reverse supply chains, integrated supply chain, sustainable supply chain, poultry supply chain process and sustainable poultry supply chain have been reviewed. At the same time, research gaps have been identified in both the sustainability and supply chain contexts. The next chapter discusses the Bangladesh poultry operation and describes the case industry in light of the current study.

CHAPTER 3:

BANGLADESH POULTRY INDUSTRY OPERATION AND RESEARCH CASE DESCRIPTION[2]

3.1 INTRODUCTION

This chapter discusses the basics of poultry industry operation in general and Bangladesh poultry in particular. It also discusses the poultry breeds, production system, structure, process, supply chain network, calamities of poultry operations and poultry waste management including by-product production. The significance of the poultry industry in Bangladesh is a focus in this chapter showing its scope and future demands. The final section includes the research case description describing their existing operations and procedures for maintaining poultry farming in the Bangladesh environment. Simultaneously, market share, coverage, various products, market demand and diversified technologies used in their operation are also included in this chapter.

3.2 BANGLADESH POULTRY INDUSTRY

The total population in Bangladesh is approximately 148.69 million at an annual growth rate of 1.1% and over 71.9% (BTI 2012) of the total population live in the rural areas and are highly reliant on the farming system. The contribution of the livestock sub-sector to gross domestic product (GDP) and the agriculture sector as a whole is currently 3.2% and 19%, respectively (BBS 2010). The Bangladesh poultry industry started to grow rapidly from 1980, and 0.15 million poultry farmers and 6 million

[2] Parts of this chapter have been published in the following publications:

- **a.** Shamsuddoha, Mohammad. 2010b. "A Sustainable Supply Chain Process Model for Bangladeshi Poultry Industry." In *Curtin Business School (CBS) HDR Colloquium 2010 Perth, Australia,* edited by Joanne Boycott, 1-7. Curtin University: Curtin Business School.
- **b.** ———. 2012. "Achieving Sustainability through Poultry Supply Chain" Emerging Research Initiatives and Developments in Business: CGSB Research Forum 2012, 57-65, Perth, Australia: Curtin University.
- **c.** ———. 2011b. "A Simulation Supply Chain Model for a Sustainable and Environment Friendly Poultry Industry: Insights from Bangladesh." In *Australian and New Zealand Academy of Management (ANZAM), Wellington, New Zealand,* edited by Kevin Voges and Bob Cavana, 1-12. New Zealand
- **d.** ———. 2013. "Poultry Wastes Reuse to Achieve Environmental Sustainability." In *Australian and New Zealand Academy of Management (ANZAM)*, *Hobart, Australia*, 52-59. Australia

livelihoods directly depend on it (Rahman 2007). More than 10 million people are indirectly involved with the poultry industry. The total population of poultry is 200-220 million, and the daily waste produced from this industry is around 15-20 million tonnes (Bhuyian 2007). The poultry industry contributes to the nation by providing a cheap source of high-quality nutritious animal protein in terms of meat and eggs (Das et al. 2008a). About, 20% of animal protein in Bangladesh originates from the poultry sector (Das et al. 2008a, 2008b). The chicken population is particularly dominant within poultry species at about 90%, followed by ducks (8%) and a small number of quails, pigeons and geese (Das et al. 2008b, 2008a). Recently, the commercial poultry breeds have been popular with farmers rather than the traditional scavenging breed, which is helping to increase the poultry population every year. Moreover, the life cycle for the commercial breed is comparatively short which is convenient for economic mobility in terms of gaining profits.

Historically, Bangladesh rural people have reared free range (backyard) and scavenging poultry species, helping them to generate a small income along with maintaining required protein for their family through eggs and meat (Das et al. 2008b). These indigenous birds have relatively low productivity (35-40 eggs and 1-1.5 kg meat per bird per year) (Das et al. 2008b). In rural areas, the majority of the people are landless, underprivileged, malnourished, uneducated, and living below the poverty line (Jabbar et al. 2005; Shamsuddoha and Sohel 2004). For these people, small-scale poultry rearing plays a very significant role in additional income generation, poverty reduction, women's empowerment, supplementing required protein and nutrition, and overall economic development (Shamsuddoha and Sohel 2004). The poultry sector has immense opportunities for engaging unemployed people, meeting protein deficiencies, making various sustainable by-products from its wastes, and the possibility of earning money, empowering people and eliminating poverty from the country. The present status of Bangladesh poultry is discussed in the following section.

3.3 PRESENT STATUS OF BANGLADESH POULTRY INDUSTRY

As mentioned earlier, Bangladesh has a long history of poultry rearing under the traditional backyard, free range and scavenging species system (Reneta 2005). In this poultry rearing system in most of the rural part of Bangladesh, local chickens (Desi or local breeds) are dominant over other similar types of species (Nielsen 2007). In this way, poultry is established as an alternative income generating activity for the rural people of Bangladesh (Shamsuddoha and Sohel 2004). Poultry not only provides a small income and protein but also contributes enormously to the country's GDP (Gerbens-Leenes, Nonhebel, and Krol 2010). In the early 1990s, a number of private parent stock (PS) and breeder farms shifted their operations to produce commercial day-old broiler and layer chicks (Reneta 2005). Thousands of poultry farms were established through private ownership without adequate scientific knowledge. Hundreds of poultry owners practice the triple bottom line framework of sustainability (social, economic and environment) in an unorganized way. In fact, they only follow the profit motive and do not spend time on implementing sustainable processes.

In addition, poultry owners are currently integrating foreign technology and rearing improved genetic breeds in their commercial farms: this has the potential to make the industry more profitable and sustainable. Importantly, Bangladesh is self-sufficient in parent stock (PS) day-old chicks in meeting existing demand (Bessei 1993). This achievement helps commercial poultry farmers to get a steady supply of day-old chicks from local genetic farms. On the other hand, massive poultry production is also creating an enormous amount of poultry wastes. Huge opportunities still exist to utilize poultry wastes as not many farmers are capitalizing on poultry wastes to make economically viable reusable products. Reversing poultry wastes to the same industry or individual small and medium industries can help to achieve more economic, social and environmental benefits for Bangladesh society. In this manner, the environment can be protected from unorganized dumping of poultry wastes and can generate additional income through making by-products. By doing so, other benefits can be achieved such as poverty eradication, women's empowerment, involving new entrepreneurs, food value addition, filling the nutrition gap and maintaining food security. Thus, from the above discussion, it is evident that the Bangladesh poultry industry is increasing its production day by day to meet the demand. However, the industry is yet to follow the modern concepts to achieve sustainable benefits. The following subsections address trends in Bangladesh poultry, meat and egg consumption; nutrition status; costing and pricing; day-old chick pricing; profitability; and protein status.

3.3.1 Bangladesh Poultry Industry at a Glance

The Bangladesh poultry industry has immense potential to contribute to individual livelihoods, the country's economy and aggregate GDP. The Bangladesh poultry industry started scientific farming from the mid-1990s (Kabir 2013). Over the last two decades, the poultry farming sector has grown into a formal industry attracting BDT (Bangladeshi Taka) 150 billion in investment with six million people directly and indirectly employed (Saleque 2009). Currently, there are five grandparent (GP) farms producing 280,000 parent stock (PS) per week (Rahman 2013b). According to Kabir (2013), 32 parent stock farms are producing 5.3 million day-old chicks per week. In addition, 50,000 large- and medium-scale commercial farms along with 100,000 small farms are producing over 9,800 metric tonnes of broiler meat, and 125.8 million eggs per week. Table 3.1 and Figure 3.1 provide evidence of the above information relating to the Bangladesh poultry industry and its status.

Table 3.1: Snapshot of Bangladesh Poultry Industry 2012 (Kabir 2013)

Particulars	2012
Investment	150 Billion BDT
Employment Generation	6 Million
Number of Grandparent Stock Farms	5
Production of Parent Stock/Week	2.8 Million
Production of Day-old Chicks/Week	5.3 Million
Broiler Meat Production	9,800 Metric Tonnes/Week
Egg Production/week	1260 Million

Table 3.2 presents some parameters on the Bangladesh poultry industry which were explored by Boddington (Boddington 2007). The parameters consist of grandparent and parent stock supply, government policy, stability, input industry, grain, genetics and day-old chick (DOC) sales. The number of GP farms, market trends, mortality and feed conversion ratio (FCR) are vital information for the Bangladesh poultry industry. These reveal that the industry is still far behind the standard practice. For instance, FCR is 2.0 to 2.2, which is remarkably higher than the standard FCR of 1.0 to 1.2. This ratio increases the ultimate meat cost creating losses for farmers. The next section presents statistics on trends in the Bangladesh poultry industry.

3.3.2 Trends of Poultry Farms in Bangladesh

Trends are important to consider in understanding the growth rate of certain items. Figure 3.1 reveals that there were 43,589 poultry farms in 1993 and this increased to around 150,000 in 2007. Informally, poultry experts have indicated that Bangladesh has more than 200,000 poultry farms of various sizes. Figure 3.2 presents the number of GP and PS farms from 2008 to 2012, showing the upward trend. As there is no mandatory farm registration system, government or related authorities are not aware of the current exact number of poultry farms in Bangladesh. It is evident from observation that the poultry industry has expanded by a significant percentage in the last decade. The Bangladesh poultry industry has failed to maintain that pace due to policy; calamities, including bird flu (avian influenza) outbreaks and natural disaster; and misjudgement of supply–demand projections (Sonaiya 2007). The next section is discusses poultry meat and egg consumption.

Table 3.2: Bangladesh Poultry at a Glance (Boddington 2007)

Parameter		Parameter	
Grandparent (GP) farms	>8	Retail channel	99% wet market (fresh meat and produce)
Parent stock (PS) supply	100% self-sufficient	Price $/kg	$1.14
Stability	Growing – Immature growers >130,000	Broiler flock – Performance – FCR	2.0-2.2
Input industry		Mortality (%)	7-7.2
Grain	Imported	Market weight (kg)	1.08-1.43
Genetics	100% self-sufficient	Market age (days)	30-33
DOC sales	Dealer/Agent	Integration	<1% non-integrated

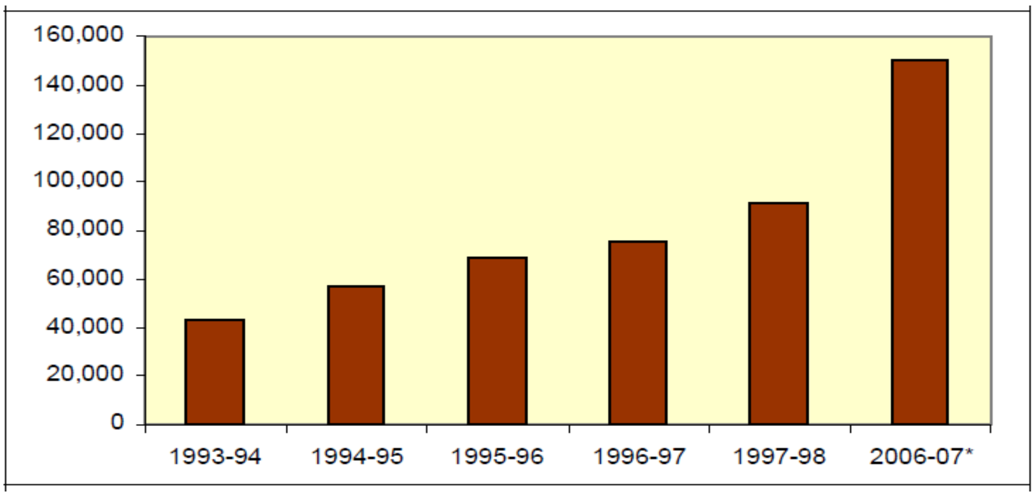

Figure 3.1: Trend in the Number of Poultry Farms (Fattah 2000; Raihan and Mahmud 2008)

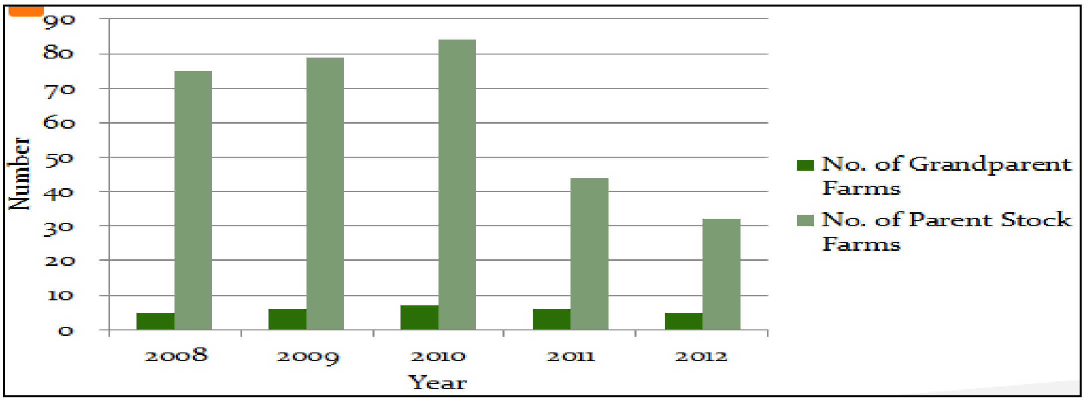

Figure 3.2: Number of GP and PS Farms (Kabir 2013)

3.3.3 Poultry Meat and Egg Consumption

Poultry meat and egg consumption is an important national issue. The more broiler meat consumed by people, the more opportunities there will be to extend poultry farming. Bangladesh is still below the standard level in its consumption of chicken meat. As shown in Table 3.3, the people of Pakistan, Sri Lanka, Indonesia and Malaysia are consuming 5.5, 5.7, 7.0 and 38 kg of meat per capita per year, respectively. Furthermore, chicken egg consumption correspondingly is 60, 54, 87 and 320 eggs per capita per year. In comparison, Bangladeshi people only consume 3.2 kg broiler meat and 41 eggs per capita per year. This rate shows the low consumption of both broiler meat and eggs per year compared with neighbouring countries. There is an opportunity for poultry farmers to fill the supply gap if they keep the price within consumers' expected range. For this, the poultry industry in Bangladesh needs an effective supply chain to maintain standard pricing on meat and eggs. The next section addresses nutritional status coming from animal meat sources.

Table 3.3: Per Capita Poultry Product Consumption (Kabir 2013)

Particulars Kg/Capita/Year	Bangladesh	Pakistan	Sri Lanka	Indonesia	Malaysia
Broiler Consumption	3.2	5.5	5.7	7.0	38
Egg Consumption	41	60	54	87	320

3.3.4 Nutritional Status

Nutrition is an important concern for a country like Bangladesh where huge number of people lives below the poverty line and consume significantly less nutrition than their actual needs. At present, the average calorie intake from animal sources is 6% compared to the global average of 15%. Increased poultry consumption can lead to attaining a balanced diet for the population. Expansion of poultry farms leading to economies of scale and lower prices can ensure chicken affordability and steady consumption of poultry meat. In this way, Bangladesh can reach the Millennium Development Goal (MDG) nutrition target level for exterminating hunger and malnutrition among children. Figure 3.3 supports the above statement of calorie deficiency and targeted standard consumption. The next section discusses the day-old chicks' (DOCs) price, which is important for this study as it is dealing with DOCs.

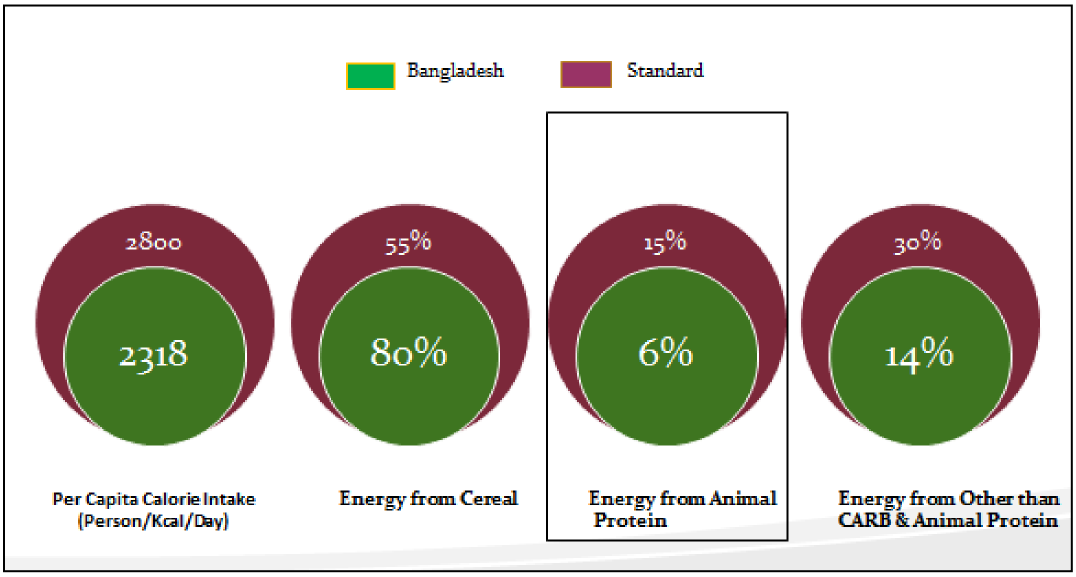

Figure 3.3: Nutrition Status (Kabir 2013)

3.3.5 Costing and Pricing for Day-Old Chicks

Discussions and debates are continuing about the pricing of day-old broiler chicks. Broiler farmers complain about the higher price of day-old chicks (DOCs) while DOC producers grumble about the costing per unit chicks. The in-depth interviews verified that both are correct in expressing such protests. The price is increasing day by day as raw material prices escalate. Moreover, expensive medication and utilities prices are also increasing total costs per unit chicks' production. On the other hand, farmers are not getting an optimum chicken price from the final market which is causing frustration over the chick's price. Figure 3.4 shows the DOC price and cost lines where the cost is rising while the price is lagging behind the cost line. As a result, broiler farmers and parent stock (PS) farmers are losing their capital due to consistent negative profit. The DOC price and profitability are described in the next section.

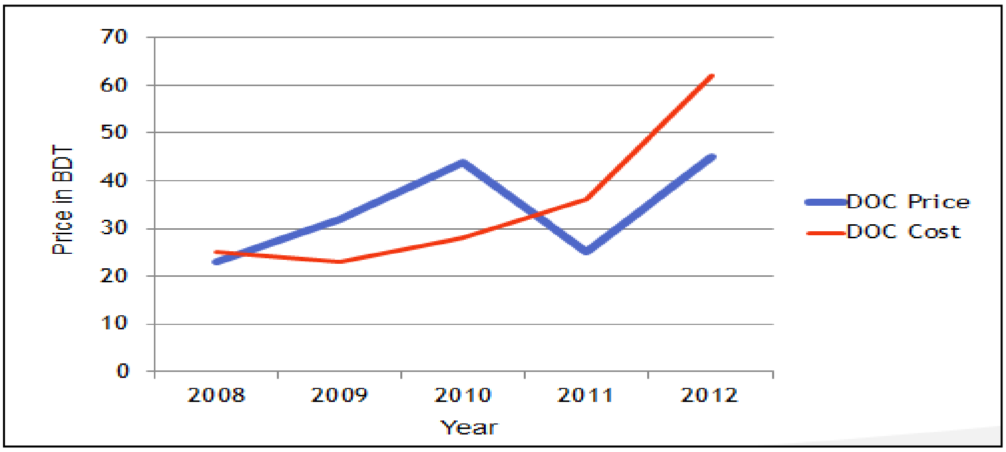

Fig 3.4: DOC Costing and Pricing (Kabir 2013)

3.3.6 Day-old Chicks' (DOCs) Price and Farmers' Profitability

This intrinsic mismatch in supply and demand of day-old chicks (DOCs) makes it extremely difficult to predict variability in prices. Figure 3.5 depicts the status of farmers' profit and loss information from January to December 2012. The graph shows that farms had to accept losses for eight cycles out of twenty-three cycles. Such frequency is alarming to recover the losses based upon trivial profit cycles. It is noticeable that farmers face low price challenges several times within a year. This forces them to accept capital losses thus hindering the growth of new poultry businesses. The following section briefly discusses agent-level profits which are vital for supply chain members.

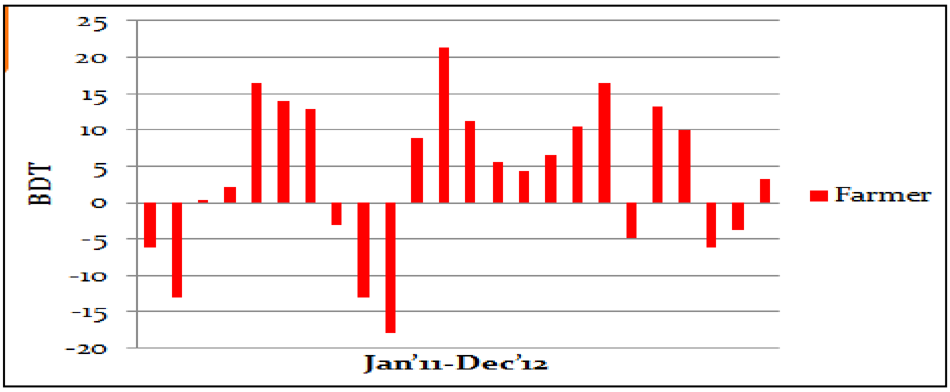

Figure 3.5: Profit/kg at the Farmer Level (Kabir 2013)

3.3.7 Agent-level Profits

Agents make minimum profits even if the market is unstable for pricing or if there are supply–demand matters. Figure 3.6 reveals that for most of 2012, agents made profits although farmers failed to do so. Agents usually deal with chicks based on commission. Thus, they are able to protect themselves from losses in comparison to farmers. The next section discusses protein sources from different species of fish and meat including broiler chicken.

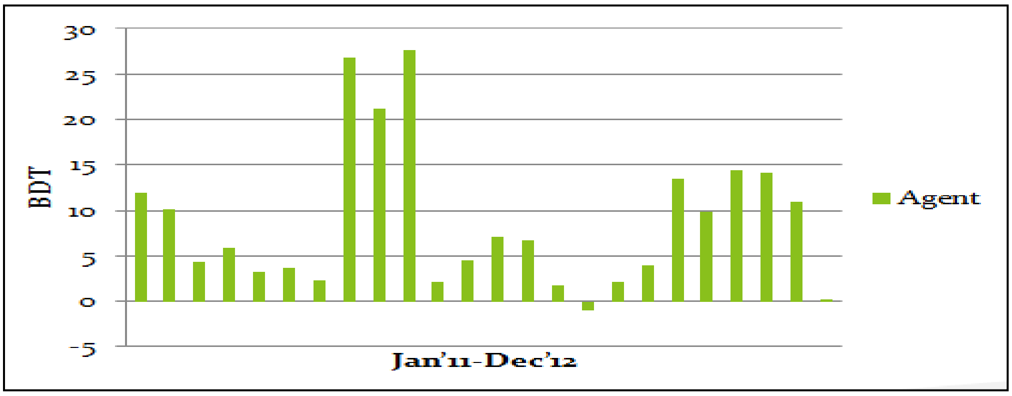

Figure 3.6: Profit/kg at the Agent Level (Kabir 2013)

3.3.8 Protein Sources

Figure 3.7 shows the comparison between species such as fish and animals providing evidence that chicken is the cheapest protein source in Bangladesh. The figure also provides information on growth in recent years for every species.

Year	Beef	Mutton	Roih	Hilsa	Small fish	Broiler	Egg
2005	145	250	120	200	100	80	4.90
2012	260	400	300	600	220	140	7.13
% increase	*79%*	*160%*	*250%*	*300%*	*220%*	*75%*	*146%*

Note: *Roih* and *Hilsa* are types of fish.

Figure 3.7: Poultry – The Cheapest Source of Protein (Kabir 2013)

The above discussion has revealed the basic information relating to the Bangladesh poultry industry. The trend of poultry farm growth was found to be substantially higher than expected. In addition, information about meat consumption, protein requirements and nutrition requirements helps us to understand the importance of this sector in supplying the meat and eggs required by the nation. In addition, profitability and the costing of products is important for the poultry industry. Consequently, trends of pricing, costing and profitability have been discussed in order to understand the opportunity and scope. The following section discusses the scope of the poultry business in Bangladesh.

3.4 SCOPE OF POULTRY BUSINESS

The scope of poultry farming is huge due to its various methods of rearing such as scavenging, free range, indigenous, commercial and semi-commercial. On the other hand, per capita chicken meat consumption in Bangladesh is only 3.2 kg whereas in Malaysia, people consume 38 kg (Boddington 2007; Kabir 2013). Having a huge population with minimum consumption creates a large demand-supply gap. In addition, Bangladeshi people depend on commercial farming rather the naturally growing poultry bird due to its short life cycle. Naturally growing birds take longer to generate meat than commercial poultry which can complete a cycle within 25-40 days. Moreover, the supply–demand gap is the main concern for policy makers and farmers. In other statistics, the projected meat consumption was approximately 582 million kg in 2010 whereas the projected production was approximately 300 million kg (Kabir 2013). This huge production gap is what poultry producers are attempting to meet. Furthermore, it is recognized that Bangladeshi people's food intake involves the consumption of significantly less calories than standard requirements. Such deficiency of calorie intake can be met through massive and structured poultry rearing. Thus, there is plenty of scope to increase poultry production in Bangladesh in order to adjust the protein and calorie deficiency of the whole nation.

3.5 CONTRIBUTION TO RURAL AND NATIONAL ECONOMY

Small-scale poultry production which is an important earning source for rural people has developed in large numbers. In the last few years, recognition of small-scale commercial poultry production has accelerated the pace of poverty reduction (Ali and Hossain 2012). Various articles in the literature reveal another picture and additional information about the Bangladesh poultry industry. It is difficult for a researcher to find out authenticity unless a governmental portal or statistical bureau provides confirmation of its accuracy. In line with this, Ali and Hossain (2012) reported that in

Bangladesh 44% of the daily human intake of animal protein comes from livestock products having US$1.5 billion investment with direct employment of six million people. In another article, Chowdhury (2011) highlighted that per day poultry meat and egg production are 1.6 million kg and 23.5 million, respectively.

Table 3.4: Contribution of the Livestock Sector to GDP (Raihan and Mahmud 2008; BBS 2008)

Particulars	Year			
	2000-2001	2005-06	2008-09	2012-13
GDP (%)	2.95	2.92	2.73	2.45
Annual Growth Rate	2.81	6.15	15.83	13.91

The Livestock Production Index shows that Bangladesh has been able to register growth in livestock since 1990. The livestock sector's contribution to GDP was 2.80% in 1990-91, which increased to 2.92% in 2005-06 (Raihan and Mahmud 2008). Yet, the livestock sub-sector grew at a rate higher than the annual growth rate of the overall agricultural sector. Again, poultry constitutes 14% of the total value of livestock output. From 1983 to 1996, the chicken population increased substantially with an annual growth rate of 3.6% (Giasuddin et al. 2002; Rahman et al. 2002; Alam et al. 2003). To gain an understanding of the poultry production process, the following section discusses the forward and reverse supply chain processes in the poultry livestock sub-sector in Bangladesh.

3.6 INPUT, OUTPUT AND PROCESS OF BANGLADESH POULTRY

The input, output and process of a business operation are important aspects to note. Every industry operates its business with input, processing the input and coming up with final products. Studies on most businesses are primarily on market feasibility, market potential, existing demand and supply, societal impact, environmental hazards, economic output, and government rules and regulation. The poultry industry in Bangladesh is no exception. Figure 3.8 shows the poultry input-process-output sequence which starts from the imported or locally collected grandparent (GP) breed. The grandparent (GP) breed is produced from pure line genetics. The pure line breed is managed by a few countries such as the USA, Canada, France, China, etc. The immediate successor breeds (GP) are then supplied to various suitable countries through direct/indirect channels. Bangladesh has 8-10 grandparent (GP) farms with parent stock (PS) breed chicks' production by Paragon, Kazi, MM Agha, CP farms, etc. A number of parent stock/breeder farms are available to rear these day-old chicks (DOCs) to produce eggs for broiler day-old chicks.

It is noted that rigorous management, a bio-secured environment and huge investments are required for this kind of sophisticated farming. As a result, broiler and layer day-old chicks grow up within a certain period of time to produce meat and eggs for final consumers. This study has focused on the meat producing broiler industry due to its research scope. Figure 3.8 shows that feed, medicine and vaccines, skilled-unskilled-semi-skilled labourers, management decisions, egg production, mortality rates, utilities such as electricity, gas and water, transportation and government decisions are the key input for the poultry industry. These basic elements are vital for this industry to achieve sustainable production and better profitability. The supply chain network can later be enhanced from the ultimate products of meat and eggs towards different processed foods. This is also a major scope for further research.

The process phase generates large amounts of poultry wastes comprising excreta, reject and broken eggs, culled birds, rejected day-old chicks, feathers, intestines and waste feed. Poultry wastes can be used as raw materials in various small and medium industries (SMEs) for making economically viable by-products. Examples include small-scale power using poultry excreta biogas, pillow-making industry using feathers, industry manufacturing fertilizer from manure and wastes, fish feed from intestines and rejected eggs, and artificial charcoal (fire sticks) from poultry litter. In fact, the whole poultry supply chain network is more complex than it appears in Figure 3.8 even though this research has only focused on the broiler meat producing industry that is associated with grandparent farms, breeder farms and broiler farms. It is clearly shown that the poultry process is generating a number of valuable by-products in addition to its main products of meat and eggs. In addition, a number of other industries are involved with the poultry industry such as feed, medicine, pathological/diagnostic, logistics, cages, expertise, breed suppliers, importers, distributors and other associated farmers. This huge network creates so many opportunities for farmers, people and investors. At the same time, structuring such a network is difficult as so many players surround the main industry. It is always challenging to maintain profitable relationships with stakeholders without the implementation of an effective supply chain within this industry. For this reason, the researcher attempted to discover further improvements in this industry in light of a sustainable supply chain related to triple bottom line theory.

In Figure 3.8, the different output can easily be classified from three different viewpoints. From the economic viewpoint, fresh meat, fresh eggs and processed meat are the main economic products for the poultry owner. In addition, there is significant potential to make good quality economically viable by-products from poultry wastes. From the social viewpoint, the Bangladeshi poultry industry is rich as it engages more than 15 million people directly or indirectly (Kabir 2013). This business extends into remote areas helping to reduce poverty, diminish unemployment and empower poor women. Finally, from the environmental viewpoint of sustainability, appropriate poultry waste management keeps the environment unchanged or intact and recycles or reuses wastes economically. Table 3.5 presents possible by-products from poultry wastes that could mitigate the social, economic and environmental problems. At the same time, these by-products can be used in different industries like crops, power and fish. Every stage of the poultry supply chain process can indicate social, environmental and economic wellbeing which is essential to achieve sustainability.

Table 3.5: By-products from Poultry Wastes

Wastes	By-Products	Industry	Problems Mitigated
Poultry Droppings/ Litter	Fertilizers	Crops	Economic, social and environmental
	Biogas	Power	Ditto
	Charcoal	Power	Ditto
Poultry Feed Wastes	Fish Feed	Fish	Ditto
Broken Eggs	Fish Feed	Fish	Ditto
Poultry Feathers	Beds and Pillows	Pillows	Ditto
Unhatched Eggs	Cakes and Biscuits	Bakery	Ditto

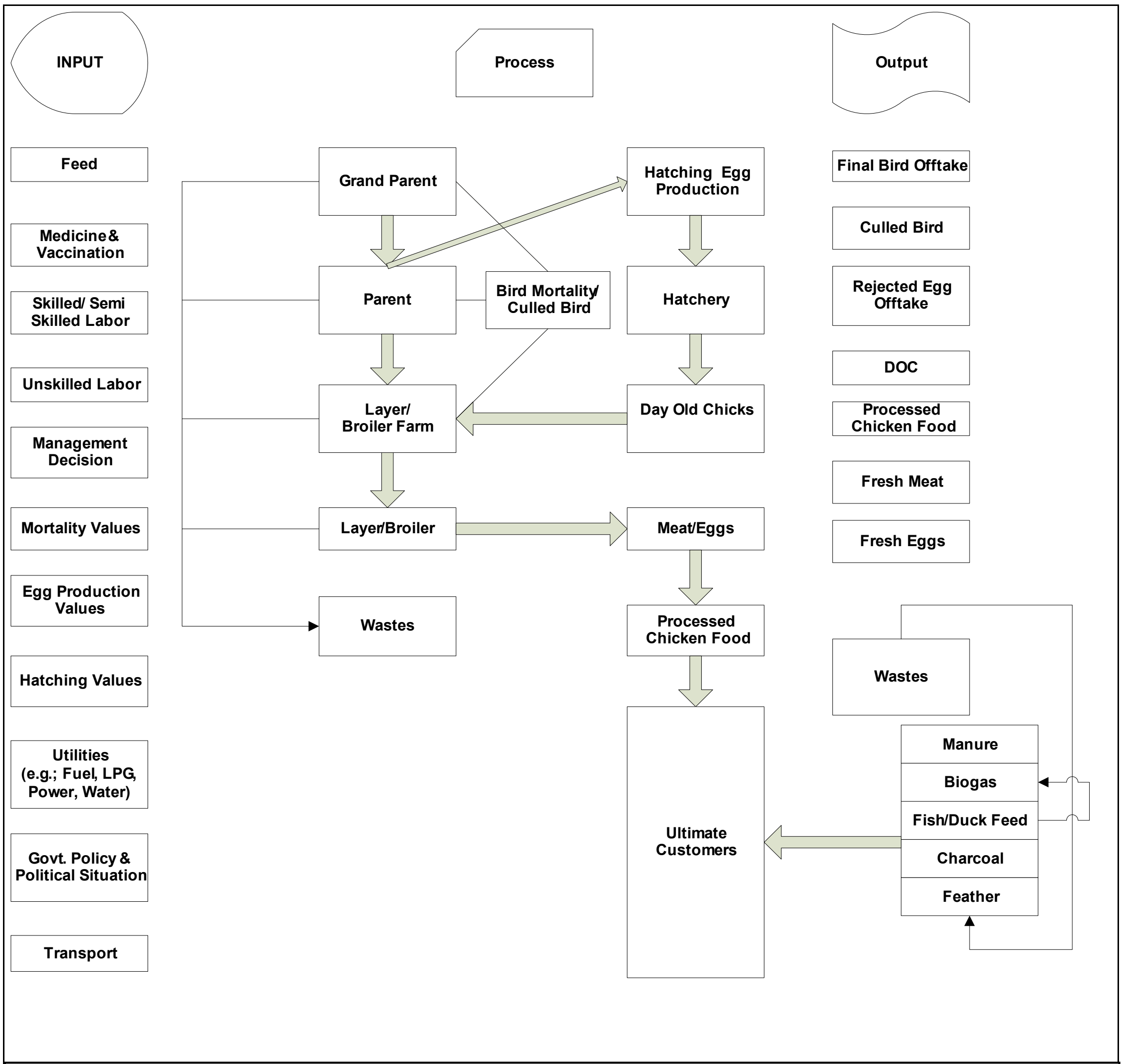

Figure 3.8: Input–Output Poultry Process Model

3.6.1 Simplified Poultry Supply Chain Process

Chicken meat is a highly consumed agricultural product and the main source of protein in the world. The high production cycle, high risks and market instabilities are some of the main challenges of poultry production which are also faced by the broiler industry. A chicken meat supply chain (Figure 3.9) consists of a pure line (pedigree) farm, grandparent (GP) farm, parent farm (P), broiler farm, slaughterhouse and the distribution channel. Figure3.9 shows a simple chicken meat supply chain.

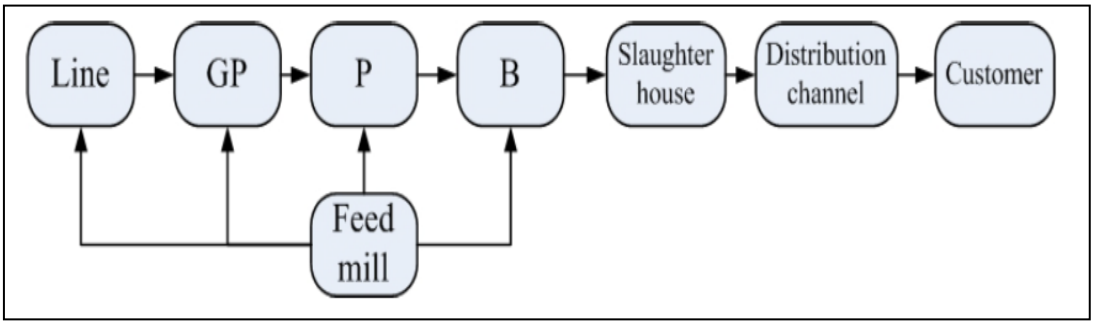

Figure 3.9: Broiler Supply Chain (Shoushtari, Ghasemi, and Zarezadeh 2011)

The broiler supply chain is a complex socioeconomic system which involves several parties and dealing with a number of sustainability aspects. Managing a complex system is a complex task. In Bangladesh, above 90% of chicken are sold in the open market as live birds to ensure compliance with the halal concept (Shafie and Othman 2006). Halal meat is mandatory for Muslim people with the reading of a particular blessing required before slaughtering the chicken. Bangladesh is a country where the majority of people are Muslim. For this, entire open slaughterhouses have the privilege of ensuring the halal meat supply. In addition, chicken meat is further processed to produce value-added chicken products that are for sale in supermarkets and restaurants.

3.6.2 Bangladesh Poultry Forward Supply Chain

The forward supply chain is the process that starts from collecting raw materials and goes through to final consumption of the finished product (Cox, Blackstone, and Spencer 1995). In the same way, the poultry forward chain starts with gathering the grandparent (GP) mother breed from abroad followed by hatching parent stock (PS) chicks, distributing them to the parent stock/breeder farm, rearing them and collecting eggs from parent stock, hatching and distributing day-old broiler chicks, rearing them for a certain period to grow into mature broiler chickens and collecting meat from broiler birds. These processes involve many ultimate farmers, unskilled-semi-skilled workers, skilled workforce, foreign consultants, scientists, entrepreneurs and middlemen at each level. Success within the poultry industry mostly relies on how each step smoothly connects with the following steps to manage steady supply as per current demand.

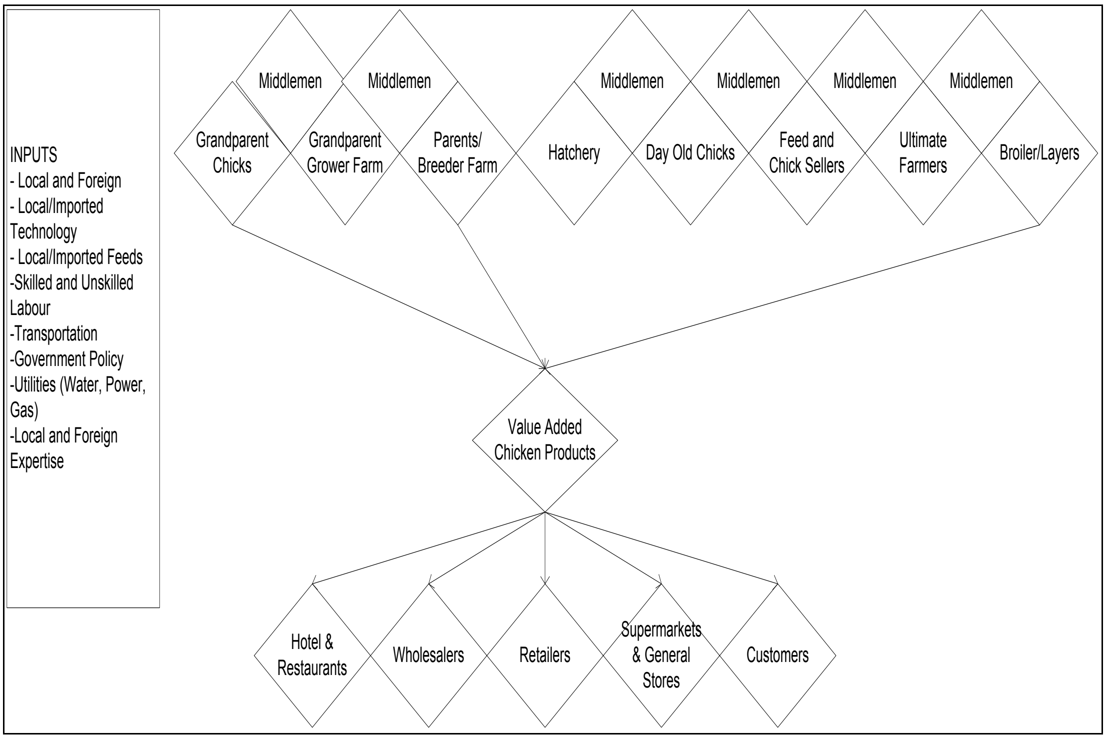

Figure 3.10: Bangladesh Poultry Forward Supply Chain

As shown in Figure 3.10, Bangladesh poultry starts from grandparent chicks and ends with the ultimate customers. Inputs are almost the same for each step of grandparent and parent stock breeding and broiler birds. Notably, every step of breeding is associated with a number of middlemen. Agents, sub-agents, distributors, transporters, consultants, food processors, food shops and restaurants, and the skilled and unskilled workforce are also linked with the poultry middlemen. Value is added as general customers, supermarkets, general stores, hotels and restaurants, wholesalers and retailers consume chicken products. Figure 3.10 shows the inputs to this industry along with major players in the forward supply chain. The next section describes the Bangladesh poultry reverse supply chain.

3.6.3 Bangladesh Poultry Reverse Supply Chain

The reverse supply chain clearly addresses the issues of disposal, recycling, reconditioning and remanufacturing (Kocabasoglu, Prahinski, and Klassen 2007); disposal or recovery value (Prahinski and Kocabasoglu 2006b; Guide and Van 2002); or reducing negative environmental impacts by extracting waste disposal (Kocabasoglu, Prahinski, and Klassen 2007). Poultry wastes can be reused for disposal, recycled to make valuable products, remanufactured into economically viable by-products or have recovered value all of which is similar to the theoretical reverse supply chain. A number of judgments lie behind calling this operation a reverse chain although the majority of people are predetermined to disagree. The explanations are the same as for the reverse chain presented in chapter 2, the literature review chapter. Various poultry wastes are generated from poultry operations such as litter (Burak Aksoy et al. 2008; Rivera-Cruz et al. 2008); broken and reject eggs (Narahari et al. 2000); waste poultry feed (El-Boushy and Poel 1994); feathers (Shih 1993); and intestines (Burns and Stickney 1980). Figure 3.11 presents details of various wastes and their sources from different poultry processing areas. For example, dead and culled chicken come from grandparent birds; similarly, litter (excreta) comes from grandparent and parent stockbreeder birds. Accordingly, the figure also shows the type of by-products that can be generated from particular wastes. For instance, poultry litter waste can produce biogas, artificial charcoal, fertilizer and fish feed. Similarly, other wastes make different kinds of valuable by-products such as bakery items from unused eggs. Most by-products have great potential to meet social, economic and environmental aspects that will make the industry and society more sustainable.

Evidently, no final products can be retrieved to the mother company from the ultimate customers, as poultry products are perishable in nature. The most common understanding of a reverse supply chain is that products or accessories are retrieved, going back to the main company to be generated into new products by recycling or reuse. However, the poultry industry uses the reuse and remanufacturing concept for reversing poultry wastes to make economically viable by-products. This process can be adopted by the same companies that are producing various poultry wastes. Alternatively, these wastes can be taken as raw materials to a third party company to produce by-products. Different small and medium industries (SMEs) can be established to handle different poultry wastes. The reverse process starts with collecting poultry wastes and ends with supplying by-products to the final customers. A number of industries are operating this reverse process within their network to get maximum benefits from by-products such as biogas, fertilizers and fish feed.

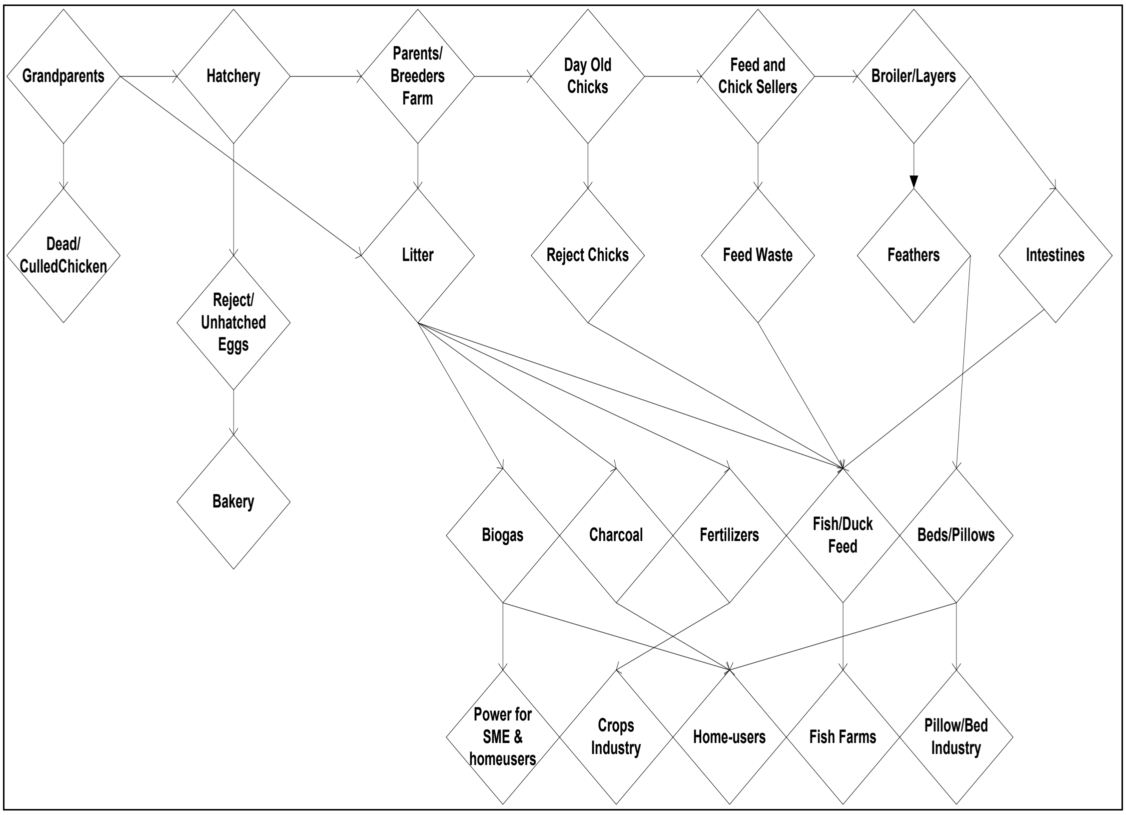

Figure 3.11: Bangladesh Poultry Reverse Supply Chain

3.7 POULTRY COMMERCIAL BREEDING

Breeding for meat and egg production is a remarkably complex process and very costly (Pym n.d.; Crawford 1990). Broiler breeders need to manage to maintain the pace of growth as it is closely related to the output of day-old chicks. Genetic improvements in breeder performance have been steady and consistent since the late 1970s (Hocking 2009). The modern poultry industry maintains scientifically improved genetic birds so that they can initiate an efficient and sustainable industry (Gillespie and Flanders 2010). Furthermore, continuous improvements in poultry genetics need to be quicker than in other species because poultry breeders have the advantages of a large population size and a short generation interval (Lister 2010). Such progress will maintain the pace in achieving a more efficient and precise breed for commercial poultry species (Hocking 2009). The following sections discuss the top genetics of poultry breeding as shown in the figure 3.12.

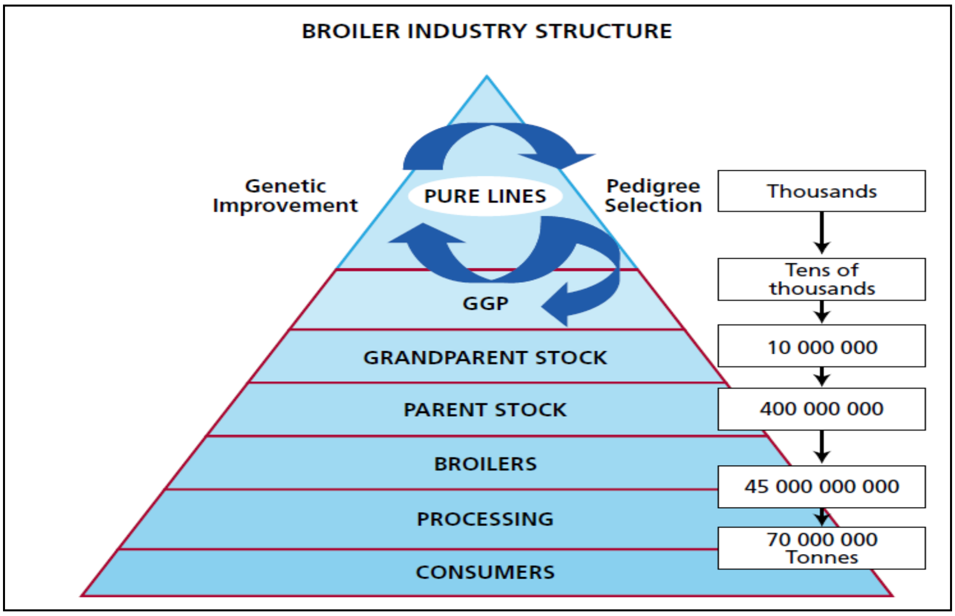

Figure 3.12: Number of Birds and Generations Involved in Transmission of Commercial Broiler Genetics (McKay 2008; Lu et al. 2003)

Above figure 3.12 shows that poultry genetics starts from pure line and ends with consumption of ultimate meat and eggs. At the same time, the right hand side of the above figure shows the numerical figures of generating following genetic from the preceding genetic. For example, a thousand of poultry pure line genetic creates tens of thousands immediate breed and 4500 millions of broiler birds which ultimately produced 7 million tonnes of poultry meats. Therefore, poultry is a quickly growing genetics with massive productions of ultimate products. The following sub-sections are briefly discussed in the following.

3.7.1 Pure Line

Pure line is a uniform strain of organism that is relatively pure genetically because of continued inbreeding and artificial selection (Marshall 1977). All successful breeding programs will ensure that welfare standards continue to improve to ensure that poultry production is a sustainable industry (Hocking 2009). The pure line is genetically the topmost breed within commercial poultry (Muir et al. 2008) which ensures the quality of successor breeds like great grandparent and grandparent. For example, one thousands pure line mother poultry breed can produced around tens of thousands great grandparent which known as GGP breed to the farmers. These breeds are sophisticated in nature to rear with a prescribed control housing systems. In Bangladesh, there is no pure line farm established yet.

3.7.2 Great Grandparent (GGP)

The Bangladesh poultry industry recently achieved self-sufficiency in parent stock (PS) production (Boddington 2007). More special care and management is needed to optimize the performance of a PS producing farm as these farms are highly sophisticated (Boddington 2007). Currently, Bangladesh poultry owners are producing around 350,000 to 400,000 PS per year (Saleque 2013). At the present time, commercial parent breeder poultry farms are supported through five to eight (the majority say five) grandparent farms with production of approximately 130,000 per week of parent stock day-old chicks: however, they are not always in production (Saleque 2009). Saleque also reported in the same article that five grandparent farms produce 62% of the parent broilers. Kazi, Paragon. CP, Aftab and Nourish are the major grandparent farms in Bangladesh (Saleque 2013). Recently, three or four existing parent breeder companies extended their business into GP farming. The situation depends on the existing demand for PS chicks by the PS farms. As shown on Table 3.6, PS production in 2005 was 120,000 increasing to 168,800 in 2010. These numbers of PS are sufficient for the existing production capacity. It is expected that GP farmers are now capable of increasing production (Rahman 2013b) by up to 30-40% if demand rises. A grandparent starts producing eggs at about 22-24 weeks of age and finishes production at about 60 weeks of age, producing between 100-120 fertile eggs (Leeson and Summers 2010). These grandparent flocks produce the next generation of day-old parent breeder chicks. At any one time, there might be 150,000-175,000 grandparents of all ages on the ground across Bangladesh. These grandparent flocks produce the next generation of birds, called the parent breeders. Table 3.6 shows the population dynamics of commercial poultry in Bangladesh.

Table 3.6: Population Dynamics of Commercial Poultry (Saleque 2009)

Items	Years					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
Grandparent Stock (GPS) (‘000)	120	125	120	148.8	145.0	168.8
Parent Stock – Local	1291	2410	2040	2400	2960	2900
Parent Stock – Imported	1454	1488.7	650.0	771.5	168.8	474.3
Total Parent Stock	2745	3898.7	2690	3171.5	3128.8	3374.3
Total Broiler Chicks (Million)	192.5	288.2	325.6	301.3	297.2	320.5

3.7.3 Parent Stock Breeder

According to the Australian Chicken Meat Federation (ACMF), grandparent breeders produce fertile eggs to hatch day-old parent stock breeder chicks under the same sophisticated farming management (ACMF 2005, 2013). The third generation of parent stock breeders will then produce fertile eggs to hatch day-old broiler chicks which are then reared by the ultimate farmers until they become mature broiler chicken for final consumption (ACMF 2005). A large number of parent stock breeds were imported from the USA, France, India and Thailand. Due to avian influenza in other countries, Bangladesh put an embargo on imports. The Bangladesh poultry industry has been self-sufficient in breeder PS production since 2009 (Saleque 2013).

3.7.4 Day-old Chick (DOC)

Currently, day-old chick demand is about 9.2 million per week whenever farmers produce 9.2 million which indicates self-sufficiency. However, many calamities hamper the Bangladesh poultry operation causing falls in production that range from slow to drastic. Falls in production lead to supplies falling and farms closing down. In 2012, due to bird (avian) flu and other calamities, the number of farms dropped from 114,638 to 60,824, eliminating almost half the farms (Effedlink 2012). In interviews with poultry experts, they expressed the view that the actual figure was higher than the official statistics. They indicated that the number of broiler farms was around 200,000 (Saleque 2013) and that approximately 60,000 farms were shut down due to various calamities and lack of finance (Saleque 2013; Rahman 2013a). The volatile nature of the market is the main reason for leaving poultry farming: otherwise, it is still a profitable business for which there is a demand. Prediction is very important for the Bangladesh poultry industry as many aspects need to be considered when undertaking farming amidst calamities and disasters (Rahman 2013a).

3.7.5 Ultimate Broiler Farming

According to the Poultry Consultancy (www.thepoultryconsultancy.com), the broiler is a type of lower-level poultry breed raised specifically for chicken meat production. They are recognized for their fast growth rate with short life cycles and having a high feed conversion ratio (FCR). Usually, broiler birds are harvested at the weight level of 1.5-2.5 kg which takes a maximum of 4-8 weeks (Rahman 2013b; Saleque 2013). In Bangladesh, people like to consume broiler chickens weighing 1.25-1.75 kg. Due to this habit, farmers have to sell their mature broilers at this weight which usually takes 4-

5 weeks to harvest. Between 320-350 million mature broiler birds are ready for ultimate consumption as per 2010 data. The above information has been taken from in-depth interviews with poultry executives from the case industry.

3.8 FORECASTED GROWTH OF BANGLADESH POULTRY INDUSTRY

There are no authentic sources for getting accurate data about broiler production in Bangladesh. The main reasons for inaccurate data are improper and irregular data maintenance by the government statistical bureau and optional registration of poultry. Those rearing at least 1,000 birds in a flock are easily identifiable by middlemen or agents. However, those rearing less than 1,000 birds are hard to trace as they may not have attachments to distributors, feed producers or agents. Thousands of such farms have been established by small farmers in their backyard, rooftop or on vacant land near their home as a hobby or as an experimental case. It is assumed that the moderate farmer will be able to have eight batches of birds in a consecutive cycle per annum. Consecutive cycles depend on whether there are calamities (disease, natural disaster, rapid growth or a fall in production) throughout the country. Each cycle lasts up to 4-6 weeks with a few days' break between cycles. Commercial poultry follows the "all in-all out" rule which means that birds that came in together, go out for sale together. Present and forecasted information from Boddington (2007) is presented on Table 3.7 to show the possible growth that can be achieved.

Table 3.7: Present and Forecasted Bangladesh Poultry (Boddington 2007)

Flock Size	2007	2010	2015	2020
Grandparent (GP)	111,111	127,000	197,800	343,779
Parent Stock (PS)	5,555,555	6,388,000	10,200,000	17,188.000
Day-old Chicks (DOCs)	364,000,000	598,500,000	962,850,000	1,608,000,000
Commercial Broiler	343,800,000	541,500,000	687,775,000	1,149,206,000
Integrated/Contracted Broilers	2,000,000	8,122,500	229,000,000	383,068,000
Forecasted Consumption (kg/year/person)	315,000,000 (2.25kg/hd)	582,000,000 (3.82/hd)	867,501,000 (5.19kg/hd)	1,448,200,000 (8.67kg/hd)
Chicken Required	333,333,333	570,000,000	917,990,000	1,532,275,000

The Bangladesh poultry industry is found to be substantially growing and has forecast sustainable growth if surrounding circumstances remain same. For instance, there were 127,000 grandparents in 2007 which is projected to increase to 343,779 in 2020. Similarly, the PS breeders, DOCs, commercial broilers, contracted broilers and consumption were also forecast with all results highly satisfactory in terms of the growth rate. It is important for the Bangladesh poultry industry to maintain the pace of growth to achieve sustainable growth along with minimization of the demand-supply gap**.** The following section provides information about the case industry for this research.

3.9 THE CASE INDUSTRY DESCRIPTION

This section describes the research case which is a prominent poultry parent stock farm in Bangladesh. The current research has developed a model based on a case industry. Consequently, more needed to be known about the case industry and its history, market share, vision, production, supply chains, products and the technologies used in their operation. In addition, farming under different calamities is also discussed in this section.

3.9.1 Nahar Agro Limited – The Case Farm

The following discussion describes the research case industry. Elements discussed are confined to vision, products, market share, farm management, capacities and technology used by the case farm.

3.9.1.1 Nahar Agro Group

Nahar Agro Group is one of the largest organized parent stock (PS) farms in Bangladesh. Their main breeds are Hubbard Classic, Cobb and Ross which are breeds common to all other parent stock farms in Bangladesh. Presently, they have a number of poultry sheds in three different places based in the Chittagong Division of Bangladesh. Figure 3.13 shows the layout for one of the project unit located at Mirarsharai, Chittagong, Bangladesh. The layout shows the location with the Dhaka-Chittagong highway nearby and it is isolated from the nearest locality. Such a place is ideal for poultry farming. They have chosen an isolated and well-protected area as protection against possible disease outbreaks. The parent stock (PS) sheds are environmentally controlled so that no wild birds or species can enter, and ventilation is activated to regulate temperature. All farm employees live on the farm and a strict no visitors' policy is enforced. Appendix D is added some pictures (taken from Mirarsharai projects) to visualize how the farm look like.

3.9.1.2 Historical Background

Nahar Agro Group Limited is an agro-based industry which began operations in 1986 as a small-scale dairy and poultry rearing company. They formed an agro-based group of companies that include dairy, poultry, fisheries and crops and vegetables. Poultry and dairy are their main businesses in their roperation. Among them, poultry has been the project with the highest investment since 1995. Nahar Agro is ranked within the top ten in the poultry industry in Bangladesh. Nahar Agro Group is a family-owned company that started operations in 1986 with 35 laying hens and 15 dairy cows. The initial investment was around A$3,000. The present business is worth approximately A$10 million excluding other associated businesses. The main initiator of this small business operation was the late Tipu Sultan Mahbubur Rahman, who was an ex-officer of Bangladesh Railway having worked there since 1963. After his death in 1994, his wife, Shamsun Nahar, and two of his sons followed him into the business, inspired by his motivation to operate livestock and agro-based businesses for the company's profit as well as for the country's benefit. His elder son, Mohammad Rakibur Rahman Tutul, with much motivation, has developed himself as an outstanding entrepreneur within the limits of his capability. His younger brother has always backed the company with his knowledge, time and hard-working attitude. They started adding new concepts (technology, dynamic ideas and risk measurement) into their farming along with high technology from the USA, France, China, India and Canada. At the same time, they managed to get bank finance to develop their new projects which significantly helped them with their business growth.

3.9.1.3 Vision

The vision of the case industry is simple: they want to be a market leader by achieving sustainability and acquiring all the hi-tech (high technology) concepts in their existing farming. Initially, they simply started their business and did not put much thought to the impact of hi-tech, analysis of the supply chain and sustainability. Now, they are trying hard to incorporate this knowledge in their farming operation to achieve sustainability and stability as well as more market share to soon become a market leader.

Figure 3.13: Industry Layout (google map with reality) for Nahar Agro (Mirarsharai Project)

3.9.1.4 Market Share

It is difficult to be exact about the market share for the case industry as a developing country like Bangladesh does not have any statistics with which to evaluate it. Private agencies and newspaper reporters have accumulated relevant information about existing production and operation of various poultry companies in Bangladesh. They have prepared reports with approximate market shares and production targets. In this way, concerned people can get an idea about an individual farm's production, scope and market share. Currently, Nahar Agro Group has the highest chick production in the Chittagong Zone (Chittagong is the second largest city in Bangladesh) and is ranked in 10th position among all poultry companies in Bangladesh. They are planning to increase their business by at least 10-20% growth in every year subject to demand and the situation with regard to calamities.

Table 3.8 presents a list of the top seven day-old broiler chick producing companies in Bangladesh. Among them, Nahar Agro's farm (the research case) is positioned as fifth with its maximum capacity of 800,000 and production of 500,000 day-old broiler chicks per week. Kazi (www.kazifarms.com) and CP (www.cpbangladesh.com) farms are the leading companies in Bangladesh and produce more than 50% of the total production of broiler chicks. It is noted that the case industry has two separate farms in a different location for its parent stock farm, and the figure in Table 3.8 is the total for both projects. These farms are named as Nahar Poultry Complex Limited and Mirarsharai Poultry Farms Limited. This study has chosen Nahar Agro Complex Limited for the modelling purpose.

Table 3.8: Top Seven Day-old Broiler Chick Producing Companies (Kabir 2013)

SL No.	Hatchery	Max. Capacity DOC/week	Current DOC Production/week
1	Kazi	3,662,320	2,200,000
2	CP	2,500,000	2,300,000
3	Nourish	1,416,400	1,200,000
4	Aftab	1,000,000	650,000
5	**Nahar Agro**	**800,000**	**500,000**
6	Paragon	742,000	500,000
7	MM Agha	600,000	450,000

Table 3.9 presents the market position for day-old layer chick production in Bangladesh. Nahar Agro is positioned third among all the layer chick farms in Bangladesh. The current study did not consider layer chicks and confined the study to broiler chicks. There is a significant difference between broiler and layer farming. Layer farming collects eggs daily while broiler farming produces meat. The supply chain network, farming procedure and life cycle are significantly different between the two types of farms.

Table 3.9: Top Layer Chick Producing Companies in Bangladesh

SL No.	Particulars	Max. Capacity DOC/week	Current DOC/week
1	Kazi	260,000	250,000
2	CP	300,000	200,000
3	**Nahar Agro**	**100,000**	**75,000**
4	Paragon	500,000	75,000
5	Nourish	70,000	65,000
6	Phenix Hatchery	65,000	60,000
7	Goualondo Hatchery	50,000	40,000

3.9.1.5 Market Coverage

The market coverage of the Nahar Agro Group is mainly based in the Chittagong Zone, with Chittagong, the second largest city in Bangladesh, having an effective seaport. Chittagong is one of the fastest growing cities in the world (Citymayors 2013; Xfinity 2013). A major commercial and industrial centre, the city also has a globally competitive special economic zone (Dailystar 2012). With major infrastructure projects being undertaken in the city, including a deep-sea port, regional neighbours of Bangladesh, including India and China, have eyed Chittagong as a future regional transit hub (Indianexpress 2011). The above information reveals that Chittagong has tremendous prospects in the business sector. In addition, Nahar Agro covers markets for their chicks in Comilla, Vairab, Dhaka, Rajshahi, Bogra, Khulna and Sylhet regions. Dhaka and Chittagong Divisions hold more than 70% of the broiler market and the rest of the market share is distributed among the other divisions in Bangladesh. Table 3.10 supports the above statement.

Table 3.10: Poultry Production per Division (BBS 2009; Dolberg 2008)

Division	Number of Commercial Poultry	Percentage (%)
Barisal	1001077	4.6
Chittagong	4281804	19.6
Dhaka	11634021	53.3
Khulna	1668594	7.7
Rajshahi	2052593	9.4
Sylhet	1171560	5.4
Total	21809649	100.00

3.9.2 Nahar Products

The product line for the case industry is discussed in the following sections.

3.9.2.1 Day-old Broiler Chicks

Nahar Agro Group is the producer of the following breeds: Hubbard Classic from France, Cobb-Vantress 500 from the USA and Ross 308 from the USA which are acknowledged to be the best broiler breeds in the world. The Hubbard Classic and Cobb broiler chicks of Nahar Agro are considered among the best-performing chicks in the domestic market, and are sold through a long forward supply chain network. The other breed is also popular in the day-old broiler chick market.

3.9.2.2 Day-old Layer Chicks

Nahar Agro Group is also the producer of and distributor for Shaver 579 breed day-old layer chicks in Bangladesh. Hy-line International of the USA is the oldest poultry breeding company in the world, and is the leading breeder of layers.

3.9.2.3 Various By-products

The main products of the case industry are day-old broiler and layer chicks. In addition, they produce a number of by-products from poultry wastes generated from their farm. Biogas, fertilizer and fish feed are the main valuable by-products generated from wastes.

3.9.2.4 Other Products

Day-old chicks are the core products of the case industry. The case farm produces eggs which are mainly used for hatching chicks. A good percentage of eggs either remain unhatched or are rejects at the hatchery and farm level, respectively. They are sold to the nearest bakeries to make confectionery goods such as biscuits, cakes, etc. Moreover, they sell the aged parent birds for meat consumption in the open market through middlemen. A huge amount of meat is produced at the end of life of a mature parent flock. A flock size can be more than 50,000 birds at a time. For instance, a mother parent grows up to 4 kg at the end of their productivity life cycle.

3.9.2.5 Production Status of Various Products

Table 3.11 displays statistics of various products produced within the farm. Parent chicks are imported or locally collected: they then grow at the farm from day-old chicks to the maximum age of 70 weeks. The number of parent chicks, mature parent and day-old chicks, and the amount of biogas, fertilizer and fish feed for nine different weeks are shown on the table. It is observed that parent chicks are maintained at around 120,000 while mature parents are around 170,000 to produce the desired amount of approximately 420,000 day-old chicks. On the other hand, weekly biogas production is around 36,000 cubic metres (cm^2) followed by an average 1.7 tonne of fertilizer and 2.75 tonne of fish feed. The figures on Table 3.11 show the perceived knowledge about the farm production capacity of various products.

Table 3.11: Production of Various Products for Particular Periods

Week	Parent Chicks	Mature Parent	Chicks	Biogas (CM^2)	Fertilizer (Tonne)	Fish Feed (Tonne)
1	120890	170158	413926	36,579	1.70	2.75
2	120896	170873	419833	36,618	1.70	2.74
3	120902	169888	423896	36,540	1.72	2.73
4	120907	172903	428991	36,579	1.60	2.75
5	120913	167018	423866	36,066	1.58	2.73
6	120919	170933	417377	35,947	1.55	2.70
7	120924	167948	413836	35,813	1.55	2.69
8	120930	165963	410088	35,774	1.60	2.69
9	122936	162408	403806	36,124	1.62	2.71

3.9.3 Sources of Day-Old Parent Stock

Initially, Nahar Agro imported their day-old chicks' parent stock from different countries like France, USA, Canada and Australia. A significant percentage of chicks died while travelling thousands of miles to reach their destination. Moreover, local roads and highways are not structured well for travelling towards the destination farm from local airports. Altogether, travelling to the destination farm from the country of origin was more difficult and costly than expected. Furthermore, the local environment was completely opposite to the original country in terms of climate, humidity and temperature. To prevent this travelling disaster, Nahar Agro decided to rear some flocks from birds locally produced from different GP farms. These farms, named as grandparent (GP) farms, imported day-old GP chicks from different developed countries to produce day-old parent stock chicks. Table 3.12 provides details of GP farms' names, population and production per week. These chicks are better habituated to the existing environment because their preceding genetic (GP) mother grew up in the same environment. Breed collection from the same environment has better resistance than imported birds which come from other countries. Noticeably, different countries have different climate conditions which create adjustment problems for the parent bird. Change of climate may also hamper the production and life cycle of the birds. Currently, Nahar Agro is close to being self-sufficient in local GP farming and PS chicks.

Table 3.12: Broiler Grandparent Farms (2010)

Name	Origin	List of GP	Population	Production/ Week
Aftab GP Farms Ltd.	France	Hubbard Classic	20,000	15,000
France/USA	France/USA	Ross-308, Cobb-500	20,000	25,000
Kazi GP Limited	USA	Cobb-500	30,000	40,000
Kasila Bangladesh	USA	Cobb-500	15,000	10,000
Paragon GP Limited	France/USA	Hubbard Classic	24,000	30,000
Rashik GP	Germany	Lohman-Meat	15,000	10,000

There are a few companies that are distributing local parent stock (PS) to breeder farms situated in different parts of Bangladesh. Different breeds like Isa Brown, Shaver Brown/White/Black, Lohmann, Hisex Brown/White, Hubbard, Bovan's Goldline and Colored Broiler are used in trade with breeder farmers. Table 3.13 presents a list of major parent stock marketing companies and their breeds' original country, types of birds and breed name. The case industry is also listed as it deals with the mother chicks as a mediating company.

Table 3.13: Parent Stock Marketing Companies (2010)

Name	Imported From	Type	List of Parent Stock (PS)
Advance Bio-products Limited	France, Netherlands, Canada	Layer	ISA Brown, ISA White
Ample Animal Care	Netherlands, France, Canada	Layer Broiler	Shaver Star Cross 579 Brown, Shaver White, Shaver Black,
Advance Animal Science Co. Ltd.	Germany	Layer Broiler	Lohmann Brown Classic/Lite, Lohmann White (Lohmann LSL Lite), Lohmann Indian Runner (LIR)
Bengal Overseas Limited	Netherlands, France, Canada	Layer	Hisex Brown and White, Bovan's Brown and Goldline, Bovan's White-Nera-Gold, Dekalb White and Black
Poultry Consultant & Dev. Services	France, USA	Layer Hubbard Broiler	Novogen Brown, Novogen White, Hubbard Classic, Hubbard HI-Y, Flex, Colored Broiler
Novelty Animal Health	Germany	Layer	Brown Nick, Brown Nick, Brown Egg Layer Brown Nick, White Egg
Nahar Agro Group	France, USA	Broiler Layer	Hubbard Classic, Shaver Brown Layer

3.9.4 Farming under Different Calamities

The Bangladesh poultry industry has to face many calamities in their operation. The researcher found two types of calamities: natural and man-made/control calamities. Poultry disease and natural disaster belong to natural calamities and over/under-production, market demand, government policy and competitors' actions are under man-made calamities. Bangladesh is a densely populated country with a small area of land for living and cultivation. Moreover, there are no specific industrial policies to isolate poultry zones from the community.

3.9.4.1 Poultry Disease

Poultry disease is one of the major problems in Bangladesh, and a number of farmers are victimized every year. Standard market demand-supply is often influenced by disease outbreaks. Ultimately, this creates direct and indirect negative impacts on society and the economy (Dolberg 2008). Thus, special measurement and emphasis should be given on preventing poultry disease. At the same time, farmers need to learn about scientific farm management, farm biosecurity and preventing particular diseases. According to Rahman (2013a), poultry can be contaminated with disease from the community or marketplace by ignorant behaviour about waste management and improper vaccination. The Bangladesh poultry industry loses millions of dollars every year due to various kinds of common disease along with the new phobia of bird (avian) flu. However, bird flu is not as dangerous as expressed in the print and digital media and by the general public. There is absolutely no risk if chicken meat is boiled at over 40 degrees centigrade. The only risk is when someone eats bird flu-affected raw chicken meat or eggs (Avlicino 2007). Table 3.14 provides statistics on the number of farms and poultry birds affected by avian influenza.

Table 3.14: Farms and Poultry Birds affected by Avian Influenza (AI)

Year	Total Districts Affected	Number of Farms	Total Birds in Poultry Farms	Deaths	Culling	
					Commercial	Backyard
2007	20	68	205160	35076	136426	33708
2008	44	227	1296687	243005	975373	81769
2009	16	32	48810	3687	42281	3047
2010	13	30	191659	18004	173516	139
Total		357	1742316	299772	1327596	118663

3.9.4.2 Natural Disaster

Bangladesh is a low-lying riverine country having high risk of flood, cyclone, river discharge, storm surges, tidal interactions and other types of disasters (Ali 1999; Wisner 2004). Bangladesh is a country at high risk of natural disaster which hampers various kinds of businesses every year. The poultry industry is no exception. Market demand and supplies are completely affected by natural disasters when they occur. In the event of a massive flood, a huge number of poultry farms have to stop production due to their farm areas being washed away or under floodwater. Farmers lose their capital forever as no insurance cover is available for them. Thousands of farmers are never able to recommence farming due to inadequate sources of further finance. Others somehow manage with funds from financiers, friends or personal loans at high interest. In this way, some are successful while others are not. Nevertheless, those who carry on their businesses within the vicissitudes of calamities ultimately achieve success in terms of profitability.

3.9.4.3 Over/Under-production

Over-production and under-production are major problems for the poultry industry of Bangladesh. Poultry production is a business which is always controlled by the natural cycle. The natural cycle is one in which the production cycle cannot be manipulated (reduced or deviated from), such as the 21 days that are needed to hatch an egg. When a farm forecasts their future production, they write out their plan in such a way that this forecasted production would become a reality in the near future. Once a flock was started at their farm, it must be carried on through to completion as no one could stop the chicks growing or the farm's production. This is why the industry has under- and over-production based on market volatility. Market volatility relies on the trend of chicken and egg consumption by the general public. The consumption of eggs and chicken is also linked to seasons, festivals and the frequency of social events such as weddings, birthdays and post-wedding parties. In summer, chicken consumption is higher than that of the red meats, beef and mutton. Again, when poultry disease breaks out, people panic which leads to drastic falls in chicken-related product consumption.

Bangladesh is a country of hospitality and events involving social gatherings are frequently part and parcel of the lives of Bangladeshi people. Frequent social events create demand for more chicken. Above all, these situations and events are uncertain: it is difficult for farmers to predict exact demand arising from these circumstances. Moreover, there are no statistics that predict the current number of farmers, their capacity and possible immediate production. This is why farmers face over- and under-production circumstances. However, under-production provides extra profit but, at the same time, misses the opportunity to make a higher volume profit. On the other hand, in the case of over-production (a low demand situation), farmers are crushed by drastic falls in the prices of chicken and eggs also leading to an uncertain future. In that situation, they have to carry on their business although they start losing their capital. In fact, other factors such as disease, retail consumption tendencies and seasonality are also responsible for lost capital. For example, the outbreak of bird flu in 2007 closed two-thirds of the country's poultry farms which led to half of the five million people within this industry also being victimized (IRIN 2013).

3.9.4.4 Government Policy

The Bangladesh government's Livestock Policy from 2007 is critical to the biosecurity situation stating that: "[w]hile the growth of the poultry industry has contributed to economic growth and income of commercial farmers, indiscriminate and unplanned growth of breeder farms and commercial poultry farms, particularly in and around cities and towns is creating environmental hazards. There are at present no guidelines for environmental protection and bio-security when establishing poultry farms. The use of antibiotics in feeds is thought to be common and a cause of public health concern" (GOB 2007, 9). This statement is about environmental hazards; however, the government has never provided proper logistics support or consultancy to implement this policy. Bangladesh poultry policy is mostly concerned with environmental and import issues via legal methods or smuggling from the neighbouring country of India.

According to the Government of Bangladesh (GOB), the import of all kinds of poultry eggs is banned. The same applies to chicks, except day-old chicks of parent stock (mother of broiler chicken) and grandparent stock (mother of parent stock) (GOB 2009). It is however, legal to import poultry feed. These restrictions are because poultry meat and egg prices tend to be lower in India than Bangladesh. For instance, the price of broilers in India was reported to be US$1.35 per kg in Mumbai against US$1.82 in Bangladesh (June 2008). For eggs, the price in India was US$4.70 per 100 (www.wattpoultry.com) against US$7.30 per 100 in Bangladesh (GOB 2007). This is why smugglers attempt to push their products from the other side of border to make extra profit. Poultry entrepreneurs are always complaining about the effect of imported eggs, chicks and breeder parents. If these are imported from other countries, local businesses cannot beat them through price. Thousands of poultry businesses finally shut down for the above-mentioned reasons every year.

Recently, the government did not take appropriate initiative to control the existing market supply and demand creating an imbalance of market supply. The government made the almost suicidal decision to invite nine giant foreign companies to do business in the local market. Local companies are now really struggling to compete with them in terms of capital, technology and market coverage.

3.9.4.5 Competitors' Actions

According to *The Financial Express*, nine different foreign companies have managed to get permission from the Bangladesh government to open their businesses. In addition, foreign companies have taken loans from overseas financial organizations at a 4-5% interest rate while local farms are managing loans at interest rates of 14-16%. This pushes up the ultimate production cost for local companies. Local poultry farmers do not welcome foreign competitors and foreign investment as such a policy will destroy the country's local poultry industry. In total, 0.15 million poultry farms would be committed to meeting the local demand for meat and eggs if they could avail themselves of better policy, financing and logistics (Boddington 2007) www.thefinancialexpress-bd.com).

In the past couple of years, the government has allowed India's leading companies of Venkitashire, Suguna, Amreeta and Godrej to open their businesses which will be a complete disaster for local farm owners and processors (EFeedlink 2011). Local farm owners have assured that they are very much capable of producing 80-90 million day-old chicks per week which is the country's current demand. They also added that they were currently producing 320,000 metric tonnes of meat and five million eggs annually having BDT 120 billion (A$1.6 billion) in investments through 150,000 poultry farms and direct employment of 3.5 million people. At the same time, the bird flu of 2007-08 resulted in a BDT 50 billion (approximately A$700 million) loss and 2.5 million people became jobless (National-Chicken-Council 2012). In this situation, the Bangladesh government has recently allowed foreign investors to invest in this sub-sector without judging the possible impacts on local farmers and processors. Such decisions may be suicidal for local investors due to their financial incapability compared to foreign investors.

3.9.4.6 Market Demand

The poultry industry in Bangladesh is expanding rapidly. A parent population of 5 million produces 52 million day-old chicks a year and the annual growth rate is 15-20%. Broiler meat production is currently at 2.2 million tonnes a year, with 300 million eggs produced. Despite this rapid growth and with the emergence of a new breed of young entrepreneurs, there is still a great demand for poultry meat and eggs. The country has a population of 14 million people who need a daily protein requirement of 70-100 grams. Currently, the average poultry meat consumption is just one kilogram a person a year, while just 28 eggs per person are eaten each year (Hunton 2001). However, major challenges are that the supply of hatching eggs from imported breeds does not meet the demand, resulting in chicks of inferior quality being hatched or illegally imported. In the feed industry, the majority of ingredients (estimated at 80%) have to be imported, and since most feed mills are small and independent, the cost of imported materials is very high. This leads to the use of inferior ingredients and subsequently the poor performance of commercial birds. Such problems are not surprising in such a rapidly expanding industry. Previous data revealed that day-old chick numbers increased from 39.5 million (from 31 hatcheries) in 1998 to 106 million (from 42 hatcheries) in 2000. Layer parent stock was expected to double in number from 1999 levels by 2005, and broiler parent stock to increase five-fold in the same period (Hunton 2001). Table 3.15 supports the above statements.

Table 3.15: Demand Projection for Poultry Products (Islam 2003)

Poultry Products by Type	**Base Year 2000**	**Projection for Poultry Products Over the Next 20 YeaErs**			
		2005	**2010**	**2015**	**2020**
Poultry Eggs (Million)					
Scavenging	1323.08	1912.57	2146.10	2374.59	2581.15
Layer (Commercial)	1683.92	2434.18	2731.40	3022.20	3285.10
Total	30007.00	4346.75	4877.50	5396.79	5866.25
Poultry Meat (‘000 Tons)					
Scavenging	90.42	119.60	134.27	148.62	161.62
Layer (Commercial)	67.22	88.91	99.81	110.48	120.14
Broiler (Commercial	14.27	18.87	21.19	23.45	25.50
Total	171.91	227.38	255.27	282.55	307.25

3.10 SUMMARY

This chapter has discussed two different aspects: the Bangladesh poultry operation and the research case description. Firstly, this chapter discussed details of the existing status, trends, scope and contributions of the industry; this was followed by discussion of the Bangladesh poultry supply chain, modern poultry operation, commercial breeds, broiler meat production and other relevant matters. This information revealed the importance of the poultry sub-sector for the Bangladesh economy and its people. Poultry is also the cheapest protein source for the Bangladesh community and the industry continues to make a consistent contribution to the country's GDP and employment creation. The second phase discussed the research case's description in light of their mission, vision, market share, products, current production and technologies for maintaining sustainable farming. These sections also discussed various calamities and factors which need to be addressed in order to have successful farming. This information helps the understanding of the whole operation of the case farm among other giant farms in Bangladesh. Hence, the chapter has presented the Bangladesh poultry operation and the case industry description to further develop knowledge on both. The next chapter discusses the research methodology used in this study.

CHAPTER 4:

RESEARCH METHODOLOGY[3]

4.1 INTRODUCTION

The purpose of this chapter is to present the research methodology used to conduct the current research with particular emphasis on the fundamentals. The chapter also discusses the issues relating to the research methodology, research design and research tool of the study (Bonoma 1985). Numerous authors have defined research methodology as systematic investigation to explore the facts or principles or to collect proper information through appropriate investigation based on specific research objectives and questions (Tress, Tress, and Fry 2006; Ritchie and Lewis 2003; Bernard 2012; Denzin and Lincoln 2011; Wilkes and Krebs 1995). The relationship between the research context, methodologies and process can be conceptualized through a research framework. Consequently, this study used case study, system dynamics and design science methods to attain the research goals. This chapter also explains the details of the adopted methods under the positivist paradigm that includes the rationale and justification behind using them to conduct this research.

4.2 RESEARCH PARADIGM

The research paradigm has been defined as "a broad view or perspective of something" (5Taylor, Kermode, and Roberts 2006). An explanation of the paradigm also exposes how a research study could be accomplished and directed by a particular paradigm (Weaver and Olson 2006). In addition, paradigms are the practices and processes to

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[3] Parts of this chapter have been published in the following publications:

a) Shamsuddoha, Mohammad, Desmond Klass, and Mohammed Quaddus. 2013. "Poultry Wastes Reuse to Achieve Environmental Sustainability." In *Australian and New Zealand Academy of Management (ANZAM), Hobart, Australia*, 52-59. Australia

b) Shamsuddoha, Mohammad, Mohammed Quaddus, and Desmond Klass. 2013a. "Sustainable Livestock Farming for Improving Socio-Economic Condition " In *3rd International Forum & Conference on Logistics and Supply Chain Management (LSCM), Bali, Indonesia*, 107-116.

c) ———. 2013b. "Sustainable Poultry Production Process to Mitigate Socio-Economic Challenge." *Humanomics*

d) ———. 2013c. "A System Dynamics Approach for Poultry Operation to Achieve Additional Benefits." In *Winter Simulation Conference 2013 Washington DC, USA*, 35-43. http://www.wintersim.org/.

accomplish an investigation following proper methodological aspects. Similarly, a paradigm offers a conceptual framework which reflects how a research study is designed, how data are collected and interpreted, and how the findings are presented (Myers 1997). There are two main underlying paradigms that researchers commonly use to conduct their research: the positivist and interpretivist research paradigms (Mingers 2001; Onwuegbuzie and Leech 2007; Mingers 2003; Orlikowski and Baroudi 1991; Dwivedi 2007). The most popular definitions for these two paradigms are as follows:

***Positivism** research philosophy is defined when a phenomenon being studied has a stable reality measurable from the outside by an objective observer (Gerring 2007; Pervan 1994; Bernard 2012; Straub, Boudreau, and Gefen 2004)*.

***Interpretivism** is described as a research philosophy interested in human meaning in social life and in its clarification and description by the academic (Erickson 1985; Denzin and Lincoln 2011).*

Positivism is associated with the quantitative research method and research philosophy (Johnson and Onwuegbuzie 2004; Cresswell 2003) that uses information that flows from a logical and mathematical stream of valid scientific process (Fairclough 2003; Larraâin 1979). At the same time, data and information are gathered from empirical evidence to justify and validate the ongoing research (Cohen, Manion, and Morrison 2011). Furthermore, positivist research uses formal propositions, quantifiable measures of variables, formulation of hypotheses, hypothesis testing, and drawing of inferences about a phenomenon from the sample to a stated population (Orlikowski and Baroudi 1991). According to the above literature, the positivist paradigm deals with quantitative research as used in the current study. On the other hand, the interpretivist approach aims to develop a natural science through social interpretation (Neuman 2005). Therefore, the interpretivist researcher sees the reality and thus has to plunge into the actor's mind by feeling, hearing and observing how the actor interprets a thing (Schwandt 1994). In terms of research design, qualitative research is normally adopted by interpretivist researchers (Creswell 2003). To understand more accurately, descriptions of research methodologies are presented in Table 4.1. In reviewing previous literature, it was found that most studies either followed a mono-method approach (such as a positivist (quantitative) or interpretivist (qualitative) paradigm) or a mixed method approach. The current study is no exception to the common practice of conducting research in various fields. However, the nature of the current study matches quantitative research under a positivist paradigm. Thus, a positivist paradigm has been adopted for the sake of accomplishing the study.

Table 4.1: Research Methodologies and Paradigms (Pervan 1994; Maliapen 2003; Galliers 1993)

Paradigm	Research Methodologies	Description
Positivism	Laboratory Experiments	The study includes accurate relationships between controlled variables with participants to solve an artificial problem.
	Field Experiments	An experiment is involved with participants for solving a real problem. A small number of variables are used to solve the problem.
	Survey	A snapshot of opinions or a real-world situation at a particular point in time, usually utilizing a questionnaire to all participants and analysed using statistical methods.
	Case Studies	A planned and focused investigation of hypothesized relationships in one or more organizations. A researcher acts as an observer. A large number of variables are involved with little or no control.
	Theorem Proof	The development and testing of theorems through mathematical modelling of situations in which truth is derived based on a well-specified set of derivation rules.
	Forecasting	The use of various extrapolation methods to take facts and/or opinions using particular assumptions in order to deduce future outcomes.
	Simulation	An investigation of behavior in a system which is an idea of the real world with some controlled variables, but not to the extent of a laboratory experiment.
Interpretivism	Subjective/ Argumentative Reviews	An expression of the views of the research(s) based mostly on opinion and speculation derived from a range of experiences or reviews of literature.
	Action Research	An investigation of relationships in one or more organizations where the research is involved and the researcher's impact must be acknowledged and identified.
	Descriptive/ Interpretive	Research based on the researcher's interpretation of situations, events, phenomena, previous literature or past developments.
	Future Research	Similar to forecasting.
	Role/Game Playing	Similar to simulation.

Instead of positivism and interpretivism, the terms quantitative and qualitative paradigms are used by some researchers (Wholey, Hatry, and Newcomer 2010; Neuman 2005; Erickson 1985). The quantitative paradigm is an outcome-oriented approach and focuses on natural science world views. Laboratory experiments, field experiments, surveys, case studies, theorem proofs, forecasting and simulation are classified under positivism, whereas subjective/ argumentative reviews, action research, descriptive/interpretive, future research, and role/game playing are found under interpretivism. The current research is found to fall under the positivism approach. The next section deals with the research methodologies employed in the current research.

4.3 RESEARCH METHODOLOGIES

Studies use research methodology, a combination of a continuing process, methods and tools for conducting research, to inform their readers exactly how they intend to undertake their research and how to lever the data. This current study also employed design science research (DSR) methodology, system dynamics (SD) and the case study approach with the support of computer simulations. These research approaches provide valuable feedback to one another. For instance, the design science methodology is used to design an extended supply chain model for a particular case industry following the system dynamic process.

4.3.1 Research Design for System Development

Research design covers the methodology and procedures engaged to conduct scientific research (Yin 2009). The design of a research study defines the study type (such as qualitative, quantitative or descriptive) and its data collection methods and an analytical plan (such as statistical, mathematical or simulation analysis)(Cohen, Manion, and Morrison 2011; Yin 2009). This study adopted system dynamics and quantitative methodologies with the support of a simulation tool to generate analyses of the proposed supply chain process model.

Figure 4.1 demonstrates how a case study follows system dynamics methodology to develop and use computer simulation to accomplish required tasks. The system dynamics approach needs to be used to develop the concept, to undertake further amendment or alteration and then evaluate the impacts on stakeholders due to changes. Research has been conducted on a particular case industry using system dynamics, such as health care (Maliapen 2003), banking (Intrapairot 2000), energy (Rodríguez et al. 2002) etc. This study examined a poultry supply chain process which has not previously been examined by academics using such rigorous methodology. Thus, this study attempted to fill the gap in this field in particular, and structured poultry operation in general.

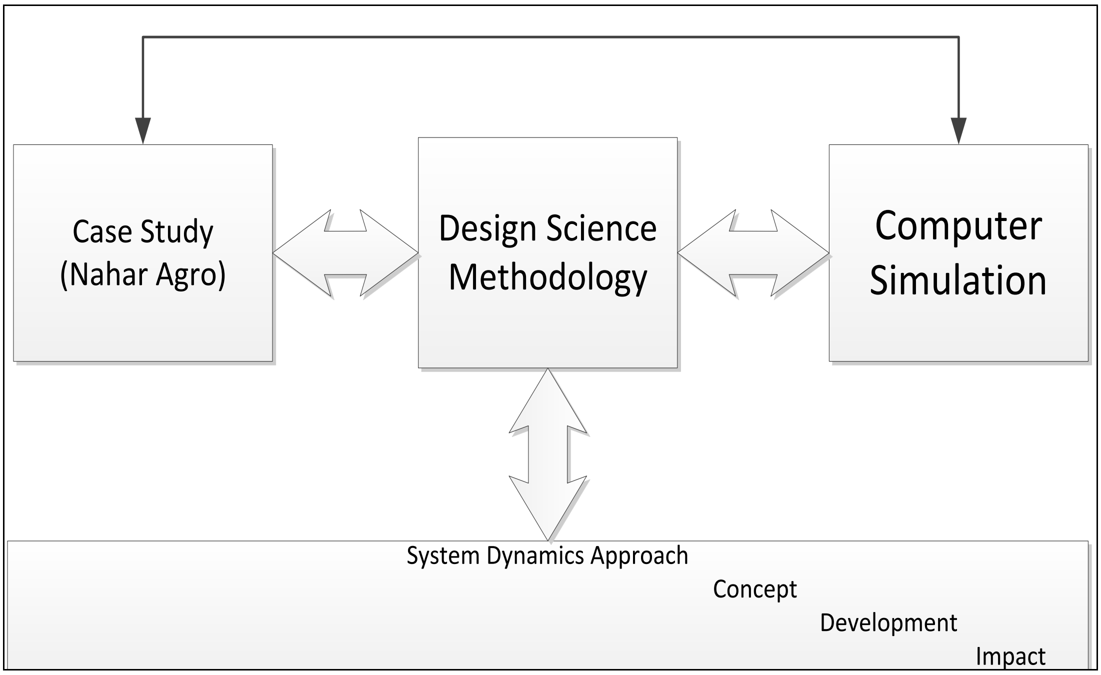

Figure 4.1: System Dynamics, Case Study and Simulation (Nunamaker and Chen 1990; Forrester 1994b; Maliapen 2003)

4.3.2 Design Science Methodology

In this study, the research paradigm of positivist ontology, empirical epistemology and quantitative methodology is used based on a real case of the poultry supply chain process. Under quantitative research, ‘design science’ methodology was chosen for this study. Historically, design science research emphasises the expansion and performance of (designed) artifacts with the explicit intention of improving performance (Peffers et al. 2008; Peffers et al. 2007). This methodology can be applied in a process model for the sake of improving the system. Design science is concerned with ‘devising objects or variables to attain goals’ (Simon 1969; Sein et al. 2011). March and Smith (1995) focused on two main activities of design science research (DSR): firstly, building an artifact and, secondly, evaluating it. They described four types of design science products: constructs, models, methods and implementation (March and Smith 1995;

Hevner and Chatterjee 2010) adding that the artifact (variable) is the component used in designing and developing soft or hard objects that can meet a specific research purpose and goal.

In addition, DSR can be used to design a model where a new or improved technology and processes are invented (Venable 2006b, 2006a; Venable 2010). Therefore, DSR is about innovation that includes derivation, design, development, construction, prototyping or other ways of creating something new. Methodologically, DSR falls under the positivist category (Venable 2010). In comparison with information system (IS) researchers, DSR helps to understand reality, and attempts to create artifacts that serve human purposes for better structural design (Peffers et al. 2008; Simon 1969). To support this, Hevner, March, Park, and Ramet (2004) proposed seven guidelines for DSR: design as an artifact, problem relevance, design evaluation, research contributions, research rigour, design as a search for new process and communication of the research. Similarly, Hasan (2003) defined design and development research as a further development and improvement of a product or program. In an experiential view, Richey and Klein (2007) specified DSR as the systematic study of design, development and evaluation processes on an empirical basis. In this current study's context, the researcher has found similarities with this design-based methodology. Therefore, design science is used as the methodology to examine the Bangladesh poultry process to redesign the integrated supply chain for targeting better outputs. The system dynamics (SD) research process (method) is also involved in undertaking the current research. The next section discusses the system dynamics (SD) method and its operation.

4.3.3 Operation of System Dynamics

System dynamics is gaining popularity at an impressive exponential rate due to its unique ability to exemplify the practical world. Moreover, it can handle the non-linearity, feedback loop structures and complexity that are integral parts of a system that may belong to the society and industry or any type of agency (Forrester 1994b). System dynamics (SD) deals with a system which is interconnected with its associated components/variables through cause and effect over time (Deaton and Winebrake 2000; Elshorbagy, Jutla, and Kells 2007; Pathak et al. 2007; Hjorth and Bagheri 2006). The cause and effect between the variables makes a feedback loop. The feedback principle in SD requires the flow of information to be communicated between the various components within the system (Nurse 2008). Jay Forrester (1961) from Massachusetts Institute of Technology (MIT) first introduced system dynamics by writing 'Industrial Dynamics'. System dynamics consists of the two key words 'system' and 'dynamics'. A system is a collection of mutually interacting, consistent and inter-reliant mechanisms that affect the whole structure of the system (Karnopp, Rosenberg, and Perelson 1976; Deaton and Winebrake 2000). Dynamics can be termed as the degree that defines any change over time (Carlsson et al. 2002). Hence, system dynamics is a technique to conceptualize the structure in the system where the components within the system are connected in such a manner that they form feedback loops, thereby representing the overall behaviour within the system (Maliapen 2003; Krasner 1984). From the modelling viewpoint, Radzicki and Taylor (Radzicki and Taylor 2008) expressed SD as a mathematical modelling technique and a dynamic methodology for constructing, perceiving and describing complex problems. Structurally, SD incorporates feedback information, causality and non-linear relationships (Williams and Hummelbrunner 2010; Cellier 1991).

To build an interactive model, a causal loop (cause–effect or influence) diagram needs to be constructed when following SD methodology (Sterman 2000). In an SD-based simulation model, there are two types of feedback loop, named as the positive and negative feedback loop (Sterman 2000, 14). To capture the feedback mechanism of a system, negative (balancing) or positive (reinforcing) feedback loops are to be determined (Sterman 2006; Maliapen 2003). In a positive feedback loop, linked variables are repetitively increasing or decreasing their values. In a negative feedback loop, linked variables and their values only decrease from the previous value (Sterman 2000; Wolstenholme 1990). At the same time, the negative feedback loop reveals goal-seeking behaviour affected by disruption(s) when the system pursues an equilibrium situation (Sterman 2006; Maliapen 2003). The qualitative (causal) loop contributes two important roles in SD modelling. Firstly, it helps to construct preliminary hypotheses (cause–effect relationship with variables) during the model development and secondly, it can create a straightforward representation of a SD model (Vlachos, Georgiadis, and Iakovou 2007; Georgiadis, Vlachos, and Iakovou 2005; Wolstenholme 1990). There is debate about constructing a causal model prior to building a stock and flow model although it can be done in either order (Sterman 2001; Forrester 1994b; McDoland 2013). Hence, the current research has constructed a causal model first then has built a stock and flow model.

The structure of an SD model contains stock (state) and flow (rate) variables which represent accumulations (i.e. inventories) and flow variables (i.e. order rate) in a system (Sterman 2000; Wolstenholme 1990). Principally, the stock and flow model (quantitative) is built based on a causal loop diagram and connected with interrelated variables of the model (Sterman 2001). In this phase, the mathematical representations are given input for connected variables to run the system in a simulation environment. (Sterman 2000; Wolstenholme 1990). The mathematical equations are formed based on the real-life relationship between the variables or how the system flow works moving forward and backward. Nowadays, high-level graphical simulation programs (such as iThink, Stella, Vensim and Powersim) support the analysis and study of these systems (Chaerul, Tanaka, and Shekdar 2008). Alternatively, a final version of the stock and flow model can draw a causal model using research tool (simulation) facilities. To understand the relationship between the SD model and simulation, the following section discusses simulation modelling techniques.

4.3.4 Simulation Study under System Dynamics

A simulation study constantly answers a "what if?" inquiry for different imaginary situations. Such epidemiological studies typically inquire about the bias, precision and accuracy of estimators, confidence intervals and statistical tests (Maldonado and Greenland 1997). Several things can possibly be done through simulation, for example, examining the impact of variable selection (Maldonado and Greenland 1997); model-form selection (Maldonado and Greenland 1993); model-form misspecification (Maldonado and Greenland 1997); misclassification (Thomas 1995); missing-data processes (Greenland and Finkle 1995); hierarchical regression (Witte and Greenland 1996); and factoring (Maldonado and Greenland 1998). Therefore, it is evident that simulation can do significant analyses which are able to play a strong role in any kind of quantitative research. The facility of simulation has inspired the current study’s researcher to deploy it to develop a suitable supply chain model and to conduct analysis and forecast the futuristic scenarios of the poultry industry. A case study can help to build a supply chain system through simulation tools to do further examination for better outcomes (Meredith 1998). To accomplish simulation modelling, the current study used the case study method to draw a supply chain model.

4.3.5 Definition of Case Study

Case study is defined as an empirical/practical investigation that inspects a current phenomenon within its real-life context (Yin 2003). A case study is used to cover contextual conditions because they might be highly pertinent to the phenomenon being studied (Yin 1994). Furthermore, case study can be called upon as the research methodology which can focus on understanding or investigating relationships in either one or many organizations (single or multiple cases). Therefore, it can be used for many purposes, including providing description, testing theory and generating theory (Yin 2009, 1994; Yin 2011; Yin 2003). Thus, a study can produce multiple levels of analysis within a single case using combined sources of data collection such as archives, interviews, questionnaires and observations. However, based on this research strategy, the researcher is an observer, and a large number of variables are involved with little or no control. Outcomes derived from a case study can be either qualitative or quantitative or both (Eisenhardt and Martin 2000; Galliers 1993; Galliers 1992). The next section provides justification for choosing the case study method for the SD model.

System dynamics (SD) models have been used for the improvement and analysis of complex systems for the past two decades (Lyneis and Ford 2007). Moreover, SD models enable the handling of strategic management decisions and plans (setting the schedule, delay, budget, structure, process model, etc.) for any complex system for a business or projects based on past behaviour of projects (Lyneis, Cooper, and Els 2001; Lyneis and Ford 2007). Normally, a case study is used to investigate organizational, managerial and operational processes within an organization to gain more holistic and meaningful characteristics of real world events (Courtney 2001). It also assists with explaining what is really occurring, producing relevant propositions which can be tested in a more rigorous fashion (Andersen, Richardson, and Vennix 1997; Coyle 2000). For example, Wolstenholme (1990) used qualitative modelling to study the unintended effects of policy on the delivery of community care. The current research used the case study method to accomplish the research objectives and questions.

4.3.6 Integration of Design Science, System Dynamics and Case Study

The above discussions have clearly described design science (DS) methodology, the system dynamics (SD) method and case study. This current study has attempted to integrate these three methods to accomplish the research objectives. This study used DS methodology to extend and upgrade the current poultry supply chain through integrating forward and reverse supply chains. The SD method was deployed so its rigorous process could be adopted for developing and analysing the simulation model. Obviously, the research has been assisted by a poultry industry case study to develop a supply chain model. Thus, the research design for this study follows system dynamics (SD) procedures to model a case industry under the design science (DS) methodology.

4.4 RESEARCH DESIGN

Every research study has its own research design which needs to be followed to anticipate the research goals. In fact, a research design is a “blueprint” which expresses the strategic plan for conducting a study (Yin 2009). This design also provides an overall structure for a systematic approach for model construction, data collection, data analysis through research tools and interpretation of the analysis for a research study. Moreover, the nature of the research problem justifies the type of research design (Yin 2009). Before commencing the research process in this study, a few research designs were considered as will be discussed next.

4.4.1 System Dynamics Research Framework

A research study is an investigation and it starts by defining and understanding problems before moving towards achieving goals for further improvements (Forrester 1987; Forrester 1994b). Forrester’s diagram illustrated a six-step SD research process (Figure 4.2) which begins from describing a system to implement changes in policies and structure through a rigorous modelling process. Furthermore, Forrester also mentioned the epistemological premises of the SD approach (Forrester, 1961). Real-world complex operations can be dealt with by the SD methodology having unchanged circumstances (Lane and Oliva 1998; Forrester 1961). This methodological diagram helps to perceive the systematic procedure including the step forward and back to the next task to accomplish SD research. Sterman (2000) later developed a comprehensive SD process (Figure 4.3) for conducting research. In this model, Sterman included the detailed process, which starts from the literature review, identifying the business process, finding the exact input and output and many rigorous steps. This model is replicated in a number of SD studies. In 2010, Van der Aalst et al. (2010) illustrated the simulation modelling procedure (Figure 4.3) under SD methodology to support the previous procedures. This procedure is as simplistic as Forrester’s prescribed SD process.

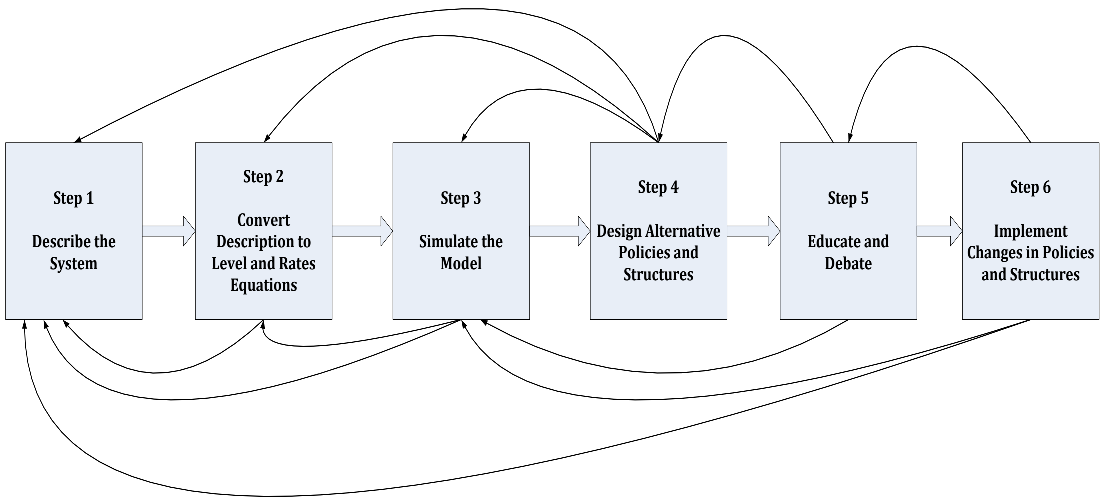

Figure 4.2: Steps of System Dynamics Approach (Forrester 1994b)

Furthermore, Donella Meadow (1989) and Dennis Meadows (1980) provided ontological assumptions of interconnections in complex patterns along with stock/level, rates and feedback loops; they indicated that information flows are fundamentally diverse from physical flows, that delays and non-linearities arise out of system structure. Sterman et.al (1994), Sterman (1989), and Sterman (2000) later justified and recommended the practice of different approaches for typical problems. However, Simon discussed the epistemological assumption of SD with 'bounded rationality'(Simon 1982; Simon 1979). Forrester (1971a) placed emphasis on building a mental model that guides a complete quantitative model. Forrester and Senge (1980), Sterman (1989) and Radzicki and Taylor (2008) observed that formal modelling in system dynamics can use simulation tools to assist with gaining correct representation and rigorous analysis for behaviour within a system. Moreover, a simulation program is highly capable of perfectly mapping particular system behaviour that can be reliable in the context of result output, using calculus for consistent inferences about dynamics yields and can fix erroneous results on simplistic maps (Sterman et al. 1994).

After reviewing relevant literature, Jutla et al. (2006) designed a popular modelling approach (see appendix B) under SD methodology. In this approach, the research process starts with problem definition followed by gaining practical knowledge, identifying key variables, defining system boundaries, developing a causal model and stock and flow model construction. The research then needs to set up their connectivity followed by the structure and reliability check, refining the model until it passes validity tests, validating the model, generating the simulation results for implementing changes, drawing various inferences and running necessary scenario analysis. Other researchers have followed a similar type of process while conducting research under SD methodology. A very similar SD procedure (figure 4.4) was developed by van der Aalst et al. (2010) in their book titled "Business Process Simulation". This book thoroughly explained how a problem can be defined followed by qualitative and quantitative model building with reliability and validity check for possible solutions. The following section discusses the research process followed in this study developed based on the information shown on Figures 4.2, 4.3 and 4.4 which support the current research flow.

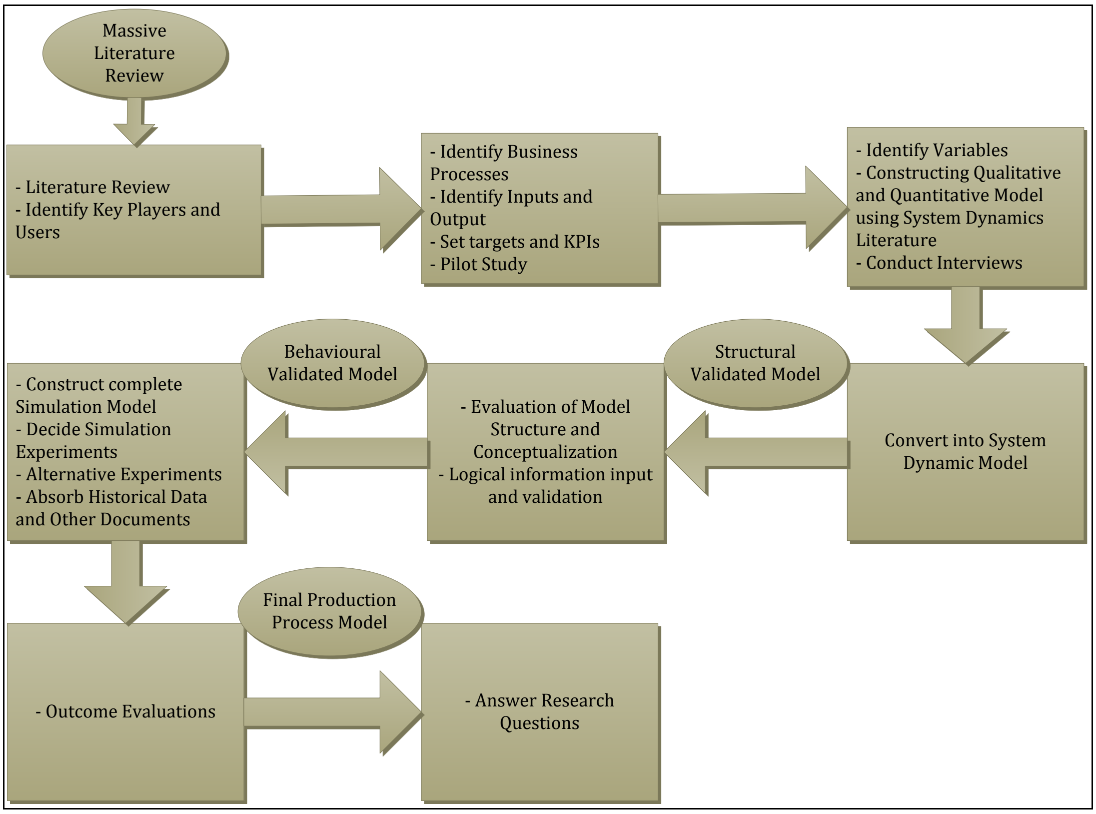

Figure 4.3: Process Needs and Considerations in "SD-based" Research (Adapted from Sterman 2000)

4.4.2 Research Process Followed Throughout This Study

This study integrates forward and reverse supply chains of a case industry. Interestingly, the majority of previous research has focused on a forward supply chain whereas only a few studies were conducted on reverse chains (Aghalaya, Elias, and Pati 2012). The systems modelling approach can be useful for the analysis of relevant supply chain processes via dynamic simulation. Examples of the application of SD modelling show that it is already implemented in the automobile industry (Sterman 2000), paper recycling industry (Spengler and Schröter 2003). According to Angerhofer and Angelides (2000), comprehensive problematic areas are used to apply System Dynamics to solve the critical and complex situation. Previous literatures shows that SD has been applied mostly to help in in corporate planning and rigor policy design (Forrester 1961; Lyneis 1980), economic behaviour (Forrester et al. 1983), public management and policy (Homer and Clair 1991) biological and medical modelling (Hansen and Bie 1987), energy and the environment (Ford and Lorber 1977), theory development in the natural and social sciences (Dill 1997), dynamic decision making (Sterman 1989), complex non-linear dynamics (Mosekilde, Larsen, and Sterman 1991), apparel (Angerhofer and Angelides 2000), pharmaceuticals (Achilladelis and Antonakis 2001), aircraft (Lyneis 1998), software engineering (Abdel-Hamid 1984), and supply chain management (Towill 1996; Barlas and Aksogan 1997; Akkermans, Bogerd, and Vos 1999). There are some other research have been found in the literature, and their domain of researches on Information sharing in supply chains (Fiala 2005), remanufacturing used in closed-loop supply-chains (Vlachos, Georgiadis, and Iakovou 2007; Georgiadis and Besiou 2008), Bullwhip effect in supply chains (Disney and Towill 2003), supply chain dynamics (Villegas and Smith 2006), Manufacturing system up gradation (Lee and Kim 2008) and so many others. The research process based on Table 4.2 is described next.

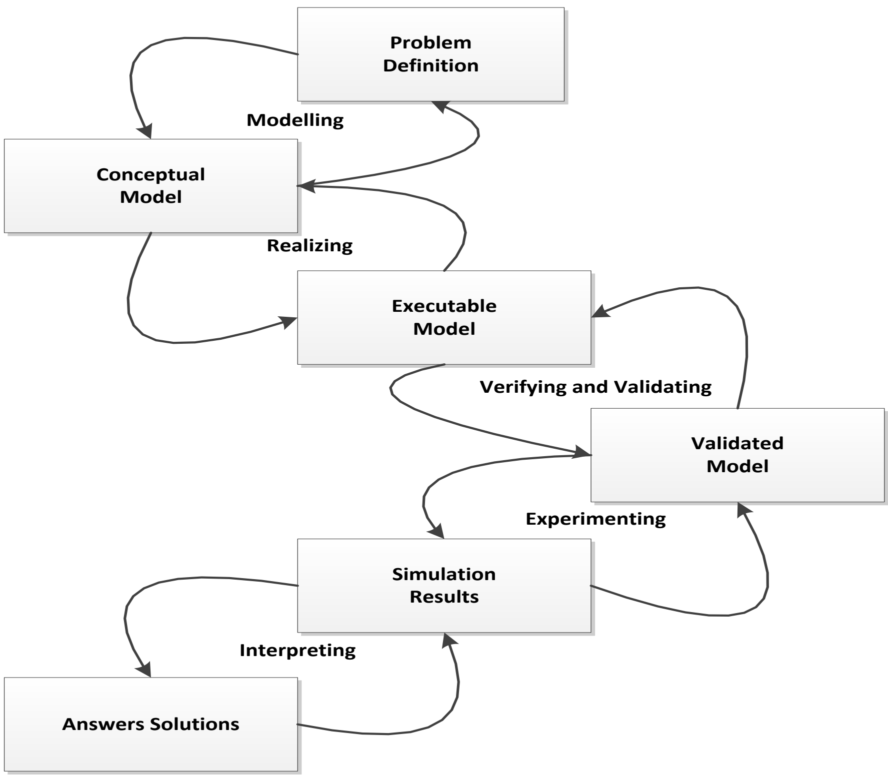

Figure 4.4: Simulation Modelling under System Dynamics Methodology (Van der Aalst et al. 2010).

4.4.2.1 Problem Definition and Structure

The following sections discuss the procedures of problem definition and structure.

a) ***Problem Definition***

The SD research study starts with a research problem definition followed by other processes to find out answers to research questions. It is important to identify the scope of the research and the targeted goal to identify the nature of perceived glitches. The scope of the research will set the boundary whereas the goal is the targeted answer to the problems. These questions should be quantifiable and easy to communicate in the implementation of the research. It was important to justify whether or not a simulation study was needed to conduct the current research. Forrester (1961) assumed that a system dynamics (SD) study should have a purpose, a defined problem, issue, or undesirable system behaviour that needs to be solved or corrected (Forrester 1958, 1968, 1971b). The long-term emphasis on problem definition has been identified in many SD studies (Forrester 1969; Meadows et al. 1972; Richardson and Pugh III 1981; Sterman 1989) and is still at the core of the SD intervention process (Forrester, 1994). In a few cases, system behaviours are identified and described through a reference graph (Mottershead and Friswell 1993). These relationships between connected variables are framed into information feedback loops which can be deployed in a model to replicate real circumstances (Lane and Oliva 1998). In addition, system behaviour can be also perceived through in-depth understanding and observation. The causal relationships between variables is called a 'dynamic hypothesis' which is a potential explanation of how the structure is causing the observed behaviour (Lane and Oliva 1998). Thus, understanding the problem definition behind building a system structure in a SD model is important to regulate the model.

b) Problem Structure

In the problem-structuring phase, a behaviour-over-time graph is developed for the case industry. Developing a ‘reference graph’ or historical trend graph is one of the tools used in systems thinking (Aghalaya, Elias, and Pati 2012) to show the real-life behaviour of the main variables in a system over an extended period of time. Typically, the data or information can be taken from periods over several months to several years. The more historical data gathered, the more accurate the prediction of future trends. Similar behaviour trends can specify the variations and trends in the variable of interest, for example, growth, decline, oscillations or a combination thereof. The key variables are captured in a graph to present and perceive the general trends, directions and variations but are not expressed in numerical values (Aghalaya, Elias, and Pati 2012).

Table 4.2: Methodological Framework for This Study

Phases	Steps	Things to do
Phase 1	Problem Definition and structure (Aghalaya, Elias, and Pati 2012; Maani and Cavana 2007; Eden 1994; Sterman 2000)	Behaviour-over-time graph development
Phase 2	Identify key variables (Aghalaya, Elias, and Pati 2012; Maani and Cavana 2007; Wolstenholme 1990)	Identify key variables through in-depth interview approach
Phase 3	Build causal loop model (qualitative) (Wolstenholme 1990; Sterman 2000; Forrester 1994b)	Connect identified variables based on cause and effect relationship. And build complete causal loop model with positive and negative loops.
Phase 4	Stock and flow (quantitative) model building (Wolstenholme 1990; Sterman 2000; Forrester 1994b)	Stock (level) and flow (rate) are to be added in the model variables to build a workable model. Rates and equations should be determined based on real-life relationship between variables.
Phase 5	Run simulation (Wolstenholme 1990; Sterman 2000)	Enter real/field data with starting variable
Phase 6	Model reliability and validity (Barlas 1996; Sterman 2001, 2000)	Examine structural validity and assess the data reliability in different phases
Phase 7	Test policy and extreme condition situation (Barlas 1996; Sargent 2005; Forrester and Senge 1980)	Considerable changes of key variable values to observe output reliability
Phase 8	Forecasting future behaviour (Wolstenholme 1990; Sterman 2000; Lyneis 2000)	Model run for 312 weeks and it has 104 weeks' real-world data

In this study, the key variables were identified through in-depth interviews, focus group discussion and observation techniques. A reference graph was later drawn (Figure 4.5) to capture the historical output (behaviour) of key variables. The selected key variables were parent chicks enter, mature parent, parent eggs produced, employment created, fertilizers and biogas produced, number of farmers, broiler chicks consumed and final broiler production. The data input in the graph covered two years (104 weeks) with poultry chick production and distribution run on a weekly basis. The fluctuations in the individual graph line denote the variations of production and distribution over time. The parent eggs produced line, for example, fluctuates a number of times in 104 weeks. Significant vicissitudes can be found in one graph line whereas a drastic fall and rise means either a collapse or sudden rise of the market. Fluctuation in the business is caused by demand-supply gap, over/under-production, calamities and policy barriers. This research tried to discover these problems through predicted/simulated future results to take appropriate action.

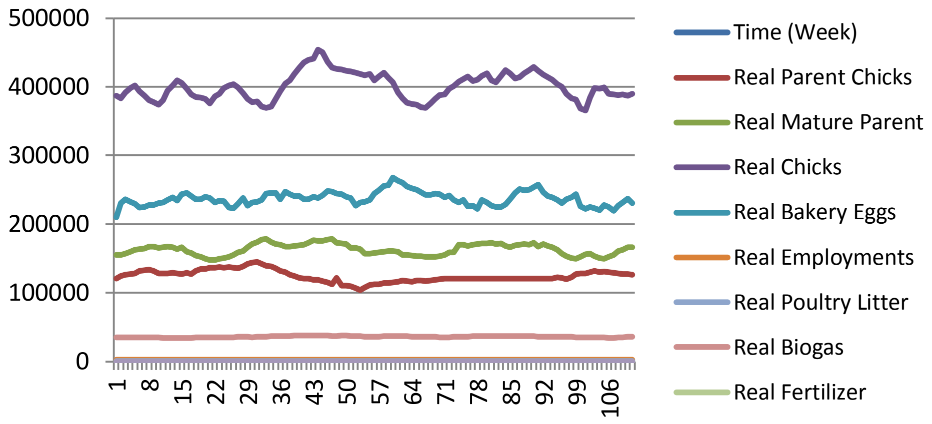

Figure 4.5: Key Variables and Their Behaviour over Time (BOT)

4.4.2.2 Identify Key Variables

Key variables' identification is an important part of an SD research model. Once, problem has been identified and defined its structure, the immediate task is to recognize key variables based in the system structure and problems. Variables can be identified through secondary literature and from empirical (case) evidence through in-depth interview, focus group discussions and observations (Aghalaya, Elias, and Pati 2012; Maani and Cavana 2007; Wolstenholme 1990). The current study is used in-depth interviews to select the main variables to build a simulation model. The in-depth interviews with various supply chain members are assisted to find out influential variables along with supply chain members.

4.4.2.3 Build Causal Loop Model (Qualitative)

In system dynamics, the causal model concept is an important phase prior to designing a complete stock and flow (quantitative) model. Before building a causal model, the modeller needs to sketch the diagram through the mental process. Without doing so, it would be difficult to understand and realize the whole system along with functions of the key variables. To define a mental model, Forrester (1961) offered the following impression:

"A mental image or a verbal description in English can form a model of a corporate organization and its processes. The manager deals continuously with these mental and verbal models of the corporation. They are not the real corporation. They are not necessarily correct. They are models to substitute in our thinking for the real system that is represented" (Forrester 1961, 49; Doyle and Ford 1998).

Authors have variously described the mental model as 'fuzzy and implicit' and 'highly adaptable, and unable to handle complexity' (Richardson and Pugh III 1981; Richardson 1986); 'extremely simple compared to reality' and 'mostly wrong' (Meadows and Randers 1992); 'not fixed', 'not simple' and 'contains rich information' (Vazquez, Liz, and Aracil 1996); and 'vastly simplified compared with the complexity of the systems themselves' and 'dynamically deficient' (Sterman et al. 1994). Although, many researchers mentioned that the 'mental model' is an incomplete model, a number of authors have recommended using this approach initially to conceptualize a process followed by rigorous refinement (Klimoski and Mohammed 1994; Johnson 1988; Storey, Fracchia, and Müller 1999; Williams, Ware Jr, and Donald 1981; Doyle and Ford 1998).

For the current research study, a mental model was used to develop the diagram of the poultry process supply chain. Focus group discussion, semi-structured interviews and observation tools were used to develop and conceptualize the current supply chain model. This mental model was later converted to a causal model followed by a stock and flow simulation model. Although system dynamics did not embrace the practice of causal loop diagrams, many academics and researchers have incorporated such a diagram in their work to make it understandable to readers (Wolstenholme 1999, 1985). Nowadays, few system dynamists suggest that these kinds of studies can be carried out without the development of formal models (Wolstenholme and Coyle 1983; Morecroft 1985; Wolstenholme 1985; Richardson 1986). It is always easier to deal with causal loop diagrams which can be formed at the beginning of a model conceptualization and which also have the strong possibility of being effectively acknowledged (Richardson and Pugh III 1981; Richardson 1986). There are number of studies in the literature which have been designed and described qualitatively from a causal diagram model which is acceptable to academia. The next two sections discuss the causal and feedback loop design for this study.

a) Causal Loop Diagram (CLD)

A causal loop diagram (CLD) is a visual interactive diagram which interconnects the nearest variables having a positive or negative effect on one another. Such relationships between the variables, represented by arrows, are usually characterized as either positive or negative (Schaffernicht 2007; Sterman 2000, 12). Most SD models contain dynamic feedback processes along with stock and flow structures, delays in time and non-linearities (Sterman 2000, 12-13). These positive (or self-reinforcing) and negative (or self-correcting) loops communicate with one another to devise the real dynamic behaviour of a system (Sterman 1989, 2000). System dynamics (SD) is mainly used to identify feedback loops created by linking resources or information flow (Wolstenholme 1990, 13). Thus, such loops represent dynamic system behaviour through flowing processes, boundaries, delays and strategic information within a system (Wolstenholme 1990, 13). There is no alternative method of creating and designing causal and feedback loops for a system in order to understand its real behaviour over time and the policy implications for particular situation.

b) Positive and Negative Feedback Loop

Various studies in the literature have mentioned positive and negative links within a causal loop. Without positive and negative links, it is difficult to judge the correct nature of backward and forward flow in a model. Polarity is indicated through the plus (+) or minus (-) sign at the top of the arrowhead. A plus (+) sign suggests that a change to the variable at the end of the arrow will cause a change to the variable at the top of the arrow in the same direction. Likewise, a minus (-) sign implies that a change to the variable at the end of the arrow will cause a change to the variable across the top of the arrow in the opposite direction (Richardson 1986). In fact, system behaviour over time depends on how and in what ways system loops are interconnected with the variables. Once causal model development is completed, the stock and flow model needs to be designed. The next phase is to the execute qualitative model (the complete causal model) which is discussed in the following section.

c) Execution of Qualitative Model

After understanding the overall concepts of a particular process or system, we need to have a modern simulation software package to convert it as an executable model (France and Rumpe 2007; Robinson 2006). If an executable model is designed using computer simulation software, it can be experimented on in various ways. The question of how to generate or design an executable model depends on the simulation tools used to develop a model (Rauch et al. 1998). Simulation involves a real-life system structure and design with an implementation phase where simulation packages allow the building blocks to which the proper quantitative characteristics (e.g. time) must be added (Zeigler, Praehofer, and Kim 2000; Van der Aalst et al. 2010).

To design an improved model, the study needs to have computer-based software which will enable the tracking of relationships between/among the variables and their dynamic behaviours (Müller and Pfahl 2008). Similarly, effective model building needs a good understanding of simulation-based software so that one can design a model that is almost similar to the real world (Senge and Sterman 1992; Andersen, Richardson, and Vennix 1997; Lane and Oliva 1998). It is important to be aware of what philosophy is used in building a simulation model so that goals can be achieved (Peterson 1992). As mentioned earlier, a causal loop diagram model envisages the effects of interconnected variables (Elias 2010). The loop diagram consists of a set of nodes representing the interconnected variables (Aghalaya, Elias, and Pati 2012; Maani and Cavana 2007).

As mentioned above, the relationships between variables, represented by arrows, can be labelled as positive or negative. In a causal loop diagram, a positive (+) sign at the top of an object (variable) denotes an increase (or decrease) at the end of an arrow causing a corresponding increase (or decrease). If an increase in the causal variable causes a decrease in the affected variable, a negative (-) sign is placed at the top of an arrow (Aghalaya, Elias, and Pati 2012). This is how positive and negative relationships are identified in the model deployed for constructing a complete stock and flow model. The detailed explanation of the causal model is discussed in the next section. The explanation also includes details of the causal and stock and flow model building process.

4.4.2.4 Stock and Flow (Quantitative) Model Building

In building a stock and flow (quantitative) model, it is necessary to analyse, experiment and test it from various aspects. Without a stock and flow model, it would be difficult to replicate the realistic process in a virtual model. The process structure for the model needs to be designed so that the system's structure is represented by resource flows. The resource flow consists of stocks (i.e. levels) and flows (i.e. rates). Due to the limitations of causal loop diagrams, the stock and flow model is more popular with the modeller and researcher. The reason for this popularity is that the stock and flow model is used for its ability to capture stocks and flow information going forward and in reverse within a system structure (Sterman 2000, 191). Causal loop diagrams are very useful for understanding the system behaviour although they have some limitations with the possibility of misinterpretation and misapplication (Sterman 2000, 191). However, there is no doubt about the importance of the causal model as it can be used to advantage for any kind of project capturing the mental model of the causal relationship between variables (Sterman 2000, 191). Next, the two key words of 'stock' and 'flow' need to defined.

Specifically, a stock is accumulated over time by inflows and outflows that only change its value based upon flows. Simply stated, a stock is an accumulation or integration of flows over time with the outflows subtracting from the stock (Sterman 2000, 192; 2001; Barlas 2007). Stocks create delays by accumulating the difference between the inflow to a process and its outflow (Repenning and Sterman 2002). As shown on Figure 4.6, stocks over time act like the formula below where outflows are deducted from inflow by adding initial stock (t0). A flow (or "rate") changes a stock over time (Meadows et al. 1972; Sweeney and Sterman 2000; Sterman 2000). It is easy to differentiate inflows and outflow that determine the value of stock over time (Vlachos, Georgiadis, and Iakovou 2007). The current model has a number of flows (rates) which are connected to levels, constants and auxiliary variables to determine the inflow and outflow rate. The following example is formed to aid in understanding how stock and flow are connected with one another.

$$Stock\ (t) = \int_{t0}^{t} [Inflow(s) - outflow(s)]ds + Stock\ (\ t0)$$

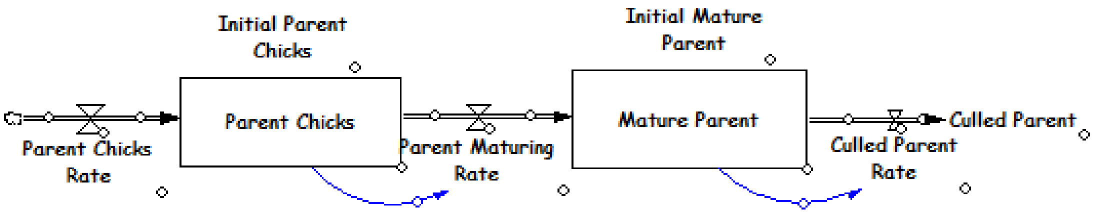

Figure 4.6: Simple Stock and Flow Model for Poultry Parent Farm

In Figure 4.6, the parent chicks' rate is an inflow for parent chicks' stock which is drained out through the parent maturing rate outflow. The preceding outflow is treated as inflow for the subsequent stock of mature parents. Inflow and outflow can be attached to auxiliary or constant variables to determine the ultimate rate. The following discussion is based upon the stock and flow diagram.

a) Auxiliary, Constant and Table Function Variables

The rate of a stock changes through a function of any stock by a constant variable or by exogenous inputs/outputs. Sterman (2000, 202) mentioned such variables as a function of net change for immediate stock. For example, 'parent chicks' rate' in Figure 4.6 is determined by other influences with the help of stock. Such influences come from auxiliary (random uniform), constant (fixed) or table function (exogenous) variables. These variables are determining and regulating the net changes of a vachon over time. The next section discusses stock and flow diagramming.

b) Diagramming for Stocks and Flows

For converting the stock and flow model from the causal loop diagram, this research has used the Vensim application. Before introducing the quantitative model, it is important to note the following (Sterman 2000, 192) based on Vensim (a software package for simulation):

- ✓ Stocks are represented by rectangles
- ✓ Inflows are represented by a pipe (arrow) pointing into (adding to) the stock.
- ✓ Outflows are represented by pipes pointing out of (subtracting from) the stock.

- ✓ Valves control the flows.
- ✓ Clouds represent the sources and sinks for the flows.

The above information is general practice for a Vensim (research tool) user. The modeller can use any customized shape to recognize a variable in the model. For example, this research used a circle for the variable 'poultry litter' and 'eggs' supply to bakery' and a hexagon for 'chicks' (see Figure 5.8 in chapter 5). In reality, both of these variables are deployed as auxiliary variables in the model. The following section discusses stock influence on dynamic behaviours.

c) Influence of Stocks on System Dynamics

According to Mass (1980) and Sterman (2000, 195), stocks are important in engendering the dynamics of systems for the following reasons:

- ✓ Stocks describe the state of the system
- ✓ Stocks deliver the basis for actions
- ✓ Stocks offer systems with inertia and memory
- ✓ Stocks are the cause of delays
- ✓ Stocks have divergent rates of flow and generate disequilibrium dynamics.

Therefore, stock is the main focus of any kind of system dynamics (SD) simulation model due to its ability to influence and properly state the model and system. Delays in a model are discussed in the next section.

d) Delays

Most systems have a delay which is the main source of unstable and oscillated behaviour in a system (Sterman 2000, 409). A delay is also treated as a pause, break or lag between initiation and finish of a resource transition (Stevenson 1994; Wolstenholme 1990). Delays accomplish a few actions in a model based upon the type of delay. For instance, when 'parent chicks' enter' in a system model, the modeller needs to consider a delay as parent chicks need at least 24 weeks to grow into the mature parent to lay eggs. Repetitive use of delays in a system may oscillate the behaviour of a stock. The subsequent section deals with organizational boundaries for a model.

e) Organizational Boundaries

Wolstenholme (1990) and Sterman (2000) stated that organizational boundaries need to be determined in order to model the system properly. Most organizations worldwide adopt different types of organizational boundaries within a system based on location, scope, finance, management, etc. Therefore, it is important to define the boundary of a model to incorporate necessary variables in a system. The next section discusses policy matters within a model.

4.4.2.5 Run Simulation Model

It is always time-consuming to convert a model from qualitative (causal model) to quantitative (stock and flow) form. Obviously, it is a great success when a complete simulation model runs successfully in its software environment. The job does not finish yet in this stage. A number of trial and errors will fix the bugs for the model. The experiments will be continued as long as it does not have a perfect match with the real-life behaviour. Such steps are challenging and time-consuming in terms of effort given to fix the model. In this situation, data may need to be collected for a number of times to crosscheck to find the errors. Successful completion of the simulation model needs to be run repeatedly to find it as workable as replicating the real-life process. The next phase needs to be tested the reliability and validity issues for the simulation model.

4.4.2.6 Model Reliability and Validity

Model reliability and validity needs to be checked when a simulation model run successfully with replicating real life outputs. The reliability and validity issues are handled in the following way.

a) Model Reliability

Modelling is an iterative process of causal diagramming, scope selection, hypothesis generation, quantification, reliability testing and policy analysis (Sterman 2000). The model refinement process continues until the model is able to satisfy requirements concerning its reality, robustness and ability to reproduce a historical pattern (Jørgensen 2004). Such efforts will not only ensure reliability but will also explore potential futures (Forrester and Senge 1980; Homer 1996). Most things in the world are not measured including many that experience tells us are important (Homer 1996;

Homer and Oliva 2001). The objects chosen provide input into the model and originate from experts' minds by being certified as important elements the relevant process (Homer 1996; Homer and Oliva 2001). However, inferences come from related data, logic, guessing, observation or adjustments considered desirable to provide a better simulated fit to history (Homer 1996; Forrester 1980; Graham 1980; Randers 1980). In practical terms, research based on reliability theory has been conducted on the power system (Chen, Thorp, and Dobson 2005); health system (Ware Jr, Kosinski, and Keller 1996); poultry operation; and the human system (Bonabeau 2002). Similarly, the reliability of the current model will be tested in chapter 6 under section 6.6. Similar to reliability, validation is an important issue for a SD model and is discussed in the next section.

b) Model Validation

The modeller has the general expectation of validating their model to gain mass acceptance of its compatibility with reality. According to Barlas (1996), there are two theoretical sides of a SD model validation: the positivist and the pragmatist with the latter approach meaning "adequacy with respect to a purpose". Usually, validation is a gradual process of "confidence building." Many researchers (Kornbluh and Little 1976; Wolstenholme 1990; Forrester and Senge 1980) also affirmed that no one method can claim complete validation instead claiming comparative usefulness for desired purposes rather than an exact fit between the model output and its past data, or extreme "true/false" or "accept/reject" calibration (Forrester and Senge 1980; Kornbluh and Little 1976; Roberts 1976; Wolstenholme 1990, 1999). Checkland's 'hard' approach stated that models must sufficiently represent a part of the real world whereas 'soft' approach models must only be internally valid (Winter, Brown, and Checkland 1995; Checkland 1995). Yang (2004) and Sargent (2005) ensured that simulation results were compared observing both historical and analysis data and indicated that verification and validation may lead to adjustments in the simulation model.

However, modellers may claim to have "verified" a model but validation and verification of models are impossible. The word "verify" means "to establish the truth, accuracy, or reality". "Valid" is defined as correctly derived from premises and also implies being supported by objective truth (Sterman 2000, 871). Models are designed for simplified representations of the real world and differ from reality in ways large and small, and infinite in number; however, a research proposition can be validated (Sterman 2000, 871). Another popular statement is that a model can be validated if the propositions are derived from the axioms of a closed logical system (Ayer 1952; Read 2012). A simulation model that is found to be accurate after validation is called a validated model. As shown in Figure 4.7, Barlas (1996) designed a model validation process which was followed to validate the model used in this study. At the same time, a core confidence building test was relied upon for structural, behavioural and policy tests (Barlas 1996; Forrester and Senge 1980; Wolstenholme 1990; Sterman 2000). Table 4.4 presents the systematic validation process which has been proposed by the above-mentioned expert researchers in the system dynamics (SD) field.

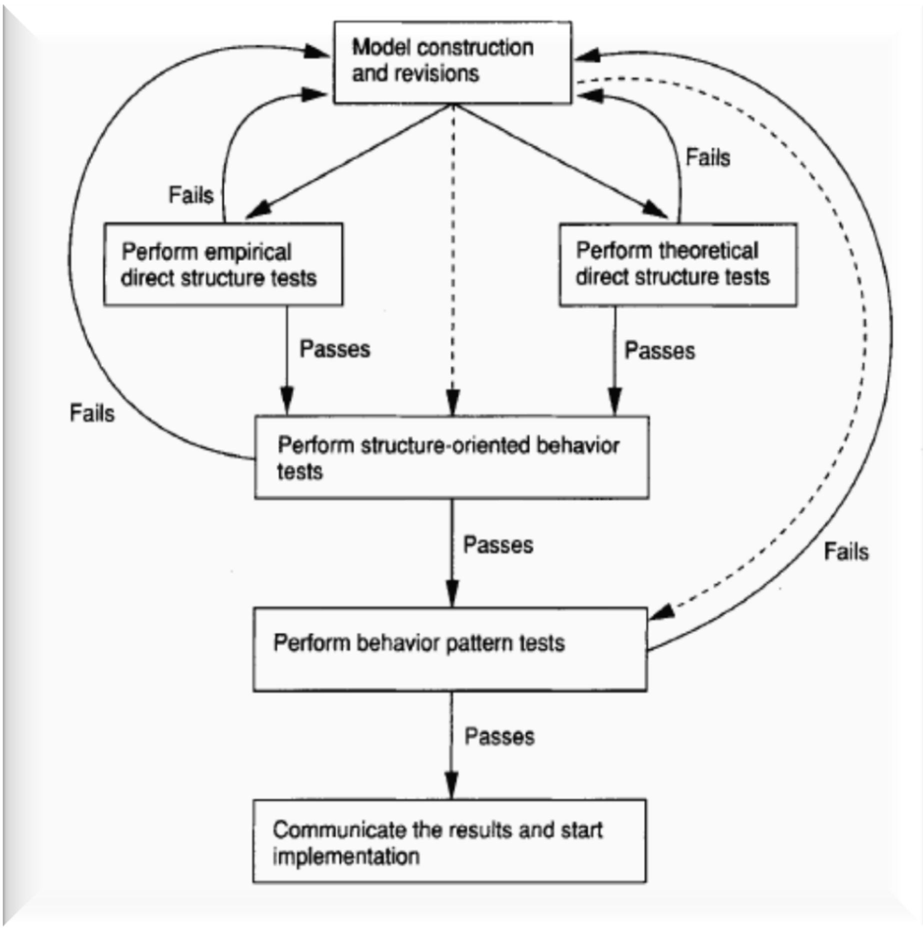

Figure 4.7: **Formal Steps of Model Validation (Barlas 1996)**

An executable model should not be thought to be correct and complete without verifying its behaviour and components; therefore, it has to be verified. Qualitative or quantitative errors, programming errors or wrong parameter settings are examined through a validation process (Van der Aalst et al. 2010; Kleijnen 1995). An executable model needs many trial runs with various changes such as input, values for the constant and auxiliary variable, and linked information (formula). In the stress test, the model is experimented on by changing the values of the key variables which are subjected to extreme situations, for example, sudden calamities, excessive demand and inadequate supply (Van der Aalst et al. 2010). The model's interconnected behaviour should behave best under extreme conditions which allows the researcher to verify its validation. This verification is very important as discussed in various literature by Sterman (2000), Forrester and Senge (1980), Barlas (Barlas 1996) and Wolstenholme (Wolstenholme 1990) who emphasised core confidence-building tests on a working model. The following section discusses experimenting through a simulation model.

Table 4.3: Core Confidence-Building Tests (Barlas 1996; Forrester and Senge 1980; Wolstenholme 1990; Sterman 2000)

Test Type	Descriptions	
Structural Validity	Structural Verification	Comparing the equations of a model with real-life practices and gaining knowledge from literature if available.
	Parameter Verification	Appraising parameters of a model against knowledge of real system, both conceptually and numerically.
	Extreme Conditions	Assigning extreme values and observing model behaviour.
	Boundary Adequacy	Aggregating all appropriate relevant structure into the model.
	Dimensional Consistency	Checking the right-hand side and left-hand side of each equation for dimensional consistency.
	Turing Test	Presenting a mixed collection of real and simulated output behaviour patterns to experts and asking whether they can distinguish between the real and the simulated patterns.
Behaviour	Behaviour Reproduction	Examining how well model-generated behaviour matches observed behaviour of a real system: behaviour reproduction tests include a symptom-generation test, frequency-generation, relative phasing, multiple-mode test and behaviour characteristics.
	Anomalous Behaviour	Discovering anomalous features of model behaviour which sharply conflict with behaviour of the real system. Used to defend particular model assumptions by showing how implausible behaviour arises if the assumption is changed.

	Behaviour Sensitivity	Conducting sensitivity of model behaviour by experimenting with different parameter values and analysing their impact on behaviour.
Policy Test	Changed-behaviour Prediction	Testing if a model correctly predicts how behaviour of a system will change if a policy is changed.
	Policy Sensitivity	Conducting policy sensitivity to reveal the degree of robustness of model behaviour, and identifying the risk involved in adapting a model for policy making.

4.4.2.7 Test policy and Extreme Condition Situation

A policy is a set of rules which policy makers use as a basis for decision making when expected future events happen (Stevenson 1994). According to Forrester (1994a), 98% of the policies for a system do not have significant influence on generating massive change; only a few highly leveraged policies can change behaviour within the system. Nevertheless, in a complex business process, finding high-impact policies may be difficult as many interconnecting feedback loops can be found in a complex system. At times, a policy, intended for solving a problem, may result in unexpected or unintended outcomes (Maliapen 2003).

After successful validation testing of the model, the next phase is to experiment which is based on research questions and objectives. These experiments should experiment efficiently to obtain reliable and consistent results. A simulation experiment is based on specified probability distributions or predictable values in a variable (Carson and John 2004; Kleijnen 1995). Quantitative results are accumulated which are returned upon completion, and experiments continue until the expected results are achieved. In many cases, this is achieved by dividing a run into sub-runs (Carson and John 2004). A few experiments will be discussed in chapter 6 in section 6.7. According to Maldonado and Greenland (1997), quantitative simulation results have to be interpreted in order to communicate answers to research problems and questions. For each answer to a research question, reliability should be checked to support the outcome. In cases in which the reliability of a variable or model is too low to disclose any certain answers, new or additional trials with experiments and model runs are required. In practice, a number of processes, including experimentation and interpretation, may frequently take place at the same time. Typically, a number of possible alternative circumstances are compared and contrasted with one another. In that situation, several simulation models are created and experimented with and the results compared. Often, several possible improvements of an existing situation have to be compared through simulation. The research questions and objectives are answered in detail in chapter 7.

When a simulation model has fulfilled and satisfied fundamental validity tests, it can then be experimented with to examine and test the various policies and their impacts on a system (Lane and Oliva 1998; Forrester 1961, 1968), to explore 'what-if' scenarios (Morecroft 1988a) or to optimize key decisions (Wolstenholme and Coyle 1983; Coyle 1996, 2000; Keloharju and Wolstenholme 1988; Coyle 1985). If a model is complete, valid, verified and dimensionally correct, then simulation can play 'what-if' analysis as much the researcher wishes to (Maldonado and Greenland 1997). The model can be repeatedly adjusted to represent possible or expected future situations by changing parameters in the executive model. In each successive trial with its changes, the adjusted model needs to be validated (Oreskes, Shrader-Frechette, and Belitz 1994; Sargent 2005). The alternative model resulting from different trials then needs to be analysed based on the consequences (Maldonado and Greenland 1993; Sterman 2000). These sorts of experiments are mostly done over policy and uncertain related variables. The above discussion acknowledges the research process followed in this study.

4.4.2.8 Forecasting Future Behaviour

Future projection is a vital thing for most of the operation. By doing so, industry can achieve their targets and protect possible losses respectively. Bangladesh poultry is making losses due to wrong prediction of disease time and demand variation for different reasons like season, festivals, market situation and the likes. The current research is operated the simulation model for 312 weeks which means six years. It can be done for more than this if the farmers require it. This is how the model can forecast the future trends which will help the farmers to prepare themselves to face the situation. The following section describes the study's data collection method.

4.4.3 Methods of Data Collection

This study employed five methods of data collection, namely, observations, interviews, questionnaires, documents and focus group workshops. This study used several data collection techniques to disclose, understand and experience the following:

- ✓ Business and supply chain processes and procedures
- ✓ Interactions and roles of stakeholders

- ✓ Forward and reverse supply operation
- ✓ Procuring process and markets for by-products
- ✓ Probable integration of poultry forward and reverse supply chains
- ✓ Creating equations based on relationships
- ✓ Necessary information to construct simulation model

4.4.3.1 Observation

Observation is one of the most effective data collection methods for obtaining an understanding of subjects (e.g. persons, groups and systems) under study. A researcher can easily observe the subjects perform activities as a participant or as an onlooker (Whitten, Bentley, and Barlow 1994). Data from observations consists of detailed descriptions of people's activities, behaviours, actions and the full range of interpersonal interactions and organizational processes. Researchers use observational data to understand the context of the observed subjects to an extent not entirely possible using interviews or written documents. They also have the opportunity to see things that may routinely escape conscious awareness among participants. Therefore, direct experience gained from observations allows researchers to create a holistic perspective, be open and be discovery-oriented and inductive in approach (Patton 1987). Similarly, the current research has used observation technique to find out the actual cause and effect relationship between variables. For instance, observation is appropriately used to identify different rates and stocks' variables of the study. To do so, the researcher stayed in and visited all the relevant areas to find the similarity with the information acquired from the in-depth interviews and focus group discussions. It is noted that the researcher has covered farm operation (parent stock), hatchery process (day-old chicks' production), middlemen (agents, dealers and sub-agents level) to understand the real facts for the sake of build a simulation model appropriately. Later, the information was merged and matched for the convenience of the current study.

4.4.3.2 In-depth Interviews

There are two types of interviews: formal and informal. Formal interviewing is conducted through structured questionnaires in sequence, and occasionally recorded in a standardized form whereas informal interviewing does not require set questions or a pre-determined framework (Bailey 2008; Moser and Kalton 1986; Robson 2011). In-depth interviews are considered as the informal type and are often described as a normal conversation between interviewer and interviewee (Legard, Keegan, and Ward 2003). An in-depth, qualitative interview is a useful tool to inquire and discover the case's status and situation through the methods of an open-ended, semi-structured format, understanding and interpretation and recording responses to gain insights on a subject (Guion, Diehl, and McDonald 2011). The main purpose of using this data collection technique was to gather necessary information about the poultry process. In addition, such technique is helped to crosscheck the variables and their relationships in terms of cause and effect. Again, the current research has used in-depth interviews to learn about the poultry process and operation at farm, distributor and supplier levels. A simulation model was developed based on in-depth description and observation methods. Stock, auxiliary and constant variables and their interrelated co-variables, and rate values for each inflow and outflows were identified through the in-depth interviews. With regard to the current study, primary information for this study was collected mainly through in-depth interviews from the sample respondents of a poultry case industry. This research used the in-depth interview technique to gain insights and develop a poultry supply chain model. There were 12 respondents in total comprising the top 12 executives, including the case farm owner, who each participated in an in-depth interview.

4.4.3.3 Focus Group

Recently, focus group sessions have been used in research to gain insight into the dynamic relationships, attitudes, opinions, motivations, concerns and problems related to current and projected activity (McDaniel 1979). Moreover, focus group sessions are helpful in answering questions of how and why something happens (Folch-Lyon and Trost 1981). A focus group is a conversation in a group session that may have six to 12 respondents under the guidance of a moderator (Folch-Lyon and Trost 1981). Furthermore, the main advantage of a focus group is that it provides the researcher with the opportunity to observe a large number of interactions on a topic in a limited period of time: it also provides clues about the range of variation of certain opinions or characteristics. Focus groups were originally used as a marketing tool to help consumer specialists find out what a group of people were thinking (Stewart, Shamdasani, and Rook 2007). The main objectives of using this technique was to determine, verify and acknowledge the various poultry operations, cause and effect relationship between variables, equation formation for the rate variables and so on. The current study conducted a focus group discussion with eight members who were selected from the different units of the poultry process, namely, the parent stock (PS) farm, hatchery, distribution and waste processor. The owner of the case industry and three top-level executives also participated in this session to authenticate the process information. Such diversified participation in a focus group meeting streamed valuable information related to model variable, cause and effect relationship, equation formation and the likes. Later, collected information was matched with other sources of information like in-depth interview and observation.

4.4.3.4 Documents and Records

Documents are obtained directly from records, official publications, reports, personal diaries and open-ended questionnaires. Documents provide basic information as a background for conducting research or making decisions and stimulate a researcher to generate additional ideas to pursue through direct observation and interviewing (Charmaz 2006; Meystre et al. 2008). The main purpose of using this technique was to determine stock and flow variables. In addition, documents and records is helped to collect historical data set to compare with model output for verifying model and reliability. Such information makes easy to build real-life relationship in a virtual world like simulation. For the current research, secondary information was collected from various documents and records maintained by the head office of the case industry. Specifically, rate variables were adjusted accurately through the observation technique.

4.4.4 Research Tool

The research tool is an important component for any kind of research. Without having an appropriate research tool, it would be hard to conduct analysis which guides a study to find ultimate outcomes. The current research used rigorous simulation techniques to analyse the model to respond to research questions. In the literature, Jay W. Forrester introduced the principles of feedback and control to social variables which dealt with the two key lessons of choosing an appropriate system and using the simulation technique to discover the surprise behaviour of a system (Forrester 1971b). To simulate a system, convenient and competent software such as Vensim is needed. The development of Vensim has been motivated by modellers, researchers and relevant consultants since its inception (Eberlein and Peterson 1992).This research used Vensim simulation software.

Vensim™, the Ventana® Simulation Environment (Ventana Systems 1999), is an interactive software environment that allows the development, exploration, analysis and optimization of simulation models. Business process simulations with Vensim software (Repenning 2002; Pfahl and Lebsanft 2000; Peterson and Eberlein 1994) are used to refine theories, test system behaviours and perform sensitivity analyses for strategic policies, reliability and validity through a reality check. Since computer simulations provide time compression of visualized results of model analyses, they are useful for enhancing insights about system behaviours and ways of improving them. Vensim was created to increase the capabilities and productivity of skilled modellers and has functionality that improves the quality and understanding of models (Eberlein and Peterson 1992).

The attractiveness of Vensim software is based on its workbench-toolbox metaphor, causal diagram tracing, statistical fit analysis and SyntheSim model of variables (Eberlein and Peterson 1992). This rigorous Vensim software was used in this study to draw the supply chain operation of a case poultry farm. Causal diagramming was then developed which had positive and negative relationships between the variables. This causal diagram later helped to build a stock and flow (quantitative) model with the association of formulae, information and exogenous data. The research model was completed through these processes and by having a massive unit and relationship check of its various component variables. Finally, various analyses were made through Vensim to successfully meet the criteria of system dynamics (SD) research in light of validity, reliability and 'what-if' analysis. As computer simulations provide time compression of the visualized results of model analyses, they are useful for enhancing insights about system behaviours and ways of improving them.

4.4.5 Data Analyses

Data analysis is an important part of a research study. Generally, analysis is conducted based on the research objectives and questions. Data analysis for the study's research questions is discussed in the section below.

Research Question One

What is the most appropriate sustainable poultry production process for the Bangladesh poultry industry in light of the economic, social and environmental issues?

Analysis for Research Question One

The answer to the first research question was derived from the empirical case study. The simulation finding also helped to understand the sustainable poultry production process in light of the economic, social and environmental aspects of sustainability. This three-factor sustainability was also explored in the existing literature. Visual interfaces for the poultry case industry within the simulation model later helped to validate such questions through due procedures.

Research Question Two

How can the principles of the reverse supply chain (RSC) be used to recycle poultry wastes effectively?

Analysis for Research Question Two

The simulation model was designed based on two different supply chains, forward and reverse. The poultry process generates various kinds of wastes, including poultry litter, feathers, broken and unhatched eggs, intestines, waste feed, etc. The same information was also investigated through the literature review. When data were collected, the quantities of wastes were also noted to compare and contrast with the model's output. In reality, the Bangladesh poultry process is yet to process most of the poultry wastes except for broken/unhatched eggs and litter. The model also designed the reverse supply chain to collect wastes properly for the main operation or a third party operation to process for economically valuable by-products such as biogas, bakery products, fish feed and fertilizers. Real and model data were compared to understand the effectiveness of using poultry wastes.

Research Question Three

In what ways can the poultry forward supply chain (FSC) bring social changes leading to employment generation and, thereby, reducing poverty?

Analysis for Research Question Three

The simulation model also designed the forward supply chain which started from the poultry parent stock (PS) farm and progress though to final consumers. A number of articles in the literature were found on forward supply chains but not on the poultry process. It was observed in real life that every step of the forward supply chain creates opportunities for more employment, businesses and social changes in terms of empowering poor and unemployed people. The model was designed in such a way that a forward supply chain would determine the amount of employment based on total poultry birds transacted or reared. The more birds are reared; the more employment and business opportunities will be created.

4.4.6 Problems Faced in Data Collection

Only a few problems were faced in the data collection from the case industry: these are discussed below.

4.4.6.1 Focus Group Session

In the modelling phases, it is worthwhile to understand the nature of the process and its relevant activities (Dryer 1991). Naturally, with a small group of eight, it is much easier to converse and reveal relevant information. The issues relating to facilitating workshops and dealing with focus groups have been discussed earlier in this chapter. A few managers from the main projects did not want to attend as the ongoing daily work did not permit this to happen.

4.4.6.2 System Dynamics and Simulation Terminology

The management and respondents were ignorant about system dynamics (SD) research and simulation. Initially, it was a bit difficult to gain their understanding. Nevertheless, they gradually started to understand the model and the purpose of the simulation modelling.

4.4.6.3 Documents and Records

The case industry had stored most of its data and documents in an unorganized manner with no storeroom maintained in which to store them. Due to the chaotic storage of their documents and computer files, delays were caused which created some unhappiness among them.

4.5 SUMMARY

This chapter has described the research paradigm, methodologies and methods used for this research. The detailed research process was then described based on the system dynamics (SD) research process. In addition, relevant matters about qualitative and quantitative modelling procedures were discussed. Discussion followed and the logic was provided for why this research deployed design science (DS) methodology under the positivism paradigm with the help of system dynamics (SD) research and the case study method. The latter part of the chapter mentioned a few problems encountered while conducting the study. This chapter tried to address almost every aspect of research methodology used in this current research. The next chapter discusses the supply chain model using the system dynamics (SD) approach.

CHAPTER 5:

POULTRY SUPPLY CHAIN MODEL: A SYSTEM DYNAMICS APPROACH

5.1 INTRODUCTION AND CONTEXT

The focus throughout this chapter is to develop the qualitative and quantitative poultry process model using the system dynamics (SD) approach. The initial focus is to develop and describe the qualitative model or causal loop diagram for the particular case industry and its forward and reverse supply chains. One of the prerequisites is to have a causal or soft model before or after building a stock and flow diagram for a simulation model. The chapter also examines the dynamic relationship and impact of one variable on another through creating a loop. The key variables were identified through in-depth interviews with the employer and top-level employees within the case industry. This causal loop model was later used to develop the quantitative or stock and flow model. The quantitative model incorporated stock (level) and flows (rates) for all connected variables along with appropriate equations to express real-life relationships between the variables.

The poultry industry in Bangladesh operates through a number of steps from its mother breed through to mature chicken (broiler) consumption, which is a complex process. Earlier (see chapter 1), the current study's scope was defined with its research starting from the poultry parents stock (PS) breeder to broiler meat production. At the same time, the study in considering the reverse poultry supply chain explored the reversal of poultry wastes to the main industry or a third party industry. However, this research sought to integrate both supply chain processes so that the poultry industry could achieve maximum benefits. The profitability and feasibility of an integrated supply chain depend on the model's output. If the output showed significant benefits, the producer would then apply such concepts in their existing operation. Therefore, the study needed to build such a model which would give full insight into processing, possible output and other associated benefits such as employment. The next section discusses building a causal loop diagram based upon the poultry case industry's information and its relationships with other supply chain members. The qualitative system dynamics (SD) model for the case poultry industry is also discussed.

5.2 QUALITATIVE SYSTEM DYNAMICS MODEL FOR POULTRY SUPPLY CHAIN

The necessity for building a qualitative SD model (causal model) was described in the methodology section in chapter 4 along with discussion on recent research practices. This particular section develops a causal loop diagram for the research case industry based on in-depth interviews, focus group discussion and observation techniques. It is noted that the model is confined to the forward and reverse supply chain aspect of the poultry process. The following sections present the poultry causal model building process along with loops that exist in the poultry variables within the research boundary.

5.2.1 Causal Model Development

As a first step, the study developed a simple causal model for ‘eggs and chicks’ with a negative feedback loop. Figures 5.1 and 5.2 show a simple causal model developed using key variables indicating the plus (+) or minus (-) sign on the top of the arrowhead. As can be seen, a plus (+) sign indicates a positive relationship between the variables, and a minus (-) sign implies a negative relationship. In Figure 5.1, a simple causal loop diagram captures the feedback dependency of chicks and eggs. The arrows indicate the causal relationships. The effect is positively related to the cause: an increase in the total ‘eggs’ causes the rise in ‘chicks’. Alternatively, a decrease in egg collection causes fewer chicks. If there are more eggs, then chicks rise and, alternatively, fewer eggs produce fewer chicks: this is called a self-reinforcing (positive) loop (Sterman 2000, 13).

According to the well-known book ‘Limits to Growth’, there is no growth which can continue forever (Meadows et al. 1972). Such limits are generated from a negative feedback loop between the variables. In Figure 5.2, the model consists of both positive and negative feedback loops. Here, negative loops are self-correcting as they respond to adverse change (Sterman 2000, 13). If eggs increase, parent chickens will increase. When more hatching eggs come from parent mothers over a time, parents grow old becoming aged parents with less fertility producing fewer more eggs. This means that parents start decreasing which contains a negative tendency. Finally, the more eggs hatched to produce day-old chicks, the less hatching eggs left in the stock which is a negative loop. This is the way that loops work in a system dynamics (SD) model. The causal model works to define the relationships between the variables. This cause and effect relationship ultimately determines the influence in terms of positive and negative changes in connecting variables. The study needed to identify key variables to consider in building the causal loop model which is presented in the following sections.

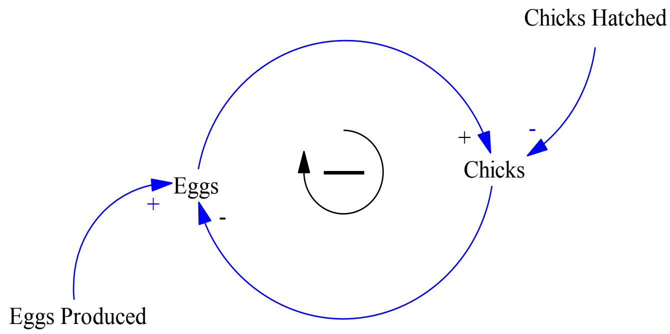

Figure 5.1: A Simple Negative Loop of 'Eggs and Chicks' Causal Model

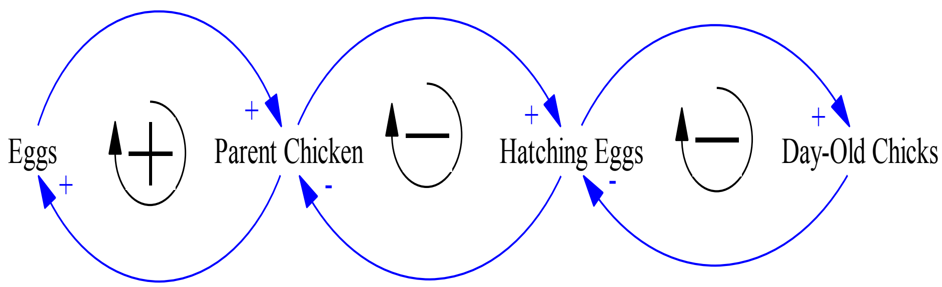

Figure 5.2: Combination of Positive and Negative Loops

5.2.2 Identifying the Key Variables

Generally, variables are chosen from the literature and their relationships with each other are explored through research investigations and secondary sources (Greenland 1987). The present research faced challenges in choosing key variables and defining the boundary of the study. No relevant literature was available on the supply chain variables with regard to the Bangladesh poultry industry. Due to this situation, the research has to accept an alternative technique where information was collected through in-depth interviews, focus group discussions and observation. Table 5.1 shows the process of collecting key information on the poultry case industry in Bangladesh. Parent chicks and mature parent units were found to be the two most important variables and both directed the rest of the poultry supply chain process. For example, a small number of parent stock will produce less hatching eggs from which to hatch day-old chicks.

Table 5.1: Process of Data Collection at Different Levels

SL No.	Information and Data	Process of Data Collection
1	Parent Chicks (Breeder Farm Unit)	In-depth interviews, focus group discussion, observation and industry records
2	Mature Parent Unit	In-depth interviews, focus group discussion, observation and industry records
3	Hatching Unit	Observation and industry records
4	Distribution Unit	Observation, in-depth interviews and focus group discussion
5	Farming Unit	Observation, in-depth interviews and focus group discussion
6	By-products Procurement Unit	In-depth interviews, observation and industry records

After conducting in-depth interviews and focus group discussion with the employer and top-level executives of the poultry parent stock (PS) farm, the study justified the selection of a number of variables which were important for both the study and poultry farming. In some cases, the observation method was also used to cross-check the reliability of responses through in-depth and focus group outcomes. The list of variables (Table 5.2) considered to be important were put into the system for simulation for this research. It was a little challenging to consider appropriate and key variables due to the lack of previous literature on the poultry supply chain. The selection of variables is an important issue that helps to build a causal or soft model. However, focus group discussion, in-depth interviews and observation made it easy to select major variables in which dynamic behaviour could be found. Clearly, dynamic behaviour depends on the dynamic loop system between variables that have a positive or negative effect (Sterman 2000, 1989; Wolstenholme 1999, 1990). Similarly, level or stock variables are linked with a few other auxiliary and constant variables with positive or negative loops (Georgiadis, Vlachos, and Iakovou 2005; Vlachos, Georgiadis, and Iakovou 2007). Key variables according to the respondents were identified with these listed in Table 5.2. In the same table, level and auxiliary variables were taken from different processing units such as the parent breeder farm, hatchery, distribution, ultimate farmers and poultry wastes. At this point, the operational scope within the variables was discussed. Ultimately, knowing the operational relationship between variables led to a clear understanding about the existence of a dynamic loop between the variables. The next section discusses the initial loop design for the poultry causal model based on the causal diagram depicted in Figures 5.1 and 5.2.

Table 5.2: Important Variables for Modelling (Source: In-depth Interviews)

Process Unit	Stock/level Variables	Auxiliary Variables	Did not consider
Parent Breeder Farm	Mature Parent Mature Parent Capacity Parent Chicks	Aged Parent Culled Parent Profits	Feed Supply Disease
Hatchery	Eggs Hatchery Day-old Chicks	Eggs per Parent Broken Eggs Eggs to Hatchery	Hatchery Incubator
Distribution	Middlemen	Retail Rate Retail Employment	Networking/ Scope
Ultimate Farm	Farmers Broiler Chickens	Time for Maturing Chicken Supply	Calamities
Poultry Wastes	Intestines Feathers	Biogas Fertilizers Fish Feed	Artificial Charcoal Feed Wastes
Others	Total Employment	Minimum Employees	Efficiency/Skills
	Chicks	Hatching Rate	Chicks Mortality

5.2.3 Initial Loop with Key Variables

After having vigorous focus group discussion and in-depth interviews with the respondents, the initial poultry supply chain was sketched, as shown in Figure 5.3. This study is based on a poultry parent stock farm, which starts from the intake of 'parent breeder chicks and is followed by rearing parent breeder chicks for the particular period to grow them into mature parents. Hatchable eggs are then produced by the mature parent and the collected hatching eggs are sent to the hatchery unit. In the hatchery, it takes 21 days to hatch the eggs then hatched chicks are supplied to the distributor or middlemen. Middlemen and associate agents help the broiler chicks to reach the ultimate farmers who rear them for another four to six weeks to mature. Finally, mature broilers are served to consumers so they can eat the tasty meat as per their requirements. This is the point of the utmost research boundary in making a causal loop diagram for the poultry supply chain.

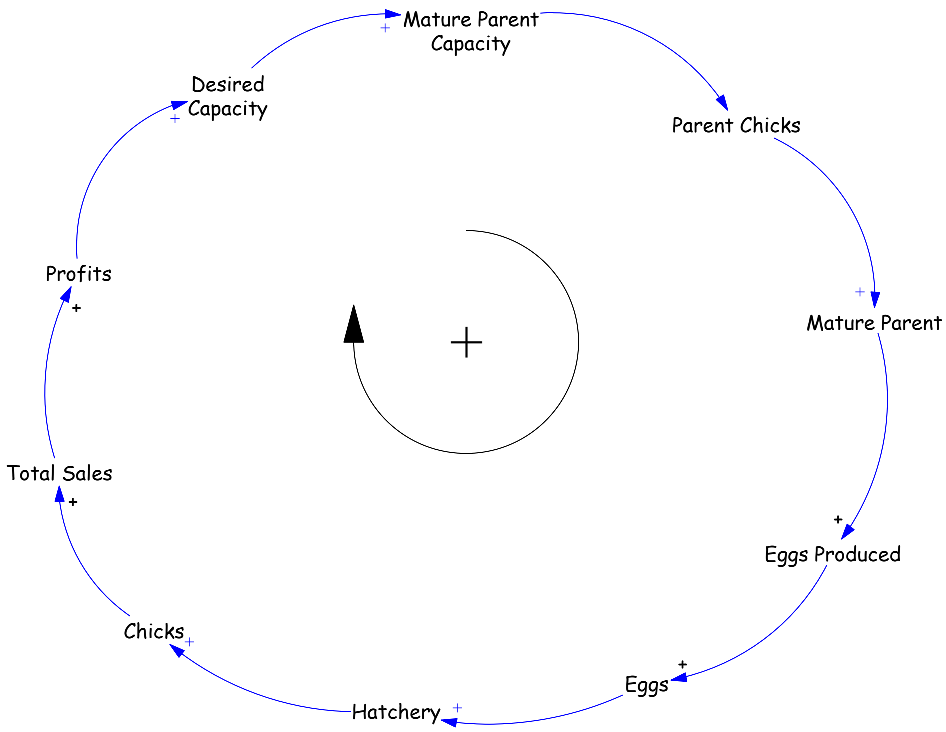

Figure 5.3: Initial Loop with Key Variables

In Figure 5.3, the causal diagram begins from the variable ‘parent chicks’ which is positively connected with the ‘mature parent’ variable. This means, if more ‘parent chicks’ input into the system, more ‘mature parents’ will grow up after a certain time. Alternatively, this positive loop may generate negative growth if input is negative (Wolstenholme 1990). The immediate variable of this poultry process is ‘eggs produced', which comes from ‘mature parent’ at an approximate rate. These eggs go to ‘eggs’ stock followed by ‘hatchery’ unit as further stock. Normally, the hatchery unit is separate from the parent stock farm for the sake of maintaining hygiene.

All the collected eggs from the farm site are then usually shifted to the hatchery storage. Hatchery storage has much larger capacity than the original capacity of the hatching incubator. The case industry’s hatchery storage has three times larger capacity than the hatching incubator for hatching chicks. The reason behind maintaining larger capacities to control chicks’ production based on market demand and the situation regarding calamities. It is also noted that eggs are input as a batch to the incubator for three weeks. The standard and unique hatching time is 21 days (Ferguson and Joanen 1982) including the three days in which the eggs stay in the setter machine. Three days later, chicks are taken out from the setter machine. Then, these outgoing chicks are examined thoroughly for proper grading by the hatchery quality control unit. High graded chicks should have the prescribed weight, colour and energy. Finally, hatched chicks (broiler or layer) are ready to travel to the ultimate farmers through dealers and distributors in a different region. Altogether, 10 key variables were used to develop the initial causal loop of the poultry process used to produce broiler/layer chicks.

The difference between parent chicks and broiler/layer chicks is genetic as parent chicks are an immediate preceding breed of broiler and layer birds. Ready chicks are packaged scientifically in a paper or bamboo box made with proper ventilation. They are ready to travel all over the country as per sales requirements. Company-owned transports deliver the chicks to the dealers of each sub-region. Dealers distribute the chicks to sub-dealers who in turn distribute them to the ultimate farmers. Farmers rear the chicks for 28-35 days depending on the market situation and demand. Mostly, farmers sell their mature broilers within five weeks. This is the total process used to create the causal loops. Within this journey, a number of equations and co-variables are associated with the main key variables. These associated variables are known as auxiliary and constant variables. The complete model was developed in the stock and flow model where most of the necessary equations and formulae were incorporated to run the model.

Figure 5.4 is an extended version of a causal loop diagram that has added 11 more variables in the same loop in comparison with Figure 5.3. These newly added variables are connected with the same loop with either positive or negative links. Newly added variables are listed in Table 5.3 below. It is noted that minor loops like deaths, culled and aged parents were ignored for model clarity. The additional variables in Table 5.3 were also considered in maintaining the supply chain dynamics in the Bangladesh poultry industry. For example, 'decision to purchase parent chicks' is an important variable which controls the dynamic behaviour of the whole supply chain. The more parent chicks are input into the system, the more mature parent, eggs, chicks and poultry wastes will be produced.

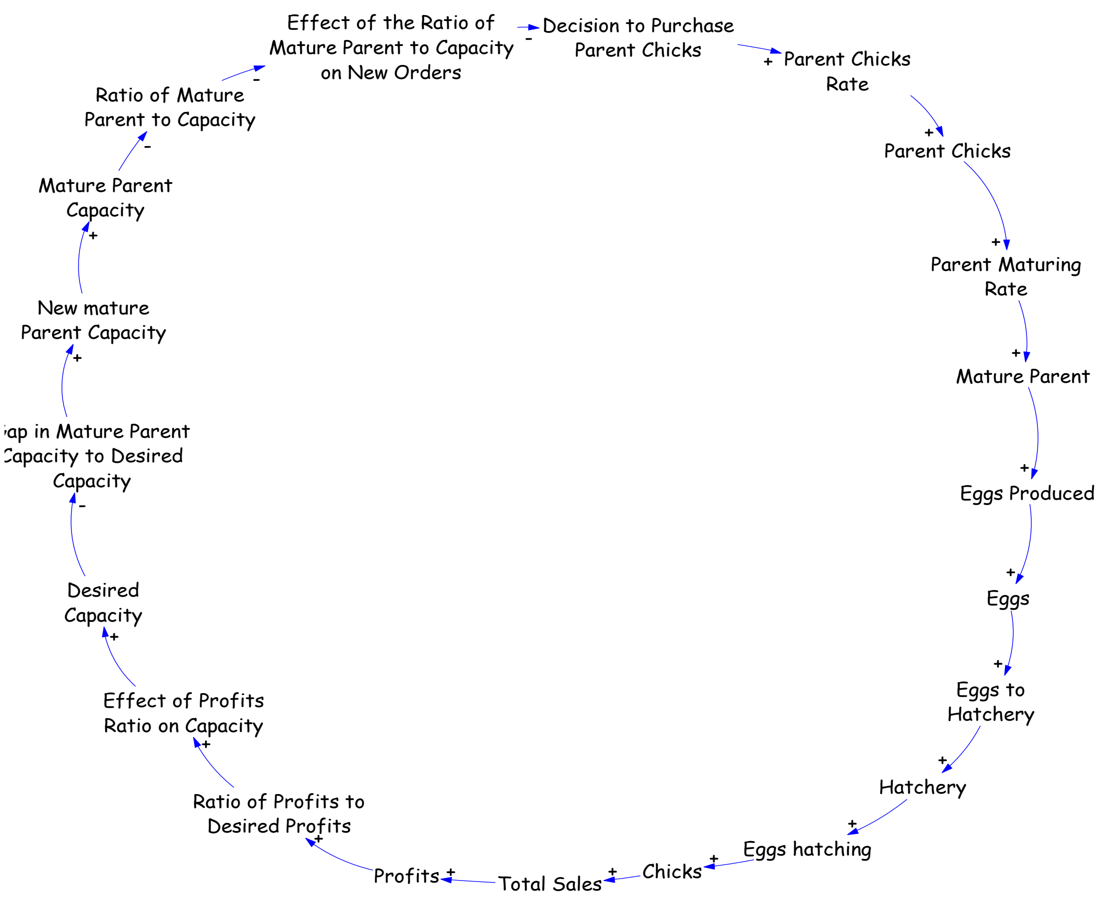

Figure 5.4: Extended Causal Diagram

Therefore, the rest of the output depends on how policy makers make the decision to purchase parent chicks. The poultry business is a process which is completely dependent on input. Poultry birds have to be maintained in a natural cycle of producing eggs and meat which is not comparable with other daily products. More precisely, no one can stop a poultry parent mother from producing eggs. At best, the eggs can be consumed as our daily food intake rather than sending them to the hatchery to hatch chicks. Similarly, the above listed variables have more importance in managing the poultry supply chain, production, reduction and other necessary matters. For the reduction of future production, farmers can cull the parent mother so that egg output will be reduced. If reduction is needed at the hatchery level, management can sell the eggs to the open market for everyday consumption rather sending them to hatchery incubators. This is how positive and negative flow can be maintained in a poultry supply chain. Such combinations of negative and positive flow build the well-organized dynamic behaviour of a system. The complete causal loop diagram (qualitative) model for the integrated poultry supply chain is presented in the next section.

Table 5.3: Eleven Additional Variables for Causal Model Extension

SL No.	Newly Added Variables
1	Decision to Purchase Parent Chicks
2	Effect of Profits Ratio on Capacity
3	Effect of the Ratio of Mature Parent to Capacity on New Orders
4	Eggs Hatching
5	Eggs to Hatchery
6	Gap in Mature Parent Capacity to Desired Capacity
7	New Mature Parent Capacity
8	Parent Chicks Rate
9	Parent Maturing Rate
10	Ratio of Mature Parent to Capacity
11	Ratio of Profits to Desired Profits

5.2.4 Comprehensive Causal Model

A number of variables exist in the poultry supply chain which starts from the 'pure line' breed and proceeds through to the ultimate consumption of meat and eggs . The study considered only significant variables which play an important role in creating dynamic behaviour in a poultry process system. An additional 13 important variables were added to the current diagram in Figure 5.5 to represent more dynamic relationships between the variables. Figure 5.5 is the complete view of the poultry causal diagram where key variables were given as input according to their importance. A number of variables were not given as input in this complete causal model due to the absence of dynamic flow. A number of loops were designed in the same figure. The longest loops of this causal model belong to 'mature parent' followed by 'parent chicks' and 'hatchery' variables. Numerous loops exist in Figure 5.5. For example, under the 'parent chicks' variable, there are 70 different loops of various lengths to express the complex nature of the poultry supply chain. Similarly, almost every important variable in this diagram contains a series of loops which is sufficient for understanding the dynamic relationship between the variables.

It was evident from the in-depth interviews with respondents that a number of loops of short length exist within the poultry forward and reverse supply chains. Figure 5.5 demonstrates a different expression of the causal diagram where most of the minor loops were identified by adding plus (+) and minus (-) signs. Some of the variables do not have a loop but instead are connected one way in a loop. This kind of variables helps to form a loop or works as a driver of a loop. For example, policy variables and calamities contain a bunch of co-variables such as political situation, disease, natural disaster, finance, government policy, under/over-production, competitors' actions and market demand. Such variables do not have any loop but instead influence the next loop of poultry 'flock repeat' and 'parent chicks' to assist the system flow of input and information. Noticeably, these variables maintain an important role in driving the model which determines the system behaviour of the entire model. Thus, the finalized causal loop diagram is presented through the figure and explanation above. Figure 5.5 itself provides an adequate explanation of the relationships and loops existing between the variables. Now, the causal loop diagram needs to be converted into the quantitative stock and flow model. The necessary values for the linked variables need to be provided to run the simulation model. Without running the simulation model, it would be difficult to analyse the model to find the desired outcome of the current research. The following section discusses converting the causal model into the stock and flow (quantitative) model.

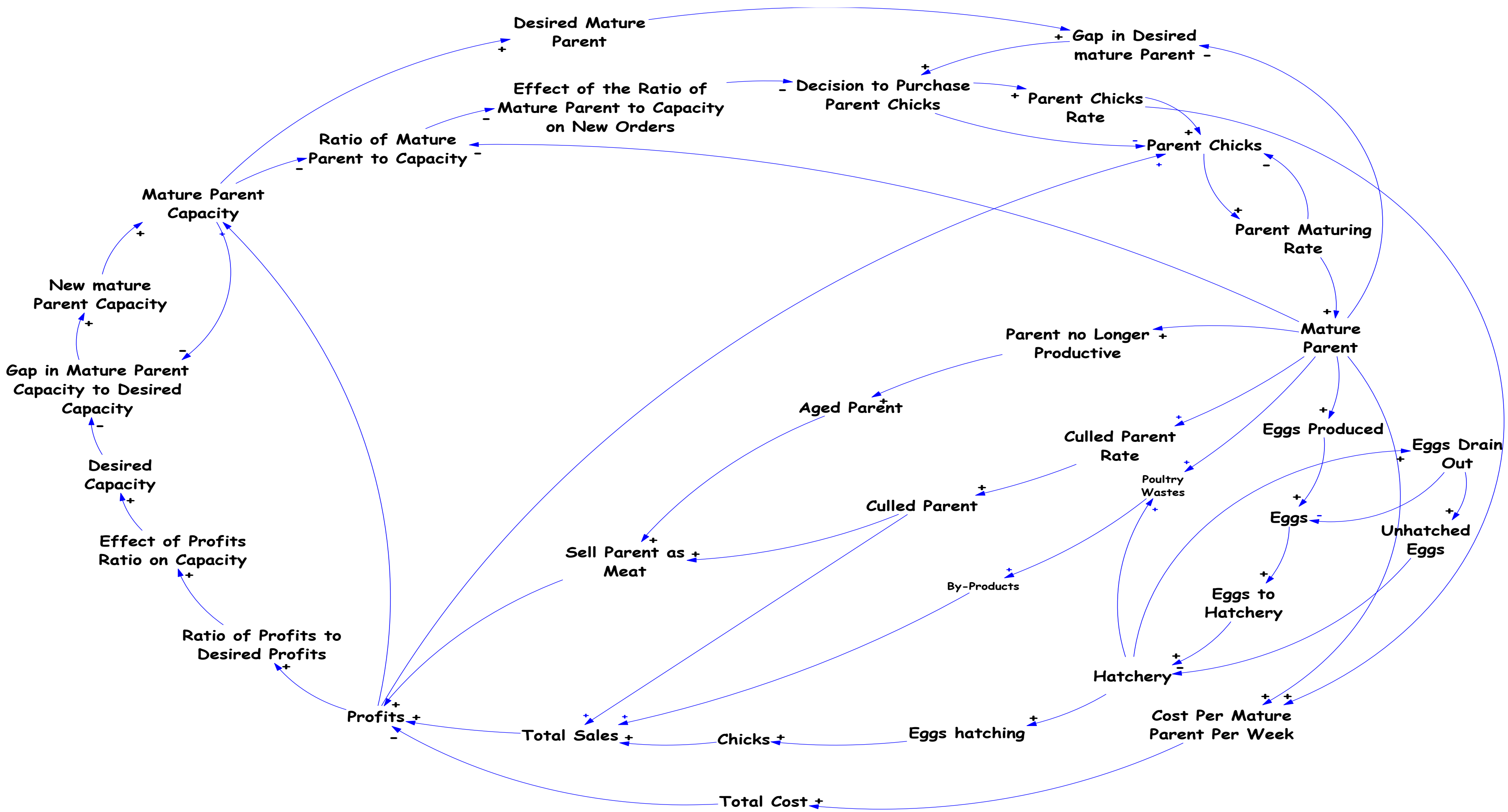

Figure 5.5: Complete View of Poultry Causal Model

5.3 STOCK AND FLOW MODEL FOR SIMULATION (QUANTITATIVE)

There is a debate on which should be built first, the causal model or the stock and flow model? The question can be answered either way (Bouwer, Machado, and Bredeweg 2002; McDoland 2013) as was discussed in the methodology chapter (see chapter 4) . Through explaining a causal loop diagram, one can understand the relationship between related variables and the nature of a model. However, it is never possible to understand whether or not the causal loop model replicated reality. To replicate reality is not the only objective for building a model which is instead used for experimentation until it achieves optimality or productive changes. To do so, there is no alternative to converting the causal loop model into a stock and flow quantitative simulation model. In addition, this model building needs appropriate research tools to run the simulated model in order to observe the behaviour of the variables. Objectives, the process and tools of the stock and flow model were discussed in chapter 4. A simulation model can extend or eliminate variables to perceive the behaviour of the model. Moreover, optimization, sensitivity, validity and reliability are major issues to be considered for a good model. Initially, a simple stock and flow model on poultry 'eggs' and 'chicks' is developed in the following section.

5.3.1 Simple Stock and Flow Model on 'Eggs and Chicks'

A simple causal loop diagram was built in Figure 5.1 using the variables 'eggs' and 'chicks'. A basic stock and flow model was developed based on the same variables, as reflected in Figure 5.6. As shown on this figure, a stock named 'eggs' can accumulate the resource and can be quantified at any point in time. The dimension of this level or stock variable is in resource units of 'eggs'. A flow or rate variable is used in both the right-hand and left-hand side of the level variable to control the increment or decrement of the flows. Such flows can be regulated by the constant variables of 'eggs collect rate from the parent mother' and 'hatching rate'. Incoming and outgoing flows are controlling the stock of eggs. Flows can also be controlled by the auxiliary or lookup variables. Outgoing chicks' rate cannot be higher than the eggs collect rates as stock is never represented as negative. If incoming flows stop supplying eggs towards stock, then there will be no eggs to hatch the chicks. This means that the operation should be stopped after a certain time; otherwise, the model needs to be directed by other inflow to continue the business process. To implement the realistic model in a virtual environment, stock and rate variables are important to determine to run the model which will act like a real-life process. The following section discusses different stock and flow rates for the integrated model.

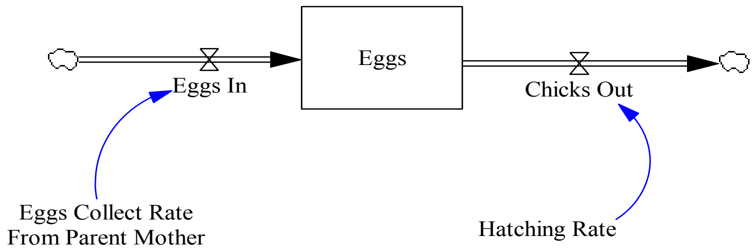

Figure 5.6 Basic Stock and Flow Model

5.3.2 Stock and Flow Rate

To construct the complete stock and flow poultry supply chain model, the researcher spent a few days in the case industry to observe various operations. By observing the related process for a few days, the researcher started to compare what was observed with the information perceived through in-depth interviews and focus group discussion. The most important task was to identify the flow rate for numerous constant and auxiliary variables. The parameters are determined using different distribution like average, random uniform and fixed rate. Different rates are determined through diverse way to justify real life context based on the case industry operation. These rates are important for the model as the real-life operation needs to be reflected in the simulation model in order to check structural validity. The information related to stock and rates was collected through in-depth interviews and focus group discussion. Collected information was later checked through the observation method. Only insignificant differences were found between in-depth interviews, focus group information and observation. Despite the insignificance of the differences, differentiated information was cross-checked which found the minor differences in comparison to the given data. This deviation is frequent in the poultry industry as this business works with live poultry birds and perishable eggs. Any kind of calamities and political unrest can change the usual plan. Even fluctuations in market demand for chicks and eggs are high in the Bangladesh economy which may cause a radical flow change in the existing process.

5.3.3 Complete Stock and Flow Model

As shown on Table 5.2, substantial stocks, auxiliaries and constants were identified through the in-depth interviews. Variables were cross-checked by the researcher's rigorous observation to match reality. Finally, the variables were selected to use as components of the model. The model building process was discussed in the methodology section (chapter 4). After careful investigation, essential variables for individual stocks were identified and then a more complete integrated supply chain model was constructed for simulating the results. Figure 5.7 is the simplified version of the completed model where the main stocks' variables were modelled with necessary rate valves and auxiliaries.

As shown on Figure 5.7, parent chicks' stock is determined through deducting from parent chicks' rate (inflow) and parent maturing rate (outflow). Outflow for parent chicks' stock is treated as inflow for the mature parent stock. Then, the mature parent has two different outflows of aged parent and culled parent. Here, 'aged parent' denotes the bird that is already aged and unable to provide healthy hatchable eggs whereas 'culled parent' means the bird that develops sudden sickness and weakness and is to be culled. At this point, total birds are counted through accumulating both parent chicks and mature parents. Mature parents provide hatchable eggs that are forwarded to the hatchery. In this stage, eggs and hatchery are the two different stocks determined by the number of eggs produced and delivered to the hatchery. Later, the hatchery is used to incubate all the delivered eggs to produce day-old chicks (DOCs). DOC production is dependent on the hatching percentage and the performance of the hatching incubator. Immediately, the DOCs are shifted towards the forward supply chain of distributors, agents and sub-agents who supply them to the ultimate farmers. Finally, farmers rear day-old chicks (DOCs) for a certain period to grow them as broiler chickens for final consumption. In addition, Figure 5.7 models the reverse flow of poultry litter, feathers, unused and unhatched eggs, and intestines for further processing. It is clearly visible in the model that these wastes are used to make different by-products which are represented as the stock variable. All these stock variables are connected with inflow and outflow valves (rates) to determine the final stock remaining. Finally, the model also displays an option to accumulate the amount of employment generation from the various processes. Thus, this model is a more simplistic view than the later model (see Figure 5.8).

Figure 5.8 shows the complete stock and flow diagram developed for the integrated poultry supply chain. This is the final model which will be used for testing, experimenting and validating with regard to the research objectives and questions. ‘Parent chicks’, ‘mature parent’, ‘eggs’, ‘hatchery’, ‘farmers’, ‘middlemen’, ‘consumer’, ‘poultry litter’, ‘bakery items’, ‘poultry feathers’ and ‘poultry intestines’ are the influential variables in this complete stock and flow model. The model has been divided into 10 different segments, named and numbered in the square boxes. For instance, No. 1 represents ‘parent stock’ where parent day-old chicks and mature parent operations are discussed. The difference between Figures 5.7 and 5.8 is that more connections are incorporated with the existing variables to make a loop. Loops are the determining factors to change a variable in either a positive or negative direction. Figure 5.8 provides a more detailed view Figure 5.7 with the inclusion of profits, capacity, diverse effects, policy matters and ratios thus making the model more realistic. The following sections discuss causes' trees of the key variables to show their domination and impact over other variables in the model. The linkage with the other associated variables are easy to identify and these can be affected positively or negatively through changing a certain value for a variable.

5.3.4 Causes Tree

According to the Vensim manual (McDoland 2013), when constructing and analysing a model, a causes tree is an easy way to realize what is causing other things to make changes. The causes tree diagram shows the causes of a variable; the uses tree diagram shows the uses of a variable. Tree diagrams show causes and use up to two variables distant (the default setting) (Eberlein 2003; Vensim 1999). It is easy to communicate the causes behind the changing behaviour of a particular variable. This helps to trace the causes variables for specific variables in a complex model.

5.3.4.1 Causes Tree for ‘Mature Parent’ Variable

The causes tree for the ‘mature parent’ variable is shown in Figure 5.9 which represents the sequential order of connected co-variables with the main variable. ‘Culled parent rate’, ‘deaths’, ‘initial mature parent’, ‘parent maturing rate’ and ‘parent no longer productive’ are the immediate connected variables for the mature parent stock. Five co-variables which may have positive or negative impacts over a loop are therefore associated with the 'mature parent' variable.

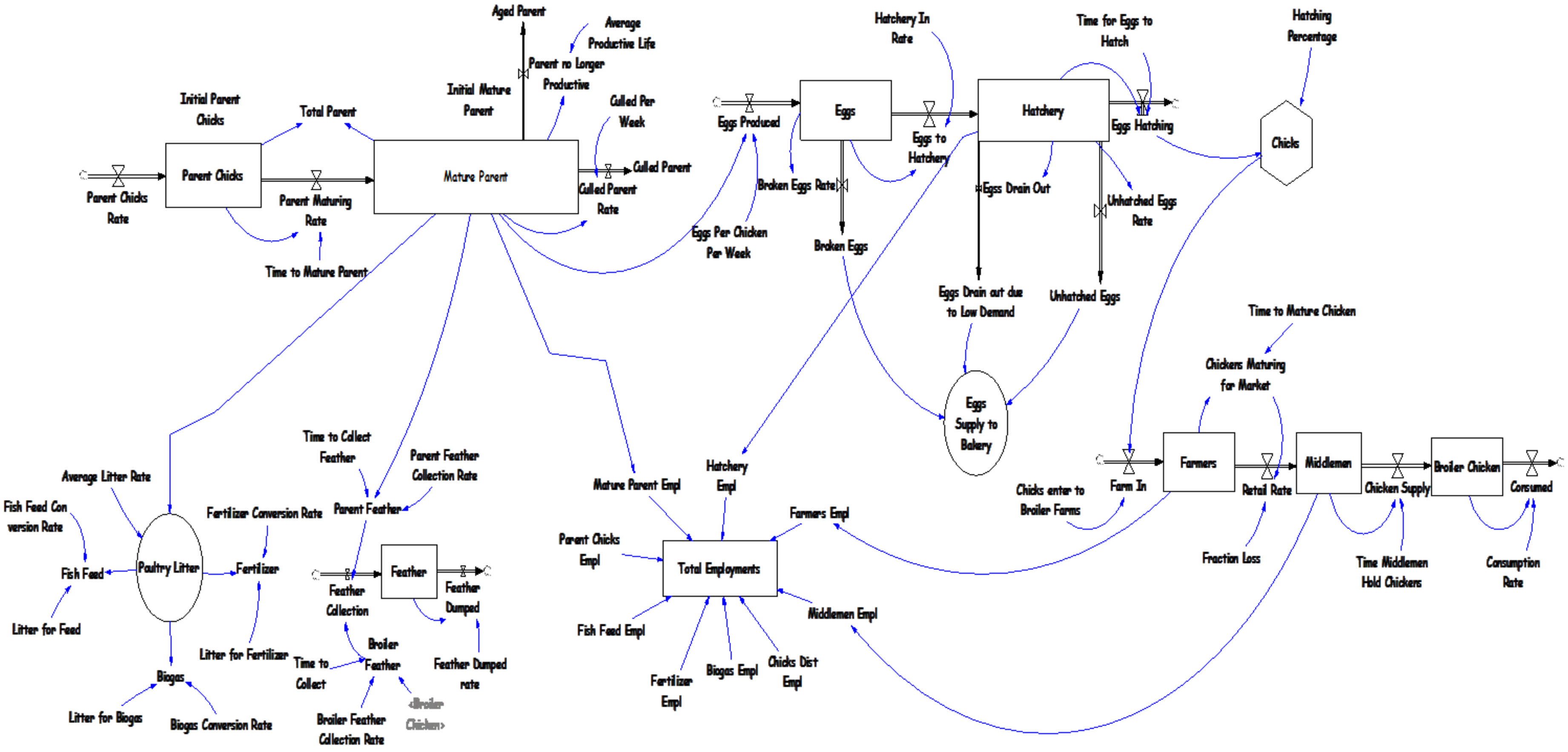

Figure 5.7: Simplified Stock and Flow Model for Integrated Poultry Supply Chain

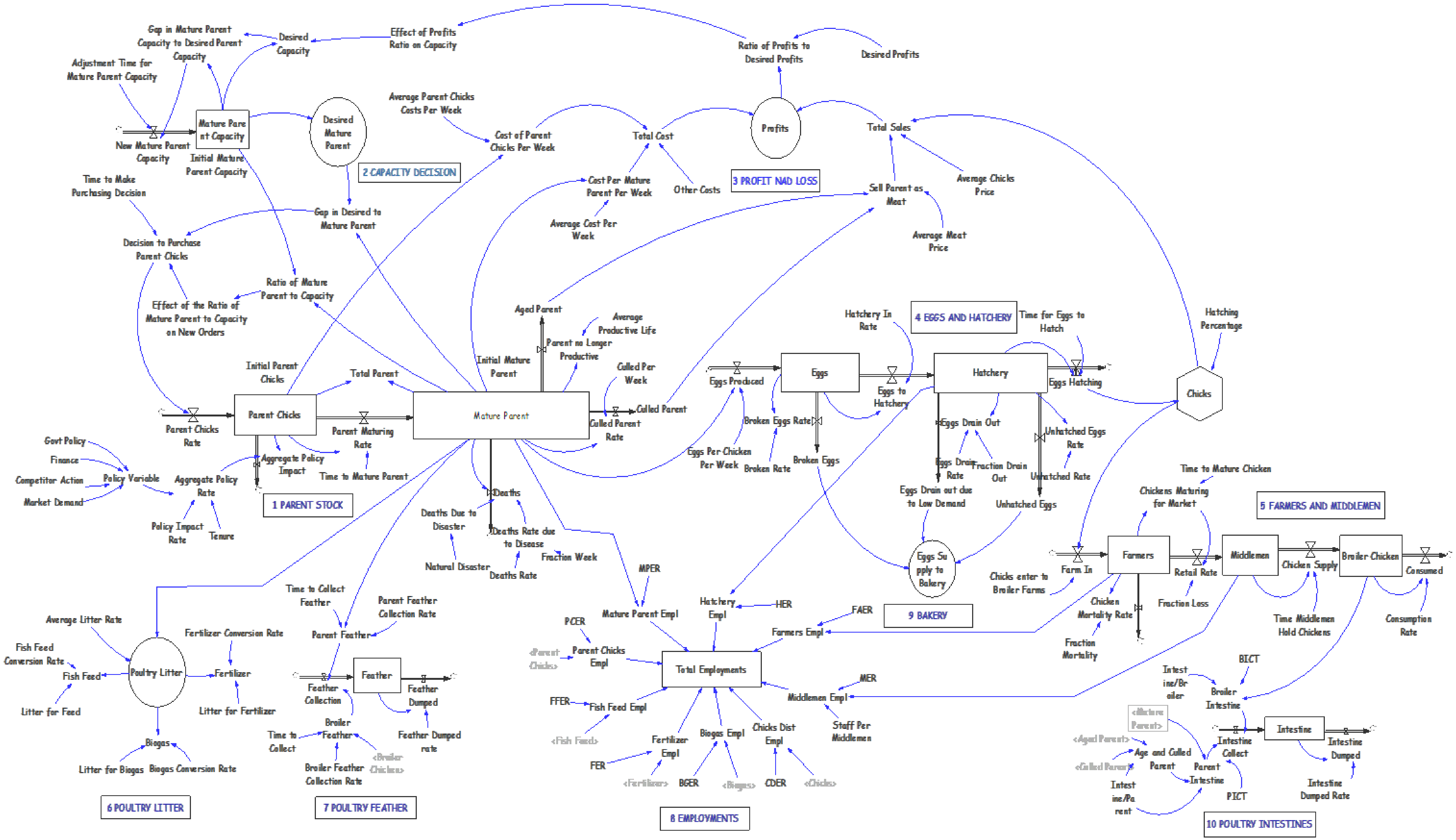

Figure 5.8: Complete Stock and Flow Model for Integrated Poultry Supply Chain

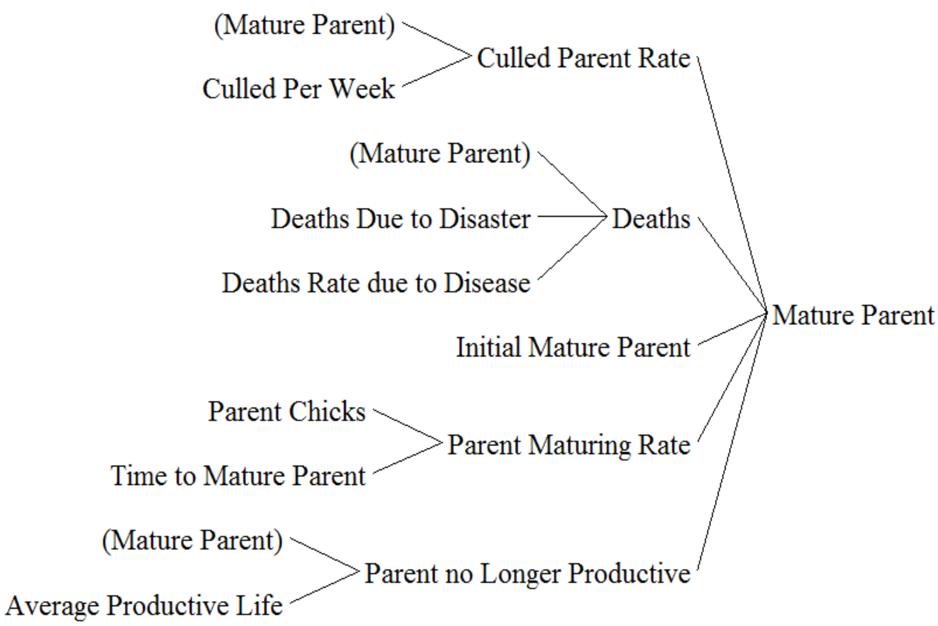

Figure 5.9: Causes Tree for Mature Parent

For instance, 'culled parent rate', 'deaths' and 'parent no longer productive' have negative impacts over 'mature parent'. All three variables will force a decrease in mature parent at different rates based on values provided in the next order variables such as 'culled per week', 'deaths rate due to disease' and 'average productive life'. The variables, inside the brackets, help the immediate variable to decrease its value depending on the particular rate values that are provided by the constant or auxiliary variable. Alternatively, a variable such as 'parent chicks' can be either positive or negative based on the rate provided through the next order variable of 'time to mature parent'. The reason is that the more 'time to mature parent' means a delay in accumulating mature parents which will decrease the flow. Conversely, less 'time to mature a parent' will lead to a flow of more mature parents to provide more production in the next phase. This is how the poultry system is working to shift value from one variable to another to maintain the optimum output for each variable.

5.3.4.2 Causes Tree for Parent Chicks

As shown in Figure 5.10, 'parent chicks' consists of four different variables of 'aggregate policy impact', 'initial parent chicks', 'parent chicks rate' and 'parent maturing rate'. Therefore, 'parent chicks' is determined based on the behaviour of these four variables that are connected with co-variables of 'aggregate policy rate', 'decision to purchase parent chicks' and 'time to mature parent'. Importantly, the 'decision to purchase parent chicks' influences the 'parent chicks rate' variable to determine the ultimate stock of 'parent chicks'. At the same time, parent chicks are drained out towards mature parents once they become mature. This is how the causes tree for parent chicks is coordinated with other variables. The next phase collects eggs from the parent mother which is discussed in the section below.

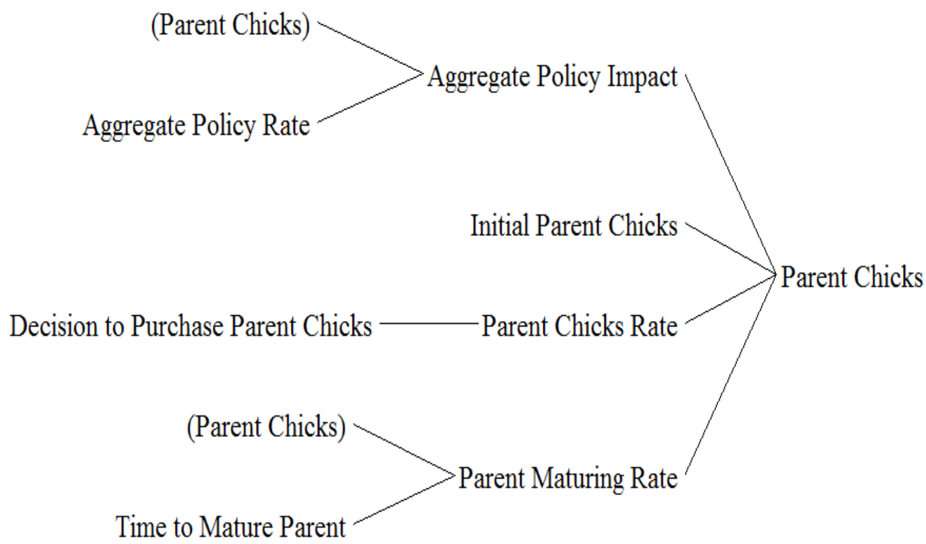

Figure 5.10: Causes Tree for Parent Chicks

5.3.4.3 Causes Tree for Eggs

As shown on Figure 5.11, 'eggs' involves the three variables of 'broken eggs rate', 'eggs produced' and 'eggs to hatchery'. The inflow of eggs comes from the number of eggs produced from the parent mothers. Later, the outflow of eggs is determined by the rate of eggs supplied to the hatchery unit and the draining out of broken eggs. Furthermore, second-order variables are connected with a few other variables. For example, 'eggs per chicken per week' determines the ultimate numbers of eggs produced from mature parents. Similarly, the 'hatchery in' rate determines the number of eggs that flow towards the hatchery. The next section discusses the hatchery causes tree.

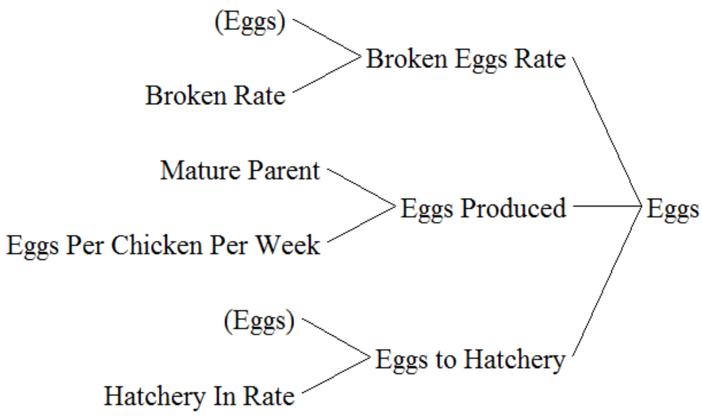

Figure 5.11: Causes Tree for Eggs

5.3.4.4 Causes Tree for Hatchery

As shown on Figure 5.12, 'hatchery' is associated with four variables of 'eggs hatching', 'eggs to hatchery', 'eggs drain out' and 'unhatched eggs rate'. The inflow of the hatchery unit is determined by the number of eggs accumulating over time from the 'eggs' variable. 'Hatchery unit' is a very important variable for the poultry supply chain. If the market is unstable and demand is low, farm management may make the decision to drain out a certain percentage of eggs to maintain the necessary chicks flow. Moreover, the hatchery unit always preserves a substantial percentage of eggs in their stock to control the demand and supply situation of the market. For instance, if demand is very high, then farmers will hatch the maximum capacity of chicks, whereas low demand will cause them to decrease the number of hatching eggs going to the hatching incubators. The following section discusses the causes tree for poultry litter.

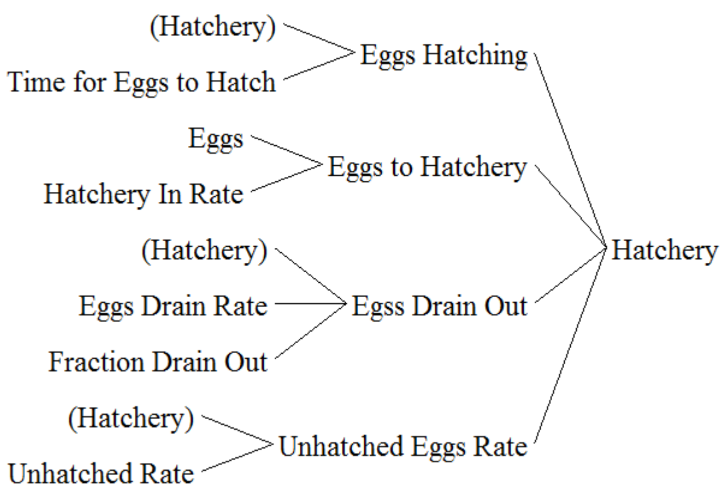

Figure 5.12: Causes Tree for Hatchery

5.3.4.5 Causes Tree for Poultry Litter

Poultry litter is one of the important concerns for the current study. Litter can flow from mature parent stock and broiler farms. However, this study is based on the parent breeder farm which has a different life cycle to the broiler farm. In addition, the broiler farm is beyond the scope of the research case. For this study, the model has only considered the parent stock farm with regard to collecting poultry litter. As shown on Figure 5.13, 'poultry litter' includes the two variables of 'mature parent' and 'average litter rate'. The accumulation of poultry litter depends on the litter collection rate over the number of mature parents. Collected litter is then distributed to small and medium industries (SMEs) to make by-products. The next section discusses the causes tree for total employment which is very significant to analysis for this research.

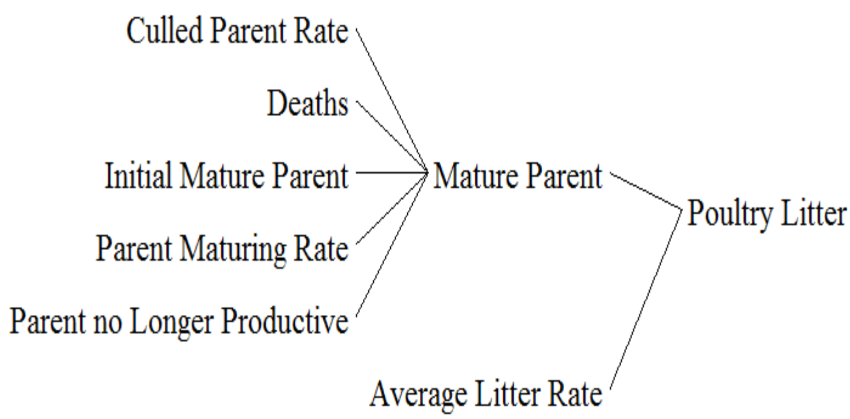

Figure 5.13: Causes Tree for Poultry Litter

5.3.4.6 Causes Tree for Total Employment

As shown in Figure 5.14, 'total employment' consists of nine variables within the employment opportunities of 'mature parent' and 'average litter rate'. The accumulation of total employment depends on various operations in a poultry supply chain. Nine different variables lead to creation of employment in the poultry operation in Bangladesh. Most employment comes from the levels of parent chicks, mature parent and farmers. It is important to realize the opportunity of creating more employment through reusing poultry wastes. The knowledge relating to cause and effects for a specific variable with its associated variables is revealed in the above discussion. The next section discusses the length of the loops which is essential for recognizing how to track associates' loops in a comprehensive qualitative SD model.

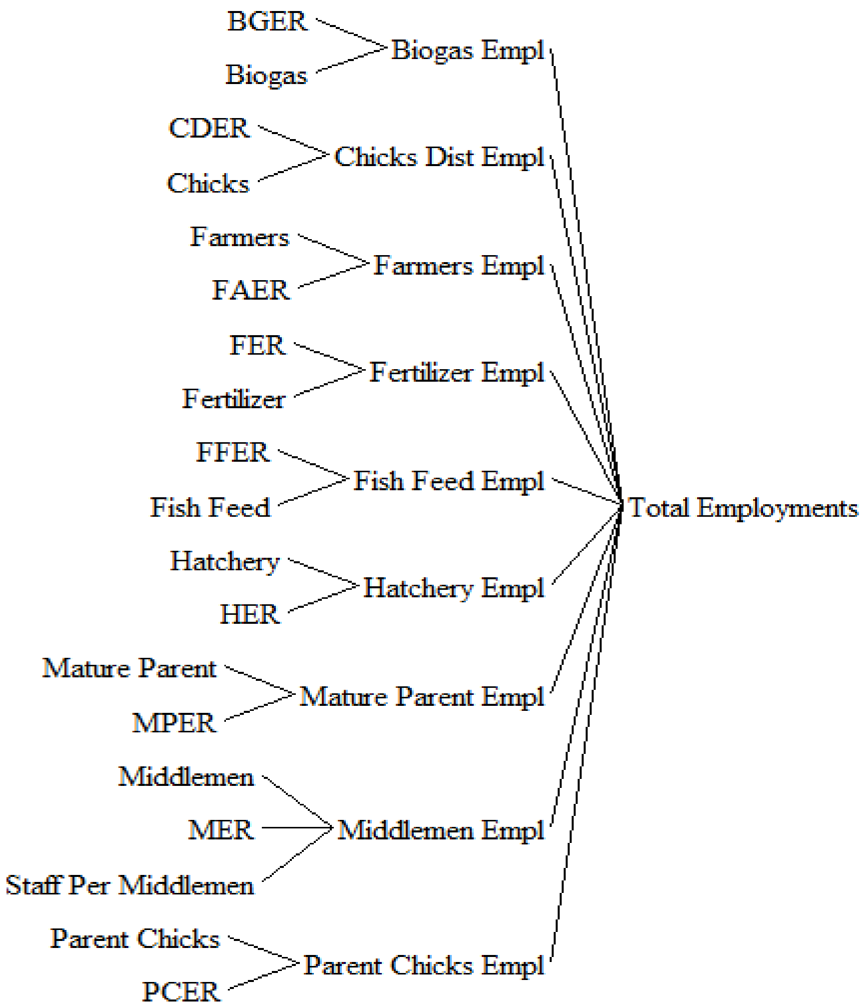

Figure 5.14: Causes Tree for Total Employment

The above discussion is presented causes tree for the important level variables of the simulation model. Mature parent, parent chicks, eggs, hatchery, poultry litter and total employment variables were discussed in the preceding sections. Causes tree is easy to identify the connected variables with positive and negative relationship. In fact, causes-tree can help to track a loop with related variables. It is also easy to understand that how a level value determines through involving several variables. For example, figure 5.12 is shown the causes tree for hatchery (level) variable where four distinct variables (eggs hatching, eggs to hatchery, eggs drain out, and unhatched egg rate) are involved to determine the ultimate value. Again, these four different variables are linked with other variables to determine their individual values. For instance, 'eggs to hatchery' is regulated by the number of eggs flow with a 'hatchery in rate'. This is how; modeller can find this tool useful to track a loop and its associate second and third order variables.

5.3.5 Length of Loops

Fundamentally, the length of loop means the loops under a major loop. Length of loop denotes the number of variables associated with a particular loop before it returns to the first variable. One variable can be used as part of a different loop. In theory, the causal loop diagram defines an impression of system behaviour along with connected variables (Sterman 1989; Wolstenholme 1990, 1999; Richardson and Pugh III 1981). A number of loops exist in the current causal model. Specifically, major loops are linked with the key variables of 'parent chicks', 'mature parent', 'eggs', 'hatchery' and 'chicks'. In fact, 'mature parent' is the most considerable variable in this causal model. The logic behind giving more consideration to this variable is its impact over connected variables. By way of illustration, if 'mature parent' declines, all other output will be decreased with chicks, eggs and waste production hampered due to the reduction of mature parents in the poultry system.

Furthermore, if 'mature parent' declines, this will have negative impacts on employment generation, by-product procurement and many other aspects. Conversely, if 'mature parent' increases, all the output will be increased or have a chance to increase to achieve more profit with optimality. Table 5.4 presents the number of loops and their length associated with the key variable of 'mature parent'. The length of loops signifies the number of variables linked with one variable which comes back to the same variable. At this point, 'loop 10 length 17' means that the mature parent loop consists of 13 different loops and it is discussing the 10th loop that has 17 different variables associated with it. Loop number 10 contains 17 different linked variables, starting from the 'mature parent' variable followed by another 16 variables which travel back to the same variable to make a loop. Value changes for one particular variable will definitely affect the following variables and the whole loop either positively or negatively. In addition, a variable can be part of various loops. In this situation, a value change for a participating variable from a different loop can also affect other loops if it is part of other loops. This means that the loop will be affected if any changes are made in a connecting variable within the same loop. Thus, the instrument for checking the loop cycle is a useful component within the research tool. Using this option, one can easily trace the sources of positive and negative influence over a variable.

Table 5.4: Loops Associated with Key Variable of 'Mature Parent'

Mature Parent Loops
Loop Number 1 of length 1
Mature Parent Parent no Longer Productive
Loop Number 2 of length 1
Mature Parent Culled Parent Rate
Loop Number 3 of length 1
Mature Parent Deaths
Loop Number 4 of length 5
Mature Parent Gap in Desired to Mature Parent Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate
Loop Number 5 of length 6
Mature Parent Ratio of Mature Parent to Capacity Effect of the Ratio of Mature Parent to Capacity on New Orders Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate
Loop Number 6 of length 15
Mature Parent Cost Per Mature Parent Per Week Total Cost Profits Ratio of Profits to Desired Profits Effect of Profits Ratio on Capacity Desired Capacity Gap in Mature Parent Capacity to Desired Parent Capacity New Mature Parent Capacity Mature Parent Capacity Desired Mature Parent Gap in Desired to Mature Parent Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate
Mature Parent Capacity Ratio of Mature Parent to Capacity Effect of the Ratio of Mature Parent to Capacity on New Orders Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate
Loop Number 10 of length 17
Mature Parent Culled Parent Rate Culled Parent Sell Parent as Meat Total Sales Profits Ratio of Profits to Desired Profits Effect of Profits Ratio on Capacity Desired Capacity Gap in Mature Parent Capacity to Desired Parent Capacity New Mature Parent Capacity Mature Parent Capacity Ratio of Mature Parent to Capacity Effect of the Ratio of Mature Parent to Capacity on New Orders Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate
Loop Number 11 of length 17
Mature Parent Culled Parent Rate Culled Parent Sell Parent as Meat Total Sales Profits Ratio of Profits to Desired Profits Effect of Profits Ratio on Capacity Desired Capacity Gap in Mature Parent Capacity to Desired Parent Capacity New Mature Parent Capacity Mature Parent Capacity Desired Mature Parent

Loop Number 7 of length 15

Mature Parent
Cost Per Mature Parent Per Week
Total Cost
Profits
Ratio of Profits to Desired Profits
Effect of Profits Ratio on Capacity
Desired Capacity
Gap in Mature Parent Capacity to Desired Parent Capacity
New Mature Parent Capacity
Mature Parent Capacity
Ratio of Mature Parent to Capacity
Effect of the Ratio of Mature Parent to Capacity on New Orders
Decision to Purchase Parent Chicks
Parent Chicks Rate
Parent Chicks
Parent Maturing Rate

Loop Number 8 of length 17

Mature Parent
Parent no Longer Productive
Aged Parent
Sell Parent as Meat
Total Sales
Profits
Ratio of Profits to Desired Profits
Effect of Profits Ratio on Capacity
Desired Capacity
Gap in Mature Parent Capacity to Desired Parent Capacity
New Mature Parent Capacity
Mature Parent Capacity
Desired Mature Parent
Gap in Desired to Mature Parent
Decision to Purchase Parent Chicks
Parent Chicks Rate
Parent Chicks
Parent Maturing Rate

Loop Number 9 of length 17

Gap in Desired to Mature Parent
Decision to Purchase Parent Chicks
Parent Chicks Rate
Parent Chicks
Parent Maturing Rate

Loop Number 12 of length 20

Mature Parent
Eggs Produced
Eggs
Eggs to Hatchery
Hatchery
Eggs Hatching
Chicks
Total Sales
Profits
Ratio of Profits to Desired Profits
Effect of Profits Ratio on Capacity
Desired Capacity
Gap in Mature Parent Capacity to Desired Parent Capacity
New Mature Parent Capacity
Mature Parent Capacity
Ratio of Mature Parent to Capacity
Effect of the Ratio of Mature Parent to Capacity on New Orders
Decision to Purchase Parent Chicks
Parent Chicks Rate
Parent Chicks
Parent Maturing Rate

Loop Number 13 of length 20

Mature Parent
Eggs Produced
Eggs
Eggs to Hatchery
Hatchery
Eggs Hatching
Chicks
Total Sales
Profits
Ratio of Profits to Desired Profits
Effect of Profits Ratio on Capacity
Desired Capacity
Gap in Mature Parent Capacity to Desired Parent Capacity
New Mature Parent Capacity
Mature Parent Capacity

Mature Parent Parent no Longer Productive Aged Parent Sell Parent as Meat Total Sales Profits Ratio of Profits to Desired Profits Effect of Profits Ratio on Capacity Desired Capacity Gap in Mature Parent Capacity to Desired Parent Capacity New Mature Parent Capacity	Desired Mature Parent Gap in Desired to Mature Parent Decision to Purchase Parent Chicks Parent Chicks Rate Parent Chicks Parent Maturing Rate

The above information on various loops is only related to the 'mature parent' stock variable within the model. These causes can be traced from the model (see figure 5.8) by using the research tools. The linked variables are listed in Table 5.4 along with their loop number and length. Altogether, 13 individual loops are associated with the 'mature parent' variable, which contains various lengths of loops. Length of loops starts from minimum 2 to maximum 20 variables. This list helps decision-makers and policy makers to estimate the overall changes based upon the deviation of a key variable. It is very important to communicate the loop's length which assures the scope of the loop. One particular loop may contain positive and negative relationships between different variables. If so, it would be difficult to presume the ultimate behaviour of the system until it was, or unless it was not, modelled with the stock (level) and flow (rate). A stock and flow model can be produced showing the real behaviour of the system and the behaviour of its individual variables over time. The current research is focused on an integrated supply chain process which is discussed in the following section.

5.3.6 Integrated Stock and Flow Model for Poultry Supply Chain

An integrated poultry supply chain model was developed based on the causal loop diagram depicted in Figure 5.5. All the necessary stock and flow variables were connected with each other just as they are in real-life practices. The complete view of the integrated poultry supply chain model is shown on Figure 5.7 on which necessary variables have been connected with appropriate information, rates and formulae. Altogether, 143 variables, including 22 auxiliary and constant variables and nine level variables, were used in this model. After identifying the key variables, this study detected the relevant auxiliary, rate and constant variables for the sake of replicating the poultry supply chain operation. In doing so, a number of variables were found to be associates with a key variable. The researcher split the whole model into 10 different areas and also identified key variables for each area, as shown in Table 5.5.

Table 5.5: Identifying Key Areas and Variables for Quantitative Model

SL	Main Areas	Key Variables
1	Parent Stock	Parent Chicks Rate, Parent Maturing Rate, Deaths, Aggregate Policy Impact, Culled Parent, Aged Parent, Policy Variable
2	Capacity Decision	Mature Parent Capacity, Desired Mature Parent, Ratio of Mature Parent to Capacity, New Mature Parent Capacity, Initial Gap in Mature Parent Capacity to Desired Parent Capacity, Adjustment Time for Mature Parent Capacity, Time to Make Purchasing Decision, Decision to Purchase Parent Chicks, Effect of the Ratio of Mature Parent to Capacity on New Orders
3	Profit and Loss	Cost Per Mature Parent Per Week, Effect of Profits Ratio on Capacity, Ratio of Profits to Desired Profits, Desired Profits, Profits, Total Cost, Other Costs, Total Sales, Average Chicks Price, Sell Parent as Meat, Average Meat Price
4	Eggs and Hatchery	Eggs Produced, Eggs Per Chicken Per Week, Broken Eggs, Eggs, Eggs to Hatchery, Hatchery, Eggs Hatching, Chicks, Unhatched Eggs, Time for Eggs to Hatch, Hatching Percentage
5	Farmers and Middlemen	Farm In, Chicken Mortality Rate, Time to Mature Chicken, Chickens Maturing for Market, Retail Rate, Middlemen, Farmers, Broiler Chicken, Chicken Supply, Consumed, Time Middlemen Hold Chickens
6	Poultry Litter	Biogas, Biogas Conversion Rate, Fish Feed Conversion Rate, Fertilizer Conversion Rate, Poultry Litter, Fish Feed, Average Litter Rate, Fertilizer Conversion Rate
7	Poultry Feathers	Feathers, Feathers Dumped, Feather Collection, Broiler Feather Collection Rate, Broiler Feathers, Parent Feathers, Parent Feather Collection Rate, Time to Collect Feathers
8	Employment	Total Employment, Mature Parent Empl, Hatchery Empl, Farmers Empl, Middlemen Empl, Chicks Dist. Empl, Biogas Empl, Fertilizer Empl, Fish Feed Empl, Parent Chicks Empl
9	Bakery Items	Eggs Supply to Bakery, Broken Eggs, Unhatched Eggs, Unhatched Rate, Eggs Drain out due to Low Demand, Eggs Drain Rate, Broken Rate
10	Poultry Intestines	Intestines, Intestines Dumped, Intestines Collect, "Intestines/Broiler", "Intestines/Parent"

The above-mentioned areas play important roles in operating a sustainable poultry industry if they interact between variables. For example, reversing poultry wastes needs to be organized to handle the different kinds of wastes for diverse usage. Poultry litter can be used for making by-products such as fertilizers, fish feed, biogas, artificial charcoal and also is used for land filling and fertilizing uncultivable lands. Therefore, different by-products have distinctive processing which should have coordination between the related variables. Furthermore, the producer needs to think about the capacity and volume of poultry wastes that they can collect at best from their operation. To establish a large or small by-product processing unit, it is expected that the producer might consider either profitability or protecting from environmental damage. Profitability is the main motive for running any kind of business (Teece 2010; Lo 2010; Narver and Slater 1990) with a business always striving to do more and more for its individual industry. Therefore, profitability or economic issues must be considered when processing further by-products. However, at the same time, a hygienic environment is one of the prime concerns with regard to the poultry business: this may require farmers to process their poultry wastes to achieve environmental sustainability rather than to obtain profits. Parent stock component from the model is discussed in the following section (see figure 5.8).

5.3.6.1 Parent Stock

The topmost poultry breed is called pedigree stock or 'pure line' which is kept on high-level biosecure farms in a few countries. The eggs collected from 'pure line' birds are hatched in a special hatchery, and their immediate breeds are named as great grandparent (GGP) and grandparent (GP) generations. Eggs collected from GPs are then hatched to get a new breed of parent stock (PS) (AAFC 2012). Fascinatingly, 45,000,000 thousand commercial broiler genetics form a pure line or pedigree mother (Williams 1999). Therefore, poultry genetics is very costly and needs to organize proper planning to manage these flocks. The current case industry maintains parent stock chicks, grows them to collect eggs, and then sends the eggs to the hatchery to hatch broiler chicks. Therefore, the quantity of parent stock that the farm needs to rear is a vital decision to maintain optimum production. The case industry must consider market fluctuation, season, supply–demand and other calamities to manage their parent stock flock.

Table 5.6 presents the 'parent stock' variable and the purposes of its co-variables and their equations to construct and drive the model. It is strategic to determine the rate of parent chicks entering the system to maintain optimum production. The difficult question is: what is the 'parent stock' requirement for different seasons in a year? The respondents of this study confirmed the seasonal adjustment of poultry parent stock due to seasonal variation of market demand for the sale of chicks. Ultimately, the production of chicks depends on the quantity of parent chicks reared by the farm. At the same time, the farm policy maker needs to consider the impacts of different policies on parent stock farming. Policies can be associated with finance, government assistance for farming, market demand and competitors' actions which are very important factors needing to be considered to maintain sustainable farming. Decisions relating to parent stock capacity are discussed in the next section.

Table 5.6: Purposes and Equations for Determining Parent Stock

	Co-Variables	Purpose	Equation
Parent Stock	Parent Chicks Rate	At what rate do parent chicks enter the system per time boundary with delays? The rate depends on the 'decision to purchase parent chicks' variable.	= (Effect of the Ratio of Mature Parent to Capacity on New Orders * Gap in Desired to Mature Parent)/Time to Make Purchasing Decision
	Parent Maturing Rate	At what rate are parents maturing with delays.	= Parent Chicks/Time to Mature Parent
	Deaths	How many deaths occurred due to disaster and disease?	= Deaths Rate due to Disease * Mature Parent * Deaths Due to Disaster
	Policy Variable and Aggregate Policy Impact	How do policy variables change the system's behaviour?	= Parent Chicks * Aggregate Policy Rate, where, Aggregate Policy Rate = (Policy Variable * Policy Impact Rate/Tenure) * PULSE TRAIN(34 , Tenure, 68, 1000)
	Aged Parent	What is the maximum age of a parent to remain productive? The maximum tenure of remaining productive is 42 weeks.	= Mature Parent/Average Productive Life
	Culled Parent	What percentage is to be culled during parent growing stage?	= Mature Parent * Culled Per Week

5.3.6.2 Parent Capacity (Capacity Decision)

Table 5.7 represents the 'parent capacity' variable and the purposes of its co-variables and their equations in constructing and determining the optimum parent capacity. It is also predetermined to control the number (rate) of parent capacity through adjusting poultry shed size. It is always expensive to maintain infrastructural support for greater capacity than is required. Capacity needs to be adjusted to the supply and demand situation in the market. Two types of capacity exist in the parent breeder farms, namely, parent chicks and mature parent-rearing capacity. Obviously, mature chicks' capacity building is much more expensive than parent chicks' infrastructure. Parent chicks' brooding can be done in the open poultry house whereas the mature parents require environmentally controlled or a scientific shed to maintain biosecurity and achieve maximum production. Moreover, the ratio between an existing number of parents and capacity may influence redesigning for the ultimate parent capacity. Similarly, a positive profit ratio may also lead to considering an increase in parent capacity.

Table 5.7: Purposes and Equations for Determining Parent Capacity

	Co-Variables	**Purpose**	**Equation**
Parent Capacity	Mature Parent Capacity	How to calculate total mature parent capacity based upon new mature parent capacity and time adjustment?	= Gap in Mature Parent Capacity to Desired Parent Capacity/Adjustment Time for Mature Parent Capacity
	Initial Gap in Mature Parent Capacity to Desired Parent Capacity	How to find out the gap between desired capacity and mature parent capacity	= Desired Capacity – Mature Parent Capacity
	Decision to Purchase Parent Chicks and Time to Make Purchasing Decision	How much time is involved in making decisions on chicks purchasing and how does mature parent capacity ratio influence the decisions?	= (Effect of the Ratio of Mature Parent to Capacity on New Orders*Gap in Desired to Mature Parent)/Time to Make Purchasing Decision
	Ratio of Mature Parent to Capacity	How the ratio of mature parent and its capacity is used for determining ultimate capacity?	= Mature Parent/Mature Parent Capacity This will create a ratio which will be used in calculating mature parent capacity

In Figure 5.7, the time factor is also considered in increasing and adjusting capacity which depends on company policy and market demand. If market demand is consistently increasing, the industry makes the decision to increase capacity. In doing so, finance is one of the main issues, that is, whether or not the farm is eligible to increase its capacity. If finance is difficult to obtain from the financier, then the company is forced to be happy with its existing capacity. If the farm has managed to secure finance and other things needed to increase its capacity, the second immediately significant factor is time. Poultry parent chicks must be reared for a certain time (24 weeks at least) to produce eggs which will need another three weeks to hatch the day-old chicks. Altogether, 27 weeks are needed to achieve production after the farm has decided to increase its production. Before this process, the industry needs to request the grandparent (GP) farm to supply day-old parent chicks which are not less than four to eight weeks old. Thus, the farm needs to have good ability to forecast its upcoming demand well in advance in order to increase its production capacity. The time to make the purchasing decision about parent chicks is linked with the adjusted mature parent capacity. Therefore, the relevant lead time should be minimized to in order to achieve additional production to catch up with the market's surplus-demand situation. The next section discusses the profit and loss component of the model.

5.3.6.3 Profit and Loss

Profit and loss are important instruments for a business, helping an industry to grow and face a challenging and competitive environment. The more profit gained by a company, the more focus goes into further extension or increased production capacity. Without profit, a firm even cannot think about to run the existing business process. In the current model, the 'profit and loss' area is already identified with several associated variables as shown in Table 5.8. Day-old broiler chicks are noted as the main business for the case farm. The main revenue comes from selling day-old chicks to distributors and then to farmers. In addition, aged parent meat, culled parent meat, and unhatched and reject eggs are additional income sources of the company. The company has set its desired profit which drives innovative decisions such as farm extension, flock addition and further capacity building. The model simply calculates profits through deducting costs from the sales. To do so, total costs are calculated from cost per parent and mature chicks along with other costs. On the other hand, average chicks' price and sold meat price are accumulated as total sales. Costs are then deducted from sales to calculate profits. Next, the eggs and chicks area of the model is discussed in the following section.

Table 5.8: Purposes and Equations for Determining Profit and Loss

	Co-Variables	Purpose	Equation
Profit and Loss	Total Cost, Cost Per Mature Parent and Other Costs	How is cost of parent and chicks to be calculated?	= Cost of Parent Chicks Per Week + Cost Per Mature Parent Per Week + Other Costs, where, Cost = Mature Parent * Average Cost Per Week
	Total Sales, Average Chicks' Price, Sell Parent as Meat	How are total sales measured?	= (Chicks * Average Chicks Price) + Sell Parent as Meat
	Desired Profits, Profits and Ratio of Profits to Desired Profits	How to set desired profit ratio?	= Profits/Desired Profits, Profit is an important issue for any business. If ratio of profit and desired profit goes up, the industry should think about extending its business. It is tricky to set the desired profit of the business.

5.3.6.4 Eggs and Chicks

Eggs and chicks are the main business for this case industry. The more eggs produced at the farm level; the more chicks will be hatched. Moreover, the more chicks hatched, the more profit will be earned if the market rate is above the cost level. Table 5.9 shows the number of eggs produced based on eggs produced per parent mother per week. A percentage of eggs is rejected or broken on the way to reaching the hatchery. In the hatchery, eggs are prepared for putting in the incubator for 21 days to hatch the chicks. Within this process, the standard practice is that more than 15% of eggs are not hatched. Later, these unhatched eggs are examined for reuse for other purposes such as unbroken eggs for bakery use and broken eggs for fish feed. For the modelling purpose, the equation for calculating eggs per parent mother uses random uniform distribution as it varies from 4.1 to 4.3 per week. Obviously, the distribution value may change if most of the birds in the flock are either aged or young. Likewise, broken, reject and unhatched eggs reduce the number of eggs ready for hatching. The following section discusses the farmers and middlemen section of the model.

Table 5.9: Purposes and Equations for Determining Eggs and Chicks

	Co-Variables	Purpose	Equation
Eggs and Hatchery	Eggs Produced, Eggs Per Chicken Per Week	To measure number of eggs to be produced	= Mature Parent * Eggs Per Chicken Per Week, where eggs per chicken per week calculated through, RANDOM UNIFORM (4.1 , 4.3 , noise seed)
	Eggs	To determine eggs stock	= Broken Eggs Rate + Eggs Produced-Eggs to Hatchery-Broken Eggs Rate
	Broken Eggs	To determine the quantity of broken eggs	= Eggs * Broken eggs rate, where rate is determined, RANDOM UNIFORM (0.03, 0.04, 1212)
	Chicks	To measure hatched chicks for distributing to the ultimate farmers	= Eggs Hatching * Hatching Percentage, where hatching percentage is very important for realizing hatchery efficiency
	Hatching Percentage	To control optimum hatching percentage	This is a constant value for particular hatch but needs to maintain a standard rate between 80% to 86%

5.3.6.5 Farmers and Middlemen

The ultimate farmers are a vital part of this poultry supply chain. Farmers receive their supply of feed and chicks through the middlemen of the agents, sub-agents and dealers. Often, middlemen have a strong role in maintaining farming across Bangladesh, including remote areas. They make it easier for farmers, and breeder farm and hatchery owners. Middlemen provide an important role in disseminating information, products, medicine, feed and processed food for farmers and retail customers. In practice, middlemen are operated through a third party where investment belongs to individual agents and sub-agents. From the parent stock (PS) farm perspective, they maintain their regional offices to control agents, sub-agents, dealers and other types of distributors. Obviously, additional costs are added to the final products of meat, eggs, and chicks by adopting services of every middleman. Table 5.10 shows the relevant co-variables and their purpose and equations for determining farmers and middlemen in constructing the stock and flow model. A standard mortality rate helps farmers to maintain sustainable farming to provide quality meat and eggs. The other variables such as maturing time, consumption and mature broiler birds also play important roles in maintaining effective farming. Consumption of chicken and eggs with an expected price are the final objectives of poultry farming. The following section discusses poultry wastes and by-products as shown on the model.

Table 5.10: Purposes and Equations for Determining Farmers and Middlemen

<table>
<tr><th rowspan="6">Farmers and Middlemen</th><th>Co-Variables</th><th>Purpose</th><th>Equation</th></tr>
<tr><td>Farmers</td><td>How many chicks are reared by the ultimate farmers?</td><td>= Farm In – Chicken Mortality Rate – Retail Rate</td></tr>
<tr><td>Chicken Mortality Rate</td><td>What is the mortality rate?</td><td>= Farmers * Fraction Mortality, where Fraction Mortality = RANDOM UNIFORM (0.03, 0.05, Noise Seed)</td></tr>
<tr><td>Time to Mature Chicken</td><td>How much time involved in maturing chicks into chicken?</td><td>= 4, the model has used 4 weeks to mature a chicken from a chick. In 4 weeks, chicken can grow up to 1.5 kg.</td></tr>
<tr><td>Chickens Maturing for Market</td><td>How much delay used to mature a chicken?</td><td>= Farmers/Time to Mature Chicken</td></tr>
<tr><td>Broiler Chicken and Consumed</td><td>What is the broiler production and consumption rate?</td><td>= Chicken Supply - Consumed, where consumed = Broiler Chicken * Consumption Rate</td></tr>
</table>

5.3.6.6 Poultry Litter and By-products

Poultry litter and by-products are another essential part of the current research. Poultry litter has a robust relationship with its conversion into diverse by-products. A huge quantity of poultry litter can be reversed towards the same industry or to a third party to be processed into various by-products. Such by-products are valuable in terms of the economy, resources, the environment and society. Table 5.11 reveals all the necessary variables relating to poultry litter and its by-products. A number of by-products can be produced from poultry litter which were discussed in the literature review section (chapter 2). Table 5.11 also provides information about fish feed, fertilizers and biogas and their conversion rates from poultry litter. The next section addresses the issue of poultry feathers which are a potentially valuable waste providing the opportunity to bring additional benefits to farms and society.

Table 5.11: Purposes and Equations for Determining Poultry Litter and By-products

	Co-Variables	Purpose	Equation
Poultry Litter	Poultry Litter and Average Litter Rate	How much poultry litter generated from a parent per week?	= Mature Parent*Average Litter Rate, where Average Litter Rate is 0.00441 tonne/parent/week
	Fish Feed and Fish Feed Conversion Rate	How much fish feed produced using poultry litter per week?	= Poultry Litter * Litter for Feed * Fish Feed Conversion Rate
	Biogas and Biogas Conversion Rate	How much biogas produced using poultry litter per week?	= Poultry Litter*Litter for Biogas * Biogas Conversion Rate
	Fertilizer and Fertilizer Conversion Rate	How much fertilizer produced using poultry litter per week?	= Poultry Litter * Litter for Fertilizer * Fertilizer Conversion Rate

5.3.6.7 Poultry Feathers

Poultry feathers are used to generate artificial plastic, pillows, beds, sofas, etc. Unfortunately, the case industry is not using this waste for processing further by-products. The study learnt that a small proportion of poultry feathers is taken by third party processors who use it to make by-products. The case industry plans to reuse this valuable waste in the near future. Table 5.12 shows the important variables associated with collecting poultry feathers from the case industry. Feather collection time, total feather collection, total feather dumped rate, parent feather and broiler feather information are provided in the above table. Employment generation from different supply chain processes is discussed in the following section.

Table 5.12: Purposes and Equations for Determining Poultry Feathers

	Co-Variables	Purpose	Equation
Poultry Feathers	Feathers and Time to Collect Feathers	How much feather collected in a certain time?	= Feather Collection-Feather Dumped: collection time used was 4 and 26 for Broiler and Parent respectively
	Feather Collection	What quantities of feather remain in the stock?	= Broiler Feather + Parent Feather
	Feathers	How much feather dumped	= Feather * Feather Dumped

	Dumped	in a certain time?	Rate
	Broiler Feathers and Collection Rate	How much feather collected from a broiler bird?	= (Broiler Chicken * Broiler Feather Collection Rate)/Time to Collect
	Parent Feathers and Collection Rate	How much feather collected from a parent bird?	= (Mature Parent * Parent Feather Collection Rate)/Time to Collect Feather

5.3.6.8 Employment

Employment was one of the major concerns of this study in observing the social benefits gained from poultry rearing. Every step of a poultry supply chain generates employment opportunities. The most employment is generated from farming parent chicks, mature parents and broiler chicks. The standard employment required is around 1,000 birds per person. Millions of birds are reared in this poultry chain which is a prime source of providing employment. Table 5.13 shows the important variables associated with the total employment. It was also found from observation that the reverse supply chain of processing and reuse of poultry wastes creates significant opportunities for more employment. The purpose and equation formation of bakery items is discussed in the next section.

Table 5.13: Purposes and Equations for Determining Employment

	Co-Variables	Purpose	Equation
Total Employment	Total Employment	How much employment is created over a particular time?	= Farmers Empl + Biogas Empl + Middlemen Empl + Fertilizer Empl+ Fish Feed Empl + Hatchery Empl + Mature Parent Empl + Parent Chicks Empl+ Chicks Dist Empl
	Mature Parent Employment	How much employment can be created by rearing mature parents?	= Mature Parent * MPER, where MPER stands for Mature Parent Employment Rate
	Parent Chicks Employment	How much employment can be created by rearing parent chicks?	= Parent Chicks * PCER, where PCER stands for Parent Chicks Employment Rate
	Farmers Employment	How much employment can be created by rearing broiler chicks?	= Farmers * FER, where FER stands for Farmers Employment Rate

5.3.6.9 Bakery Items

Although bakery items are not part of the poultry industry, they make a valuable contribution in this poultry supply chain. If eggs do not pass the standard quality test to transfer to the hatchery, they are called reject eggs. If eggs have a minor scratch or crack, they are called broken eggs. These two types of eggs along with unhatched eggs are accumulated so they can be supplied to produce bakery items. Broken eggs and unhatched eggs are determined using random uniform distribution in the simulation model. In probability distribution under statistics, a random variable represents the continuous changes of values (variable's) due to chance (i.e. randomness) (Yates, Moore, and Starnes 2002). It is justified to measure such parameters through random uniform distribution as there is no fixed rate that can be applicable due to variation in the real data. In random uniform distribution, this research use lower and upper values along with noise seed to determine the ultimate rate in a simulation run. For instance, broken and unhatched eggs rates vary on efficiency of eggs handling and hatchery incubator machine respectively. In both the cases, the rates are unpredictable. To control this unpredictability in the simulation model, this research used lower and upper values (taken from case industry data) to determine random changes of values over time. All the appropriate variables and their equations are presented in Table 5.14. Sometimes, market demand for chicks is less, and hatchery management needs to make a decision to drain out a proportion of eggs for production of bakery items. This action will cause extra loss for the industry and hatchery. An unused waste in the case industry is poultry intestines which are discussed in the following section.

Table 5.14: Purposes and Equations for Determining Bakery Items

	Co-Variables	Purpose	Equation
Bakery Items	Eggs Supply to Bakery	How many eggs are supplied to bakery?	= Broken Eggs + Unhatched Eggs + Eggs Drain Out due to Low Demand
	Broken Eggs	What percentage of eggs is treated as broken based on real data?	= Eggs * Broken Rate, where broken eggs rate is RANDOM UNIFORM (0.03, 0.04, Noise Seed)
	Unhatched Eggs	What percentage of eggs is treated as unhatched based on real data?	= 0.15 or RANDOM UNIFORM (0.15, 0.16, noise seed)

	Eggs Drain Out due to Low Demand	How 'Drain Out' eggs are measured due to low demand?	= Fraction Drain Out * Eggs Drain Out Rate * Hatchery, model used zero (0) for eggs drain out but policy test may use a different value

5.3.6.10 Poultry Intestines

Poultry intestines are now used to produce fish feed although the case industry previously dumped them in the trash or on low-lying land. Other things can be done using poultry intestines which were discussed in the literature review (chapter 2). Table 5.15 presents the relevant variables and their equations to understand the quantity of intestines that is unused rather than taking the opportunity for it to be productively reused.

Table 5.15: Purposes and Equations for Determining Poultry Intestines

	Co-Variables	Purpose	Equation
Poultry Intestines	Intestines	How much intestines are in the stock?	= Intestines Collected–Intestines Dumped
	Intestines/Broiler and Intestines/Parent	At what rates are intestines collected from broilers and parents?	0.062 kg/Broiler Intestines and 0.088 kg/Parent Intestines
	Intestines Collect	How much intestines are collected from broilers and parents?	= Broiler Intestines + Parent Intestines
	Intestines Dumped	At what rate are intestines dumped?	= Intestines * Intestines Dumped Rate

5.4 SUMMARY

This chapter has described how the causal loop diagram was developed by following a system dynamics (SD) approach based on the case poultry industry. The causal loop diagram helped the reader to understand the relationship between one variable and another. The stock and flow model was later developed from the causal loop diagram. Importantly, all the necessary formulae, equations, values, information and data flows were incorporated with the relevant variables to make this model workable. Furthermore, the model was segmented into 10 different parts to assist with understanding and explanation. The next chapter will run the simulation and discuss the simulation outputs as per the research objectives and questions.

CHAPTER 6:

RESULTS OF SIMULATION

6.1 INTRODUCTION

This chapter presents the analysis for the integrated poultry supply chain simulation model using Vensim – a simulation-based software package (www.vensim.com). It was necessary to build a simulation model with appropriate equations, formulae and connectivity to replicate the real-life operation and outcome in a simulation environment. Extension of a system or process is needed to increase production, capacity, investment and profits. At this point, the big concern was whether the case industry would proceed to an extension or not? Most of the modellers wants to experiments with the extensions over their built model to see the impacts and consequences with the various outputs (Stephan et al. 2007). This research is not exception from it as it is always time-consuming and expensive to find this answer (regarding extension) from the real world. As such, experiments are risky in all aspects. After that, it would be wise to do experiments on the virtual worlds rather doing it in the practice first. This is the main reason for using simulation in a system dynamics (SD) research study in order to estimate possible changes in business trends. A positive trend will make it easier to make a decision to change or expand the business. Previous chapter (see chapter 5) has already discussed qualitative and quantitative models clearly defining how the two models were constructed along with mentioning the variables used in following system dynamics (SD) methodology. This chapter will now attempt to visualize the model behaviour though graphical presentation. In addition, comparisons between variables are also discussed to gain insight into the various facts.

The results of the model analysis through simulation provide clear answers for the research questions. The SD model was also developed based on the concept of decision support systems so that decision makers would be able to use it as a learning tool to perform their strategic policy analysis (Swaminathan, Smith, and Sadeh 1998). They may improve their decision-making processes through sensitivity analyses, virtually understanding the impacts of decisions, perceiving possible policy results, finding effective policies and possible scenario analyses (Intrapairot 2000).

This chapter is organized as follows. The first part presents results on the integrated poultry supply chain model and aggregate behaviour of variables. Forward and reverse supply chain simulation results are used to show social, economic and environmental benefits in the second and third part of this section. Reliability and validity issues are discussed to establish that the model is absolute, reliable and valid. Scenario analyses are then used with decision support system (DSS) techniques to understand how policy change affects the model output. Sensitivity analysis was then undertaken to observe the impacts on dominant variables. Sensitivity analysis helps in perceiving the validation of the model. The next section discusses the ways in which data were collected for calculating values for each auxiliary variable.

6.2 METHODS OF DATA COLLECTION FOR VARIABLES

This study deployed four different data collection methods, namely, observations, in-depth interviews, focus group discussion, and industry documents and records. Details of the data collection procedures were explained in chapter 4 under methodology: the data collection process for different levels of the supply chain was described in Tables 5.1 and 5.2. These two tables reveal the ways in which data and information were collected from different levels. This chapter provides additional information about the data collection methods used for different parts of the integrated poultry supply chain model shown in Figure 5.8 in Chapter 5.

Details of data collection in different areas of the model and their associated variables are presented in Table 6.1. Later sections explain more details about each area to understand how values were calculated. Quantifying a relationship between two variables is all about how they related with each other's (cause and effect). At the same time, the purposes for collecting information on different variables are listed in the same table. The main objectives of the information presented on Table 6.1 were to find out appropriate inflow and outflow rates to build exact real-life relationships between the variables. Appropriate data and information helped to compute and assign an accurate value for the different variables, especially for constants and auxiliary variables.

Table 6.1: Data Collection Methods and Purposes

SL	Areas	Variables	Method Used	Purpose
1	Parent Stock	Parent Capacity, Parent Chicks Order Rate, Parent Maturing Rate	In-depth Interviews, Focus Group	Information regarding parent stock, different inflow and outflow rates, influences from policy matters, various impact factors, etc.
		Deaths, Culled Parent, Aged Parent	Documents and Records	
		Aggregate Policy Impact, Effect of Policy Variable	In-depth Interviews, Focus Group	
2	Capacity Decision	Mature Parent Capacity, Desired Mature Parent, Initial Mature Parent, Time to Make Purchasing Decision	In-depth Interviews, Documents and Records	Information regarding mature parent, timing factors, seasonality and desired goal.
		Ratio of Mature Parent to Capacity, Initial Gap in Mature Parent Capacity to Desired Parent Capacity Adjustment, Time for Mature Parent Capacity,	Documents and Records, In-depth Interviews, Focus Group	Information regarding various ratios between capacity and desired capacity and timing factors to be considered.
		Decision to Purchase Parent Chicks, Ratio of Mature Parent to Capacity on New Orders	In-depth Interviews, Focus Group	Information regarding purchase decision and relationship between parent chicks' order and mature parent capacity.
3	Profit and Loss	Desired Profits, Cost Per Mature Parent, Profits Ratio on Capacity	In-depth Interviews	Information regarding profit, desired profit, and impact by profit ratio over capacity.
		Total Sales, Total Cost, Other Costs, Profits	Documents and Records	Information regarding cost, sales and profit.
		Average Meat Price, Average Chicks' Price	In-depth Interviews, Documents and Records	Market price of chicken meat and day-old chicks' price.
		Ratio of Profits to Desired Profits and Loss		Relationship between market price and profit ratio.
4	Eggs and Hatchery	Eggs Stock, Eggs Produced, Eggs Per Chicken, Broken Eggs, Eggs to Hatchery	Documents and Records, Observations	Information concerning eggs stock, inflow and outflow rate of hatchery unit, chicks' outflow to distributors. Unhatched
		Hatching Percentage, Time for Eggs to Hatch	In-depth Interviews	

		Chicks Produced, Unhatched Eggs	Documents and Records	rate and hatching percentage.
5	Farmers and Middlemen	Broiler Farm Capacity, Chicken Mortality Rate, Time to Mature Chicken, Chickens Maturing for Market, Retail Rate	Documents and Records, In-depth Interviews, Observations	Information regarding broiler farm capacity, timing to grow and sell the chicken and chicks, middlemen responsibilities and process, retailing process and rate, farming method.
		Farmers, Broiler Chicken, Middlemen, Chicken Supply, Time Middlemen Hold Chickens	In-depth Interviews, Focus Group, Observations	
6	Poultry Litter	Poultry Litter, Average Litter Rate	Documents and Records, Observations, Focus Group	Data for total poultry litter, litter production rate based on mature birds, by-product procurement process and its inflow and outflow frequency with conversion rate.
		Biogas, Fish Feed and Fertilizer Conversion Rate	Documents and Records	
7	Poultry Feathers	Feather Stock, Feathers Dumped, Feathers Collection	Documents and Records, In-depth Interviews	Information regarding feather stock and its inflow and outflow rates, collection time, usage of feathers, difference between parent and broiler feathers and their potentiality.
		Parent Feathers, Parent Feather Collection Rate, Time to Collect Feathers	In-depth Interviews	
		Broiler Feather Collection Rate, Broiler Feathers	In-depth Interviews	
8	Employment	Total Employment and Minimum Employment	In-depth Interviews	Observation on creating employment from different supply chain operation, perceived knowledge on social and economic impacts over farm employees, opportunities of more employment creation, minimum employment required.
		Mature Parent Empl, Hatchery Empl, Biogas Empl, Fertilizer Empl, Fish Feed Empl, Parent Chicks Empl	In-depth Interviews, Observations, Documents and Records	
		Farmers, Middlemen, and Chicks' Distribution Employment	Focus Group	
9	Bakery Items	Eggs Supply to Bakery, Eggs Drain Out due to Low Demand, Eggs Drain Out Rate, Broken Rate	In-depth Interviews, Observations, Documents and Records	Information regarding broken, unhatched and reject eggs rate, quantity of eggs supplied to bakery and bakery operation.

10	Poultry Intestines	Intestine Stock, Intestines Dumped and Collection Rate, Intestines Per Broiler Bird, Intestines Per Parent Bird	In-depth Interviews, Documents and Records	Information regarding intestine collection from parent and broiler birds, possible usage, inflow and outflow rates.

Table 6.1 clearly shows that different methods were applied for collecting information for variables. Stocks and various inflow and outflow rates were mostly collected from in-depth interviews and industry records. Some of the information is critical to measure, such as poultry litter, biogas, fertilizer, fish feed, etc. In this case, the researcher identified usage of such items for a particular time and then measured the quantity based on their usage as raw materials. Several tactics were employed to gather relevant information to compute the input values for the variables. A few variables (e.g. parent mortality, hatching rate, broken eggs) indicated very inconsistent data. In this circumstance, data were reprocessed using a trend graph then an average value was chosen. If the data series for a particular variable showed inconsistencies and oscillation, then a value was input as a random uniform distribution by computing minimum and maximum values using a noise seed. Such random uniform distribution influenced the connected variables randomly based upon minimum and maximum values given. On these few occasions, the model used random normal distribution where mean and standard deviations were considered on top of minimum and maximum values. In this way, each of the model values was computed so it could be deployed for an effective simulation run. In addition, some variables were set logically using a different arrangement such as an average, random uniform, random normal, etc. In these ways, all variables were finally set with individual values as in real practice. The simulation model was therefore ready to run and analyse. The following sections discuss the results for the variables associated with the forward supply chain.

6.3 RESULTS OF POULTRY FORWARD SUPPLY CHAIN

Figure 6.1 presents the stock and flow model for the poultry forward supply chain which is a part of the integrated poultry supply chain model. The figure is involved main variables for forward supply chain. This section specifically discusses the forward supply chain and its related variables. In this forward supply chain model, seven stocks (level) variables are available which comprise over 70% of the total level variables in the aggregate model. The forward chain consists of a long supply chain network which starts from ‘parent chicks’ through to final ‘broiler chicken’ consumption. Moreover, the model is run for 312 weeks (six years) including the previous two years for the sake of examining the similarity with real-life information. The next five sections present the key variables of the forward supply chain and their simulated behaviour. At the same time, comparisons between real and simulated data are presented to perceive how the simulation model works in generating behaviour as similar as possible to real behaviour for the supply chain process variables.

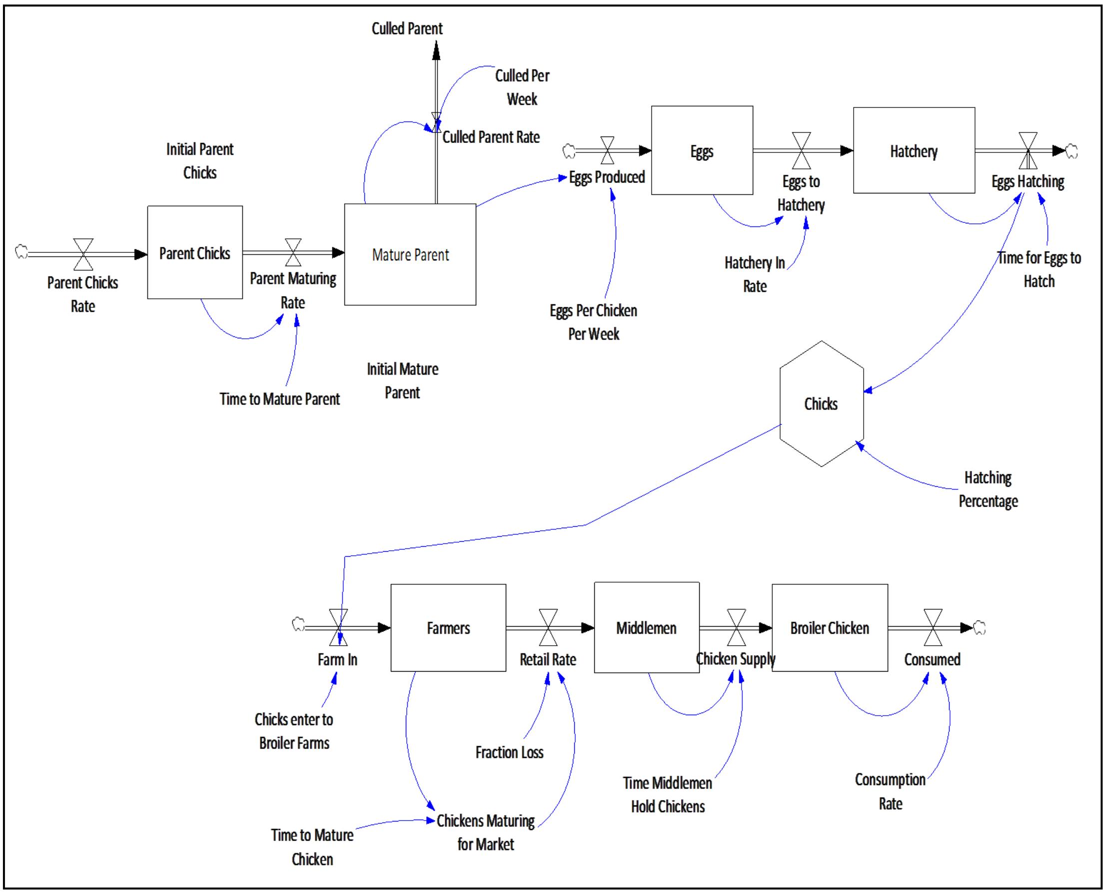

Figure 6.1: Stock and Flow Model for Poultry Forward Supply Chain

6.3.1 Parent Chicks and Mature Parent and their Rates

'Parent chicks' and 'mature parent' are the supreme variables in this research model which belong under the forward supply chain. Most of the outputs and behaviours over time depend on these two objects. The more parent chicks are given as input in the system, the more production would be expected. In Figure 6.2, 'parent chicks', 'mature parent' and their rates are considered to portray simulated behaviour for 312 weeks (six years). The numbers and colours indicate graph lines with simulated behaviour. Four different graph lines show very inconsistent behaviour rather than following sustainable growth due to seasonal variability, calamities and policy barriers. In addition, system delay was also a cause of this uneven behaviour. Notably, an uneven variable does not mean an inconsistent operation for the poultry industry as one particular parent flock stays in the farm for a maximum of 70 weeks with 40-44 weeks of active production. Therefore, 44 weeks' production is almost similar to 85% of a calendar year. If parent chicks are consistently given as input in the system, the farm will produce additional chicks which cannot be sold due to low market demand. This is why farms maintain their input based on the calculation of the parent's life cycle. Normally, the case industry receives input of parent chicks two to three times in a year so that they can maintain their desired production.

Essentially, the case industry is maintaining its desired production based on financial capability, market demand and farm capacity. Desired production fluctuates several times a year due to different causes such as seasons, natural disaster, market demand, disease, religious festivals. For instance, Bangladesh is mainly a Muslim country, with Muslims having an animal sacrificing occasion named 'Eid-ul-Azha'. This occasion usually happens once a year as per the Arabic calendar. At that time, the demand for chicken meat and eggs is drastically reduced from the normal situation. Farmers are thus forced to reduce their chicken meat and egg production to cope with the market situation.

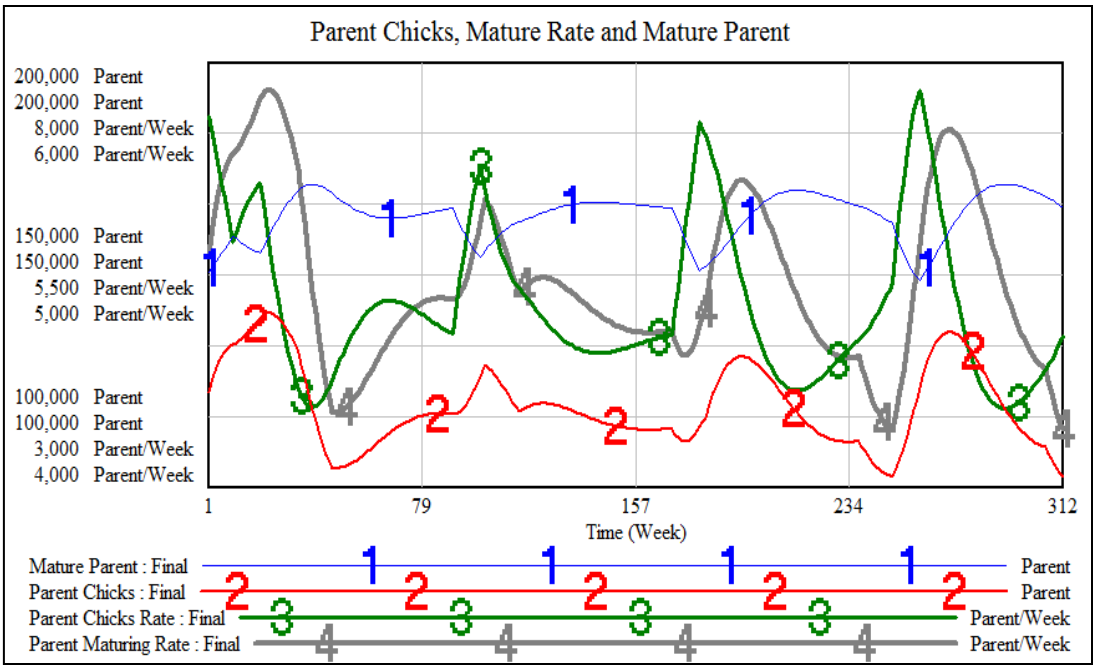

Figure 6.2: Simulated Behaviour for Parent Chicks and Mature Parent

In Figure 6.2, lines 1 and 2 represent mature parent and parent chicks while lines 3 and 4represent the parent chicks' rate and mature parent rate. There are some points in the graph where lines have gone sharply upward or downward which indicates a sudden rise or fall in demand and production. Maintaining the expected demand is a complex decision as parent chicks grow up in a flock and take 24 weeks to become mature. The mature parent will be sustained for another 42 weeks producing eggs at different rates based on their age. The mature parent provides maximum production between 30-50 weeks of age. It is also visible from figure 6.2 that mature parent graph line (1) is relatively consistent than other graph lines. Again, parent chicks rate (3) and parent maturing rates (4) are showing inconsistent behaviour due to repetitive adjustment with the market situation. The most important is to maintain a consistent graph line for the mature parents than other graphs as it determines ultimate production of day-old chicks. The reason behind of showing oscillated behaviour from parent chicks and mature parent chicks rate is continuous adjustments with the existing circumstances. On the other hand, parent chicks (2) are showing relatively less fluctuation as they exist in the system for around 20-24 weeks to grown-up. A number of parent chicks' flock with different ages can help the farmers to adjust with the necessity. Therefore, a parent breeder farm has to maintain several flocks of different ages to maintain optimum production for the whole year.

6.3.1.1 Parent Chicks: Comparison with Reality

One of the prerequisites for a system dynamics (SD) model to check reliability and validity. The literature on reliability and validity has been discussed in the methodology section (chapter 4). According to the relevant literature, comparison between simulated and real-life data should be done to realize the model structure. Simulation model results are expected to follow real-life operations and behaviour so that the model can be treated as reliable and structurally sound. Figure 6.3 depicts a comparison between the simulated and real-life data set for the 'parent chicks' variable which is an influential object of this model. The production of eggs, chicks and wastes completely relies on 'parent chicks' input. This input also varies in relation to market demand and other factors. The graph consists of two lines; line 1 represents model output while line 2 represents the real-life data set. It is noticeable that the two lines are identical and adjacent to each other yet have slight gaps. Such a close result between simulated results and real-life data provides evidence of the satisfactory structure of the current model.

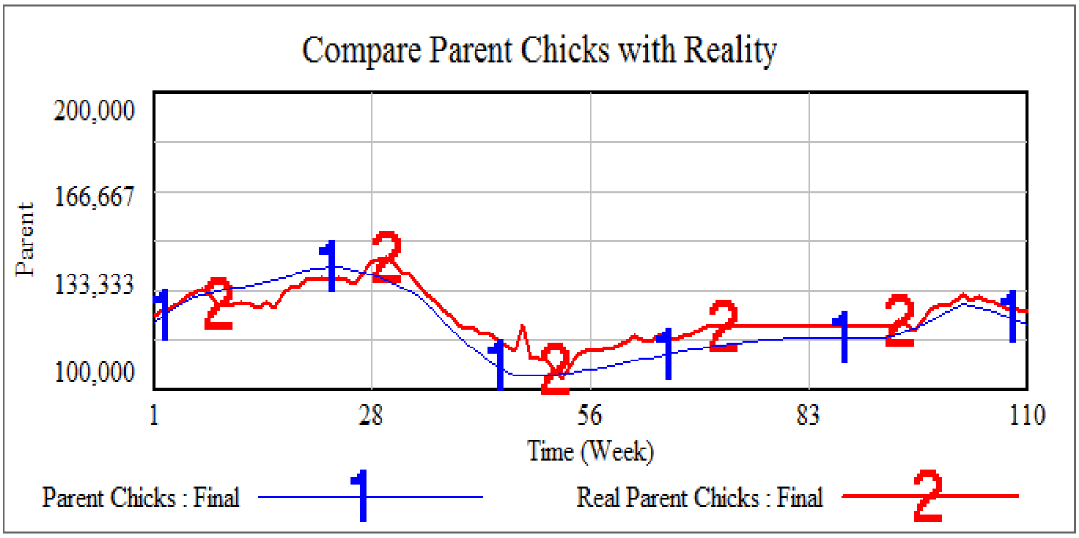

Figure 6.3: Comparison between Simulated and Real-life Parent Chicks

6.3.1.2 Mature Parent: Comparison with Reality

The topmost variable of concern in this model is 'mature parent'. The main business of the case farm is to sell day-old chicks to the ultimate broiler farms. To do so, they need to receive hatchable eggs from mature parent mothers so that eggs can be hatched to produce day-old chicks. Figure 6.4 represents a good match (between line 1 and line 2) with simulated and real data for the 'mature parent' variable. Here, line 1 represents model output while line 2 denotes real data.

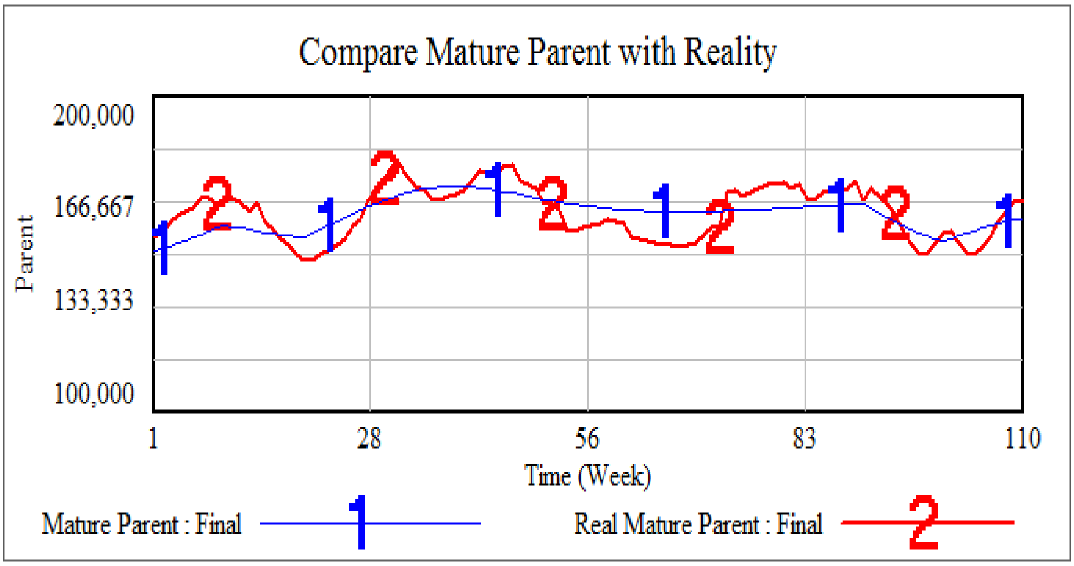

Figure 6.4: Comparison between Simulated and Real-life Mature Parent

6.3.2 Simulated Behaviour for Eggs, Hatchery Stock and Chicks

Eggs, hatchery and chick production has a strong relationship to maintaining steady production. Figure 6.5 represents simulated behaviour of these variables. Graph line 1 (chicks) shows slight variation as it sloping down then going up to hold the optimum productions. Other two graphs for eggs and hatchery output also following the same fluctuation. Although, the graph lines look like similar, they have their own measures which are displayed on the left side of the graph. For example, the maximum stock of eggs is around 600,000 to 700,000, whereas hatchery stock maintains more than one million eggs per week, and chicks' production is maintained at around 300,000 to 400,000 per week. The hatchery and egg production lines match closely with each other as the hatchery supply depends on the eggs collected. It is also clearly visible from figure 6.5 that around 400,000 chicks are finally hatched from more than a million eggs collected from the farm level. It does not mean that rest of the eggs are treated as unused rather 35-50% eggs are queued for next hatch and rest are come out as unhatched from the hatchery units. Obviously, around 4-5% are being damaged and broken on the way to reach to the hatchery incubators. Again, more eggs can hatch subject to availability of additional incubators and increasing chicks demand at the root level.

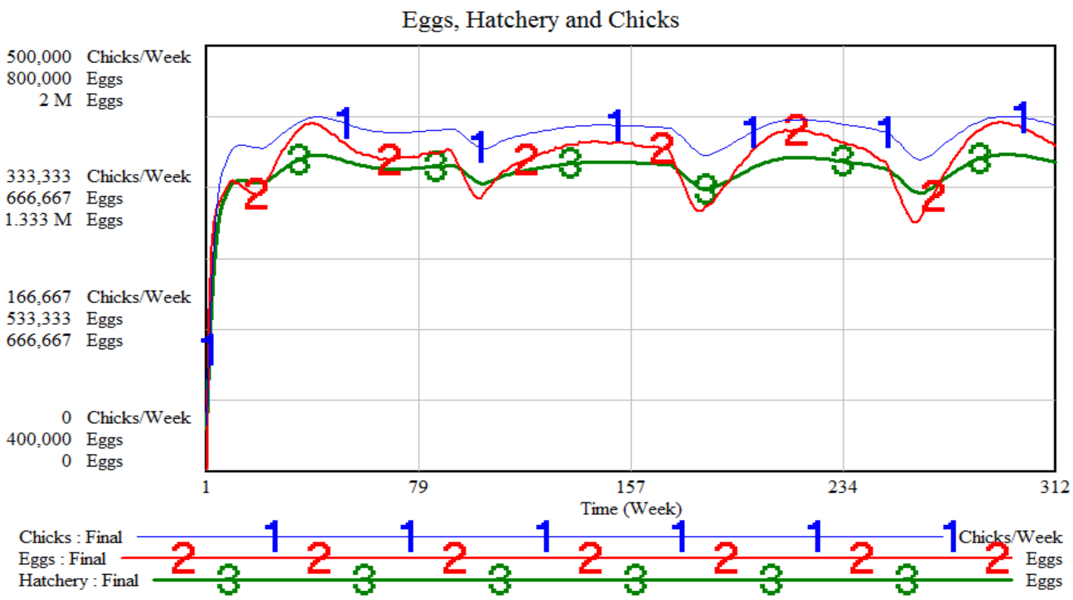

Figure 6.5: Simulated Behaviour for Eggs, Hatchery Stock and Chicks

6.3.2.1 Eggs Production: Comparison with Reality

It is important to maintain desired egg production in all circumstances. Desired egg production depends on the quantity of the mature parents reared in the parent stock farm. The main business of the case farm is to sell day-old chicks to the ultimate broiler farms. To do so, they need to receive hatchable eggs from mature parent mothers so that eggs can be hatched to produce day-old chicks Figure 6.6 portrays simulated and real data for the 'eggs' variable. It is clearly visible that the two lines are close enough to demonstrate the accuracy of the model.

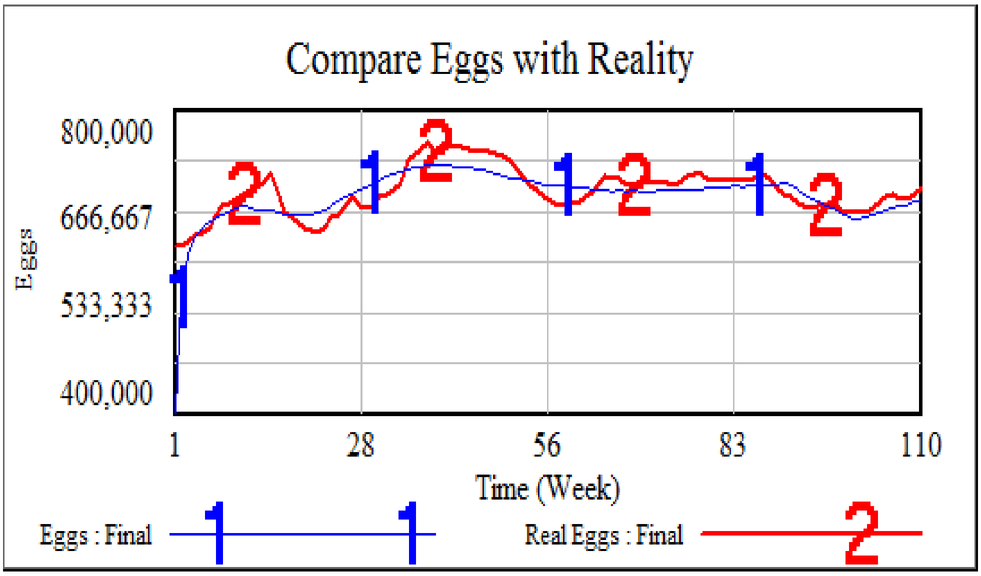

Figure 6.6: Comparison between Simulated and Real-life Egg Production

6.3.2.2 Chicks Production: Comparison with Reality

Figure 6.7 demonstrates a respectable match between simulated and real-life data for the day-old broiler 'chicks' variable. The behaviour of this part of the model is nearly consistent due to the behaviour of the number of eggs accumulated steering the following variables. Contrary, real data shows that graph line (2) reached the pick demand at the 45th to 50th week while it is going down at the 70th week. Later, it behaved nearly consistent with little vicissitudes. Chicks' selling is the main business of the case industry. Therefore, it is the main contributor for the industry in making the desired profits. Normally, the hatchery maintains two to three times the amount of egg stock in comparison with final chicks hatched. The reason behind maintaining such an amount of stock is to regulate the situation. In a normal demand situation, the industry maintains a modest production of around 300,000 to 400,000 chicks per week. However, they will decrease their hatching eggs if changes occur in the market demand situation. Furthermore, production must be hampered when natural disaster hits either these farm areas or the farm areas of the ultimate farmers who buy the chicks from parent farmers. In addition, eggs take 21 days (i.e. three weeks) to hatch. To maintain weekly production, the hatchery unit needs to set up a roster so that desired chicks can be hatched on a weekly basis.

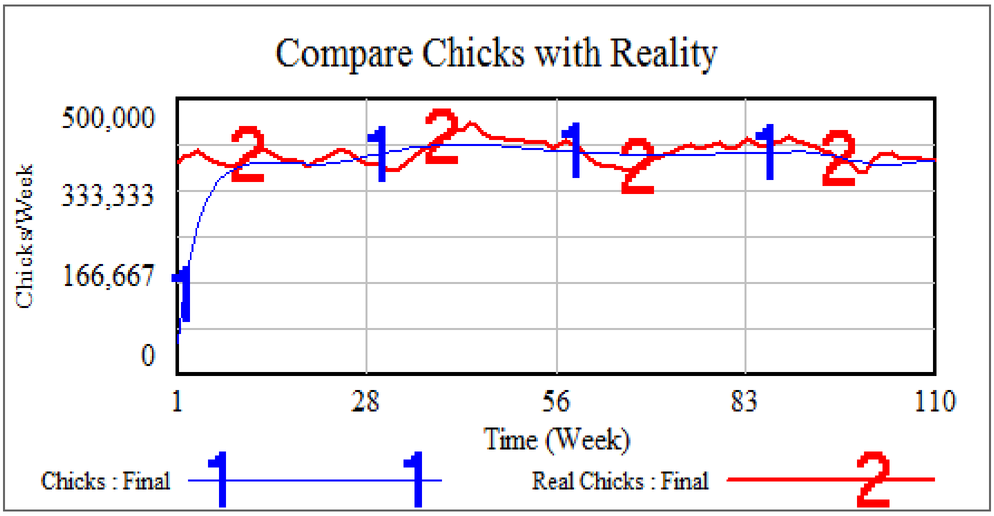

Figure 6.7: Comparison between Simulated and Real-life Chick Production

6.3.3 Chicks, Middlemen, Farmers and Broiler Chicken

Broiler chicken is the ultimate product which grown up from day-old chicks with a certain period of rearing in a standard environment. Produced chicks are delivered to the farmers via middlemen. So, 'chicks', 'middlemen', 'farmers' and 'broiler chicken' are closely related with each other. Once chicks have been graded and scientifically packaged, they start flowing towards distributors located all over the country. Distributors are located region-wide so that they can cover every part of Bangladesh. Company sales offices are established in almost all major divisions and regions. The sub-agent (i.e. commission agent) then covers sub-regional and remote areas. In this way, the company maintains a strong supply chain network to supply day-old chicks to the ultimate farmers. When chicks reach to the ultimate farms, farmers rear them for 4-5 weeks to grow to mature birds. Mature birds are then supplied to final customers through middlemen. Figure 6.8 represents the simulated behaviour of these variables. In the end, the graph lines appear identical and follow each other as the variables are related to the outflow of the preceding variable. The figure is showing the consistent match with the graph lines of chicks, middlemen, farmers and broiler chicken. However, the graph lines are matched with each other but they are producing different numbers of output based on the requirements. For example, chicks' production per week is around 400,000 while farmers have more chicken in the queue to sell it to the market. Because, all the birds are not maturing at the same time rather maintaining a standard time for gaining certain weight. All depends on market situation, whether they will sell the mature chicken at the weight of 1.2 kilogram or more than that. If they expect more weight, then they may need to wait for additional time to grow them up. The model behaviour only replicates the standard practices and found good match with a real system behaviour.

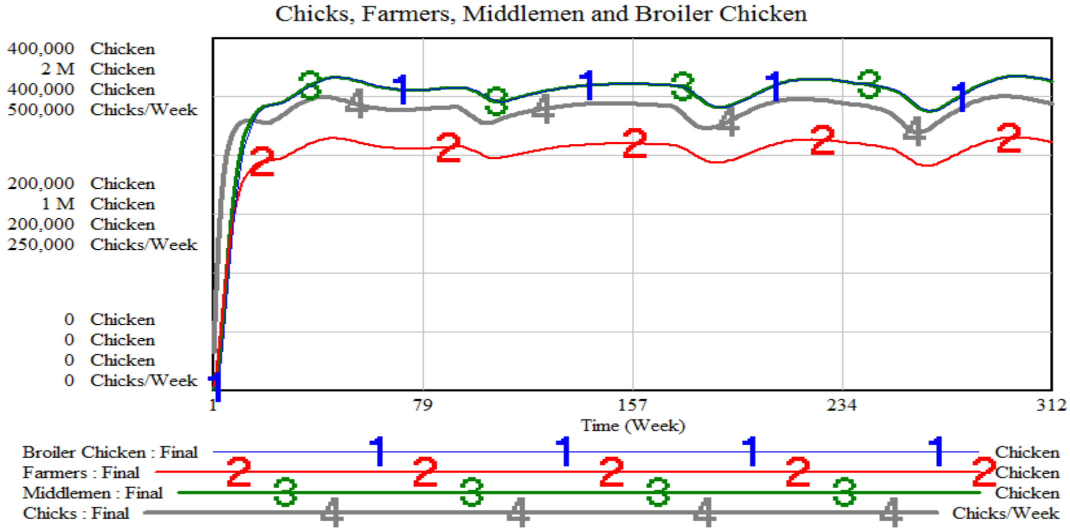

Figure 6.8: Simulated Results for Chicks, Farmers, Middlemen and Broiler Chicken

6.3.4 Mature Parent Capacity and Gap

A well-regarded company always wants to maintain optimum production with sustainable growth. They seek out new market expansion and production growth simultaneously. Supply–demand and capacity–gap are dynamic issues for the company and often change due to circumstances such as seasons, demand, disease, calamities and policy. Figure 6.9 depicts a graph which shows simulated behaviour for mature parent capacity and the desired gap condition. This graph consists of 'desired mature parent', 'decision to purchase parent chicks', 'gap in desired to mature parent', 'parent chicks' and 'ratio of mature parent capacity' variables. These are the significant variables for considering gap analysis and minimized capacity of the desired production. Graph line 1 represents the decision to purchase a new parent chick flock for the industry. Purchase decision-making time is one of the key policies for the industry which helps them to produce day-old chicks in the right time frame to meet the demand. Obviously, the number of parent chicks later determines the number of mature parents flowing through the system followed by eggs and day-old broiler chicks. It is observed that decision to purchase new chicks is varying based on demand situation exists in the market.

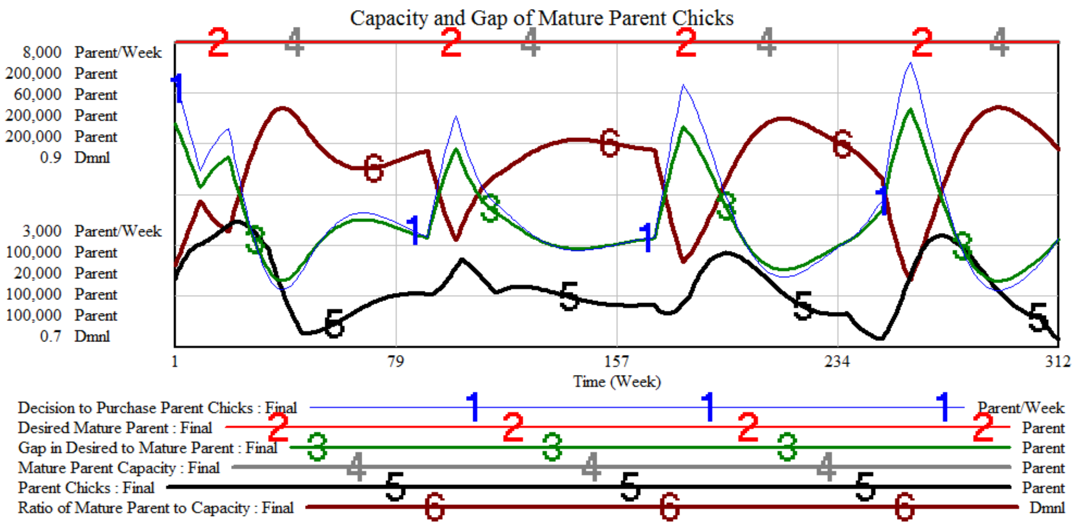

Figure 6.9: Simulated Results for Mature Parent Capacity and Gap

Graph line 2 (desired mature parent) is showing consistent straight line as it meets the target. In fact, additional mature parents forced to drain out from the system to adjust with the existing requirement. Again, graph line 3 (gap in desired to mature parent) shows inconsistent behaviour due to 'desired mature parent' requirement is not same all the time as it depends on practical circumstances. The more gap exists; the more supply need and graph line will reach high. On the other hand, graph line 4 (mature parent capacity) remain consistent on 200,000 per week. Parent chicks behaviour have been discussed in the previous section (see section 6.3.1.1). Finally; a ratio of the mature parents to its capacity shows the oscillated behaviour due to frequent changes of desired capacity and mature parent supply from parent stock farm. Therefore, above graph lines (figure 6.9) from different variables are shown the complex system behaviour of the poultry supply chain model. The value of the variables can be adjusted if it is required for the farmers by manipulating time, values, inputs and outputs.

6.3.5 Forward Supply Chain and Employment

One of the key objectives of this research is to realize the poultry supply chain's contribution to society. The forward supply chain of the poultry industry has to maintain a number of operations such as parent farming, hatchery, feed mills, distributors, broiler farm and middlemen. These operations obviously create employment opportunities at every level of the process. Figure 6.10 presents the employment creation from each of these operations. Parent farming creates the maximum number of employment as it needs two employees for every 1,000 birds while the broiler farm needs one. The case industry maintains more than 150 agents having a minimum of four to five employees for each of them. Moreover, the main positive social impacts occur in the rural areas where young unemployed people grow up seeing all the facilities in a poultry supply chain. They intend to join the chain as middlemen, sub-agents, farmers, feed sellers and by-products processors. This is how the poultry forward supply chain brings positive impact to farms, society and the economy in terms of employment. The next few sections address the variables connected with the reverse supply chain for poultry wastes.

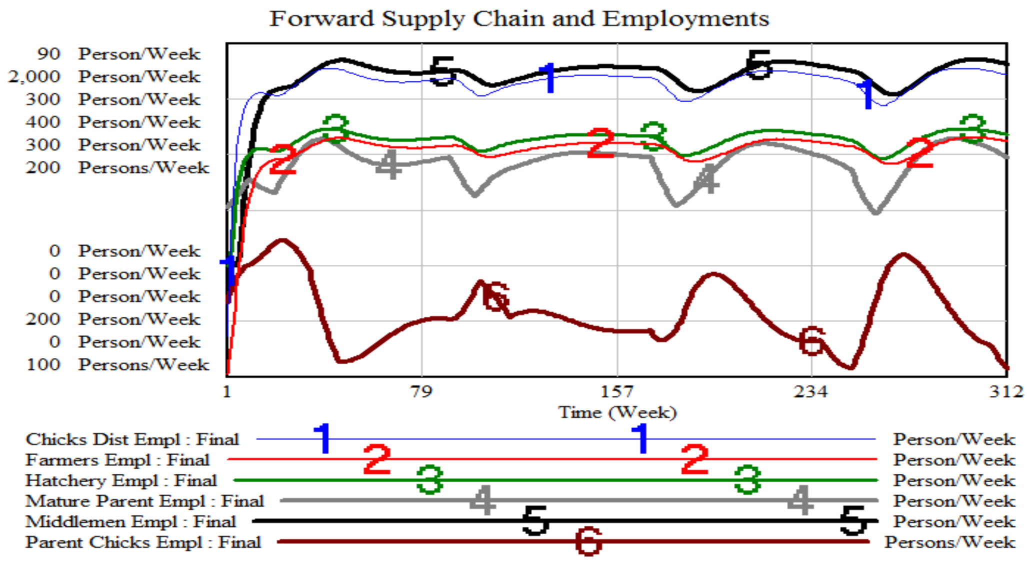

Figure 6.10: Simulated Behaviour for Forward Supply Chain and Employment

Above figure, 6.10 is represented the opportunities for creating employment through forward supply chain activities. The activities are listed as distribution, farming, hatchery unit, parent farm, various middlemen and breeder (parent) chicks farm. These are the leading areas of activities where employments can be generated based on the number of bird transacted. All the graph lines are following the behaviour of main activities. Because, the employment will be generated based on main variables behaviour. For example, 1000 birds create one employment in a farm, and then 20,000 will make 200 employments. Therefore, it depends on the original behaviour of the main variable which will ultimately guide the number of employments' opportunities in the system.

6.4 RESULTS OF POULTRY REVERSE SUPPLY CHAIN

Industry includes ‘reduce, reuse, recycle’ concepts along with its existing supply chain to manage cost and decrease inefficiencies, with this called the reverse supply chain (Partridge 2010). In the poultry industry, the concept of recycle, reduce and reuse is used for poultry wastes. Poultry litter wastes can produce biogas with other wastes producing fertilizers. In this way, the poultry supply chain can extend to a downward chain where various poultry wastes can be accumulated for reuse and recycling. The reverse supply chain has been clarified by detailed explanations in the literature review (chapter 2). Figure 6.11 is a shortened layout of an integrated poultry supply chain. Poultry waste creation, sources, processing and by-product creation are shown in the same figure. At the same time, significant numbers of employment are created through by-product processing which has also been exposed in the model.

The various poultry wastes include litter, feathers, unhatched and broken eggs, and intestines from mature parent and broiler bird rearing. Litter, feathers and intestines can be collected from mature parent and broiler farms while broken and unhatched eggs originate from the hatchery. The figure clearly demonstrates which way wastes are redirected to produce by-products using the arrowhead. Concurrently, processed by-products can be used as raw materials for small and medium industries (SMEs) which can empower and employ additional people. This part of the model is extended based on scattered practices and possibility of integrating these operations with the main supply chain. The model building process has given effort of integrating such operations into the mainstream operation to add more economic, social and environmental values. Additional sustainable benefits can be achieved through these processes. Again, the model is also considered farmers, middlemen and broiler chicks to quantify them over time to compare with the existing demand and supply situation. Moreover, poultry feather and intestine are yet to be recycling for further by-products, whether they have tremendous opportunities to utilize them as raw materials for other industries like bed and pillow and fish industry. Overall, these processes make a noteworthy contribution to Bangladesh society.

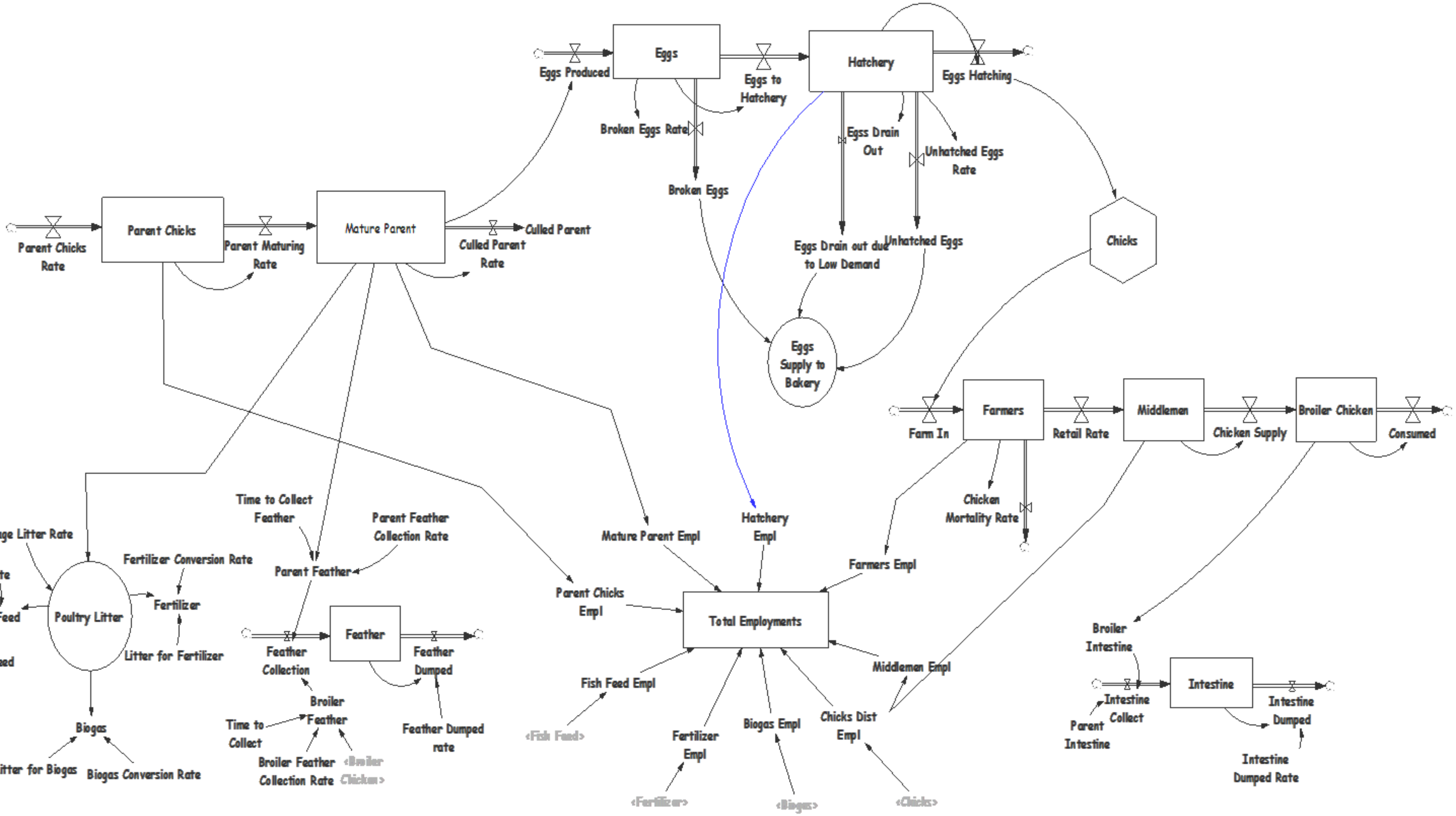

Figure 6.11: Stock and Flow Model for Poultry Reverse Supply Chain

6.4.1 Poultry Litter and By-products

Economically valuable by-products can be made from poultry litter. Figure 6.12 portrays simulated behaviour of biogas (graph line 1), fertilizer (graph line 2), fish feed (graph line 3) and poultry litter (graph line 4). As shown on the graph, quantities of poultry litter come from mature parent and broiler farms over time. All the graphs are showing nearly same behaviour having sharp increase and decrease after certain time. Less production will be creating less poultry litter which is the main cause of decreased behaviour. Alternatively, more production will create more opportunities to make additional by-products. However, the graph lines are showing same trend but they own individual values and measurement which are not similar to one another. For instance, biogas measures as the cubic metre while other by-products as tonnes. Such analysis can predict the assumption of generating poultry litter and its by-products over a time.

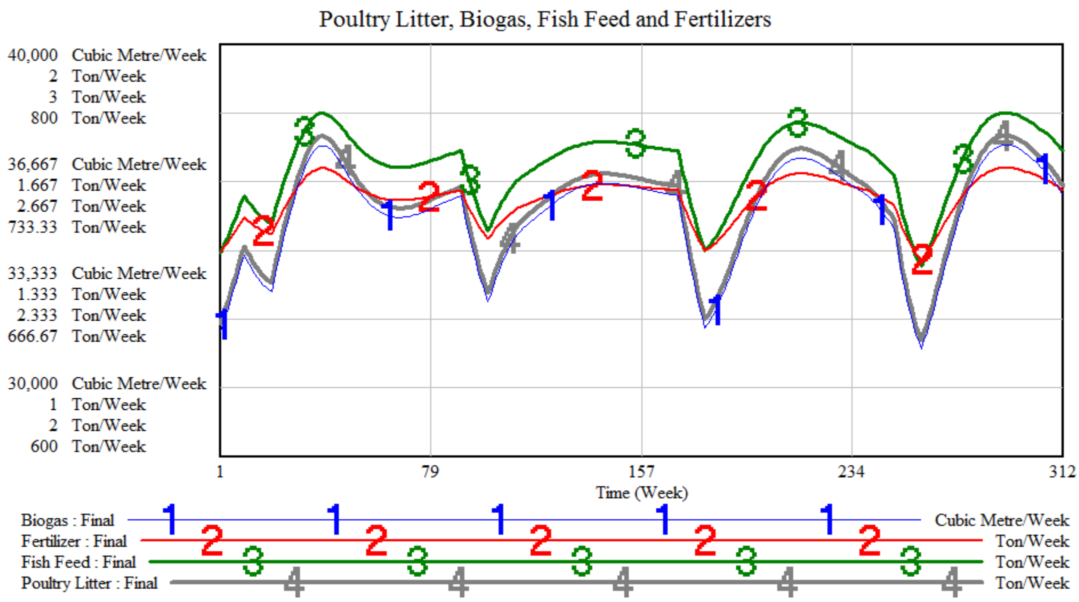

Figure 6.12: Simulated Behaviour for Litter, Biogas, Fish Feed and Fertilizers

Moreover, about 600 to 700 tonnes of litter per week are generated from both sources as depicted by line 4. The poultry litter graph line shows oscillating behaviour as accumulation of litter depends on the number of mature parent and broiler birds reared. After its accumulation, 70% of litter is prepared for biogas processing while 15% is used for both fish feed and fertilizers. It is noted that the case industry uses biogas to generate heat through the gas brooder to brood the day-old parent chicks. Plans are to convert this biogas to electricity which will help them to save a significant amount of cost. Fertilizer is used for Napier grass for the dairy project in the same company and fish feed is used for pond areas where they do commercial fish culture.

All these by-products can be commercialized if a different supply chain network is built towards another segment of customers.

6.4.2 Real and Simulated Behaviour of Poultry Litter and By-products

Figure 6.13 shows the comparison between real and model behaviour for by-products. Real data were collected for the last two year which is equivalent to 104 weeks. Three different miniature graphs are shown on the same figure comparing fertilizer, poultry litter and biogas output. For fertilizer and biogas, real data and model output are shown as a good match (line 1 and 2). In this figure, graph 1 is treated as simulated output while graph 2 is given input from reality. However, poultry litter behaviour shows more fluctuations than the real-life data. The researcher carefully investigated data and simulation output several times to ascertain the real facts. The outcome of this thorough investigation acknowledged that poultry litter collection depends on factors, including humidity, climate, season, feed and water consumption by poultry birds. Due to these factors, the quantity of litter collection fluctuates extravagantly in comparison to the standard expectation. This tool is useful to do projection of generating total quantity of poultry litter and later distribute it to the different by-product processing centre. Ultimately, the quantity of various by-products can be also assumed before they start to reprocess the wastes. If it does not find profitability, then processor can think otherwise to utilize this resource.

6.4.3 Poultry Birds and Feather Production

Figure 6.14 shows that more than 10,000 kilogram feather can be collected from matured chicken. Graph line 1 (chicken) and line 2 (broiler chicken feather) are showing same trend as feather quantity is depended on the number of chicken exists in the farm. Again, parent feather (graph line 3) is showing its production behaviour over time based on the number of mature parent (graph line 5). These graphs are maintained steady behaviour with significant variations. In addition, graph line 4 displays total number of feather collection over time which has minor variation in compare to other associated variables. In some stage, graph lines are drastically fallen due to significant decrease of a parent bird reared in the farm. In practice, total collected feather is not reusing for making further by-products rather using a small percentage to reuse it for the non-commercial reasons. However, there is an immense scope of making valued by-products which will be a valuable and additional earning source for the industry.

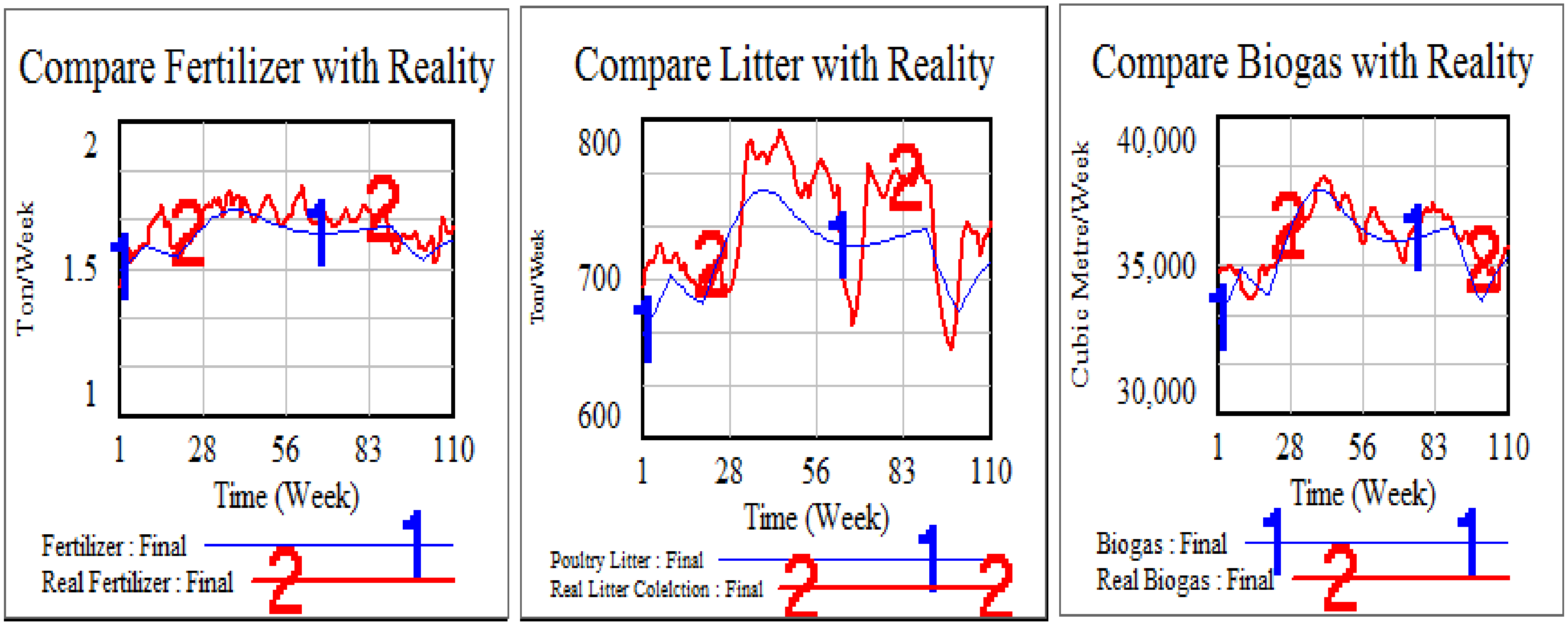

Figure 6.13: Comparison between Simulated and Real-life By-products

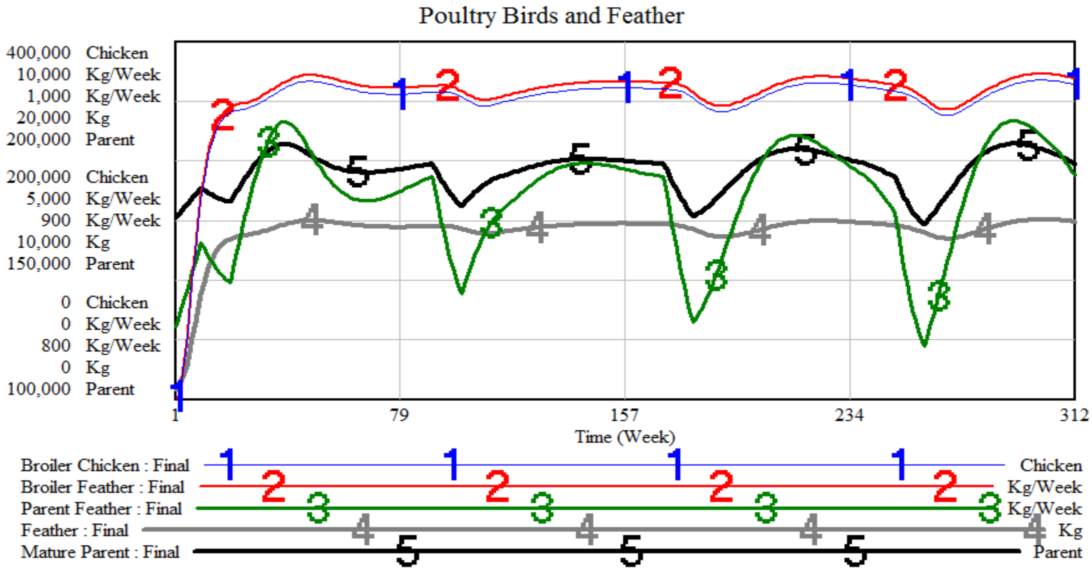

Figure 6.14: Simulated Behaviour for Poultry Birds and Feather Production

In addition, poultry feathers are a valuable resource which can be converted into products like pillows, mattresses, cushions, pads, plastic keratin, etc. Unfortunately, the case industry is still struggling to reuse this waste although they receive substantial offers from third parties seeking supplies of feathers as raw material. The collection time is different for parents and broiler birds. Feathers can be collected from broiler birds at the age of 4-5 weeks when the birds are slaughtered for final consumption. On the other hand, parent feathers can be collected at 26 weeks' age in a prescribed form. Furthermore, one parent mother can produce 0.145 kg of feathers which is collected once in a lifetime. After death or slaughter of the aged bird, the rest of the feathers can be collected. In contrast, feathers are usually collected from a broiler bird when they are slaughtered for final consumption. The life cycle of a broiler bird is between 4-6 weeks maximum. They produce approximately 0.102 kg of feather once in their lifetime. This calculation is based on real-life observation and measurements. The quantities of collected broiler and parent feathers and the behaviour of broiler and parent birds and feather stocks are shown in Figure 6.14.

6.4.4 Bakery Items, Broken and Unhatched Eggs

A large number of eggs are treated as excluded in the parent industry along with eggs that are drained out at the hatchery unit. Such excluded eggs are called reject eggs at the farm level, unhatched eggs in the hatchery unit. There is another chance of collecting more excluded eggs which are named as drain out eggs. Drain out is needed when there is low demand for broiler meat in the final market. In that situation, they hatch a minimum number of eggs and send the rest of the eggs to the other unit. Thus, all the eggs are used to supply the bakery so it can make bakery items of biscuits, cakes, and pastries. Figure 6.15 depicts the simulated behaviour for broken, unhatched eggs and bakery stock. Broken eggs (graph line 1) and un hatched eggs (graph line 3) are combined together to supply to the bakery (graph line 2). The graphs are shown their behaviour over time which seems minor variation based on different rates for eggs flowing out. The model did not drain out a significant number of eggs as there was no evidence that this had been done in the last two years. The unused eggs, whatever their number, are collected and transferred to the bakery. Unhatched eggs comprise the larger volume of these eggs ahead of the other sources as more than 15% of eggs remain unhatched in the hatchery unit. These eggs are sold to the bakery at a wholesale price similar to the way in which regular eggs are consumed by final consumers.

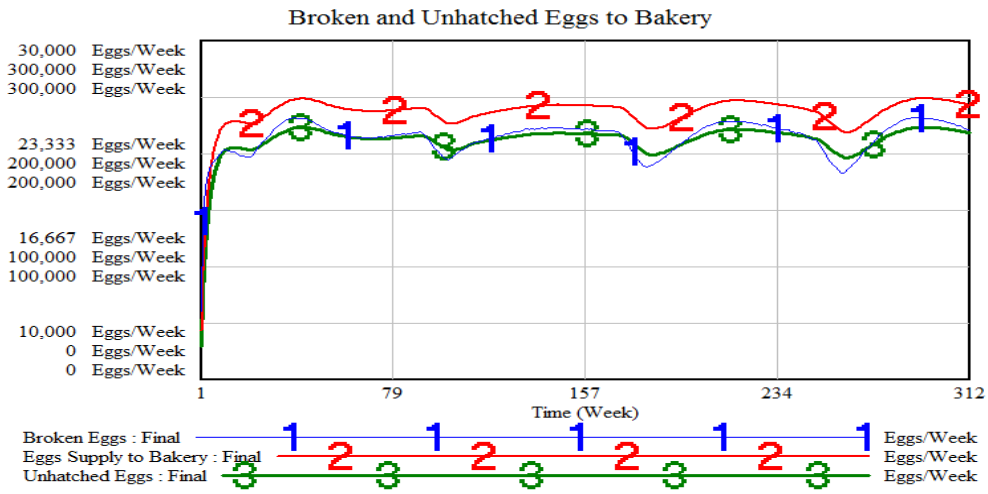

Figure 6.15: Simulated Behaviour for Broken, Unhatched Eggs and Bakery Items

Figure 6.16 illustrates the comparison between real-life and model output of bakery eggs. ‘Eggs supply to bakery’ (graph line 1) and ‘real bakery eggs’ (graph line 2) are showing a decent match with one another. Normally, unhatched eggs and broken eggs are examined whether it is suitable for human consumption or not? After having scientific investigation over unused eggs, then they are transferred into the bakery house for further process. If the eggs fail to pass the test, afterwards they are directly flown to process them for fish feed. Therefore, two graph lines express the reasonable indication of structural accuracy of the model.

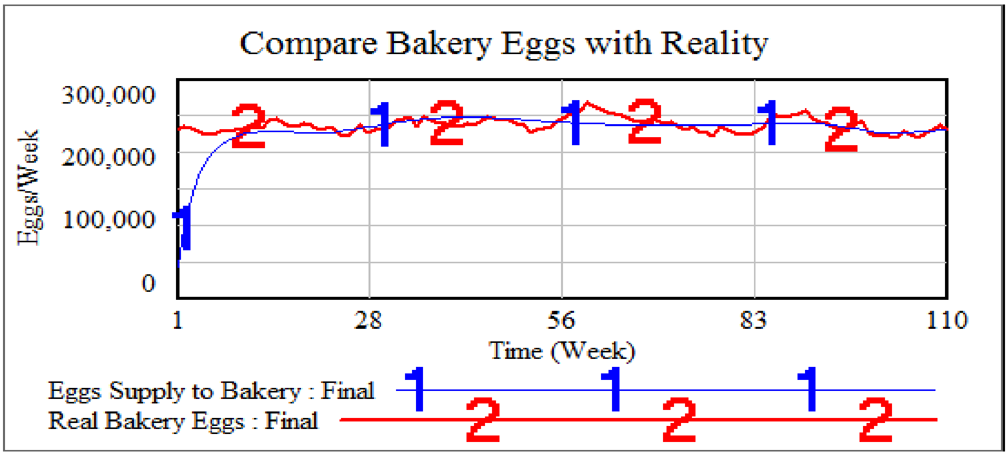

Figure 6.16: Comparison between Simulated and Real-life Bakery Eggs

6.4.5 Poultry Birds and Intestine Collection

Poultry intestine is valuable wastes that are reprocessed to make fish products and also help to grow '*Campylobacter*' for fish (Kubena et al. 1976; Lee and Newell 2006). Unfortunately, a huge quantity of intestines is simply thrown out as trash without it even being used. A few small fish farmers are using raw intestines for their Cobbler fish which is not scientifically sound as blood mixes with the pond water to make it toxic (Rahman 2013b). Even so, scientific usage of poultry intestines can contribute more than is currently occurring.

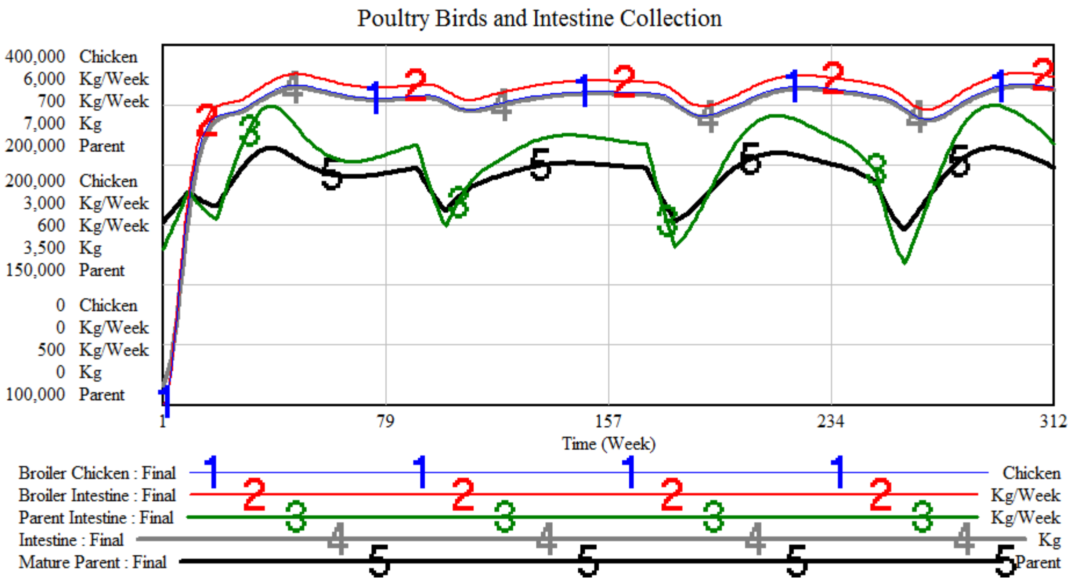

Figure 6.17: Simulated Behaviour for Poultry Birds and Intestines

Figure 6.17 shows the simulated behaviour of poultry intestine stock, and broiler and mature parent intestine quantity based on the number of birds slaughtered. Line 4 indicates that more than 6,000 kg of intestines are collected per week from the poultry case industry. If this could be processed scientifically, it might achieve significant economic benefits. At the same time, this reuse can also protect the environment.

6.4.6 Reverse Supply Chain and Employment

As with the forward supply chain, the reverse supply chain of the poultry industry is also creating significant employment opportunities. The reverse supply chain is mostly concerned with reusing poultry wastes to procure by-products. Figure 6.18 depicts the cumulative employment created through the reverse supply chain. The line numbers indicate the quantity of employment created from the various ways of processing poultry wastes. These opportunities would be widened if the case industry commercialized their by-products to the relevant consumer segments. The graph also indicates that employment of more than 3,500 jobs was created through by-product processing. Notably, the model can predict futuristic employment creation based on given input. As was previously mentioned, the model was run for 312 weeks (six years), of which 208 weeks (four years) output was treated as forecasted.

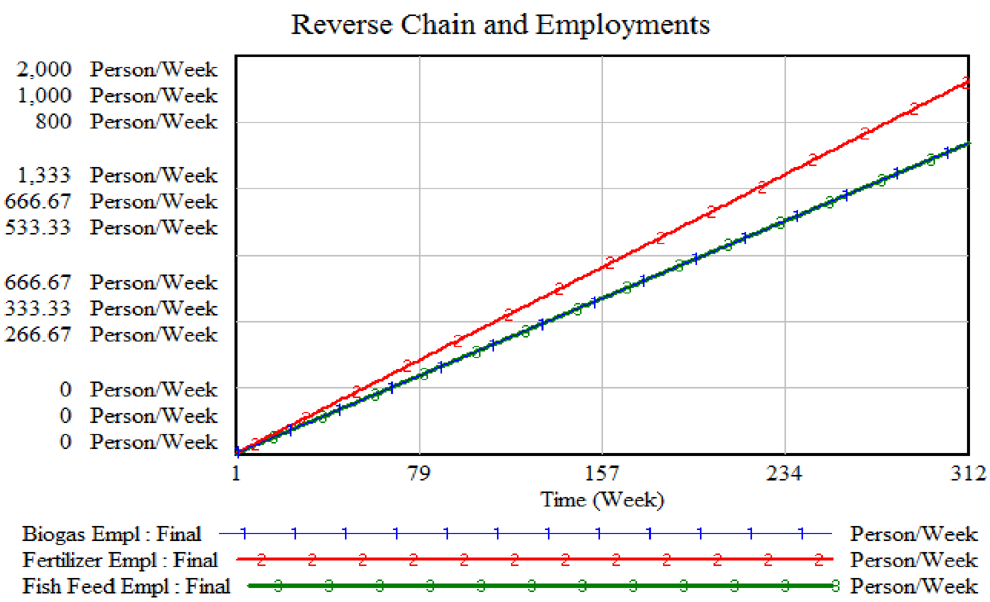

Figure 6.18: Simulated Behaviour for Reverse Chain and Employment

6.5 SIMULATION OF INTEGRATED POULTRY SUPPLY CHAIN MODEL

The model developed and depicted in Figures 5.7 and 5.8 (chapter 5) is the complete stock and flow model for the poultry supply chain within the research boundary. Simulation model building is done by a systematic procedure which considers a few key variables. Once the major variables interact with each other flawlessly, the model is then extended by associating more variables. Within this process, the results in every experiment should be checked even if it is only a minor value change of a variable. A similar process needs to be followed for other types of experiments such as adding or deducting variables, connecting a new loop with a current loop, etc. This is how perfection is finally derived after having so much trial and error. One of the objectives of this research was to perceive whether or not the simulated model worked similarly to the real-life poultry operation. If the model worked similarly to the real-life poultry operation, then the model would be used to integrate forward and reverse supply chain operations under the integrated model. The integrated model when run would provide combined results showing the total impact at the same time. The next section discusses the analysis of some relevant results of the integrated model.

6.5.1 Simulation Analysis for Integrated Model

The integrated model denotes the combined model in which the forward and reverse supply chains are linked together. The reverse supply chain is apparently dependent on the forward supply chain operation. In this research, the reverse chain depends mostly on reversing poultry wastes to the main operation with these wastes generated from poultry rearing and distribution in the forward chain. The few analyses are described in the following sections.

6.5.2 SyntheSim Mode of Integrated Model

SyntheSim is a technique in Vensim used to simulate models with considerable interactivity where changes are made to the model instantly (Eberlein 2003; Vensim 1999). SyntheSim can be run placing equations in all variables once a model is constructed, defined and complete. In addition, all constant-valued auxiliary variables turn into slider bars so that immediate effect can be seen for value changes. In addition, all stock (level) variables turn into small graphs of that variable over time. This facility helps to understand the behaviour of the changes over a particular given time.

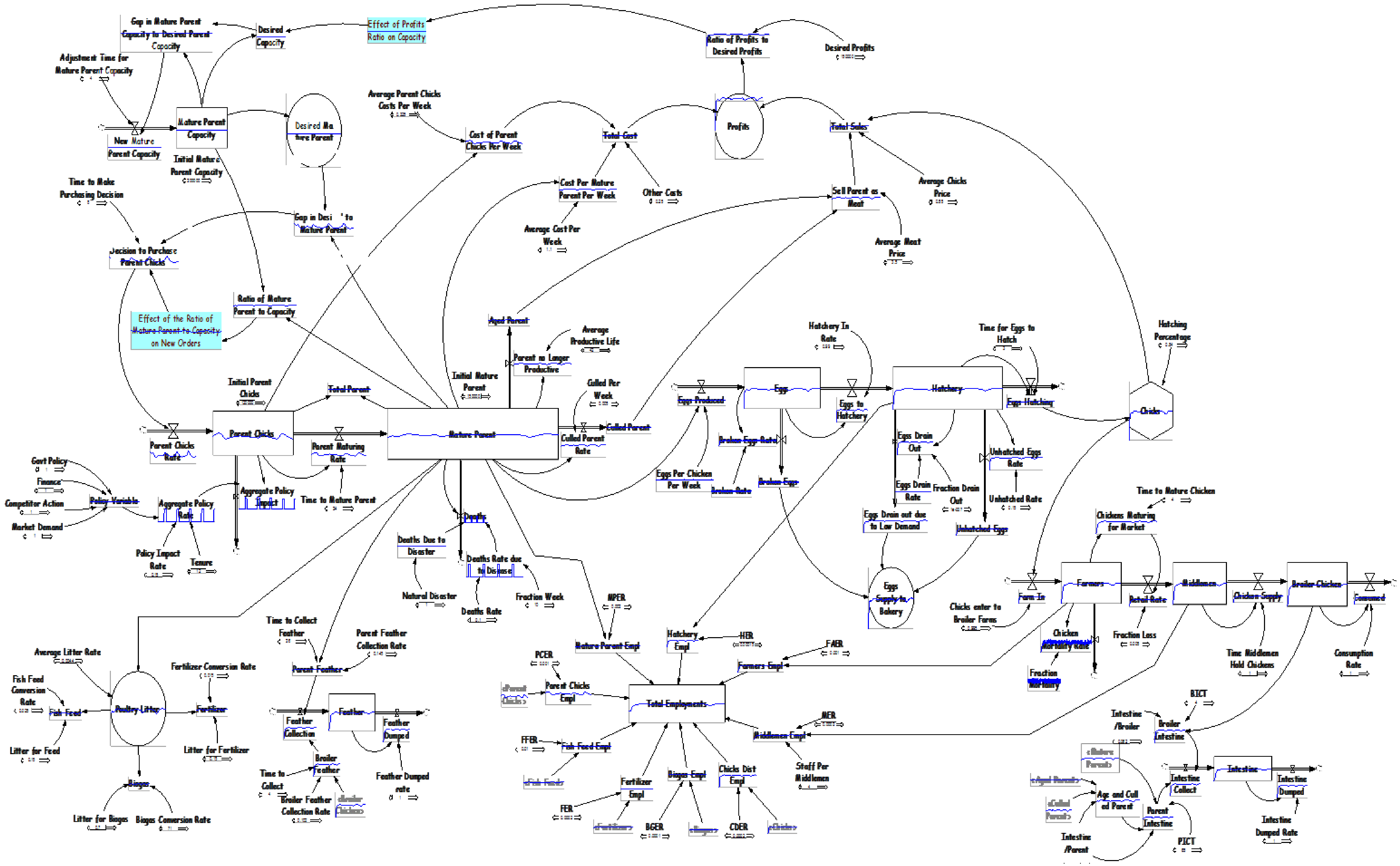

Figure 6.19: SyntheSim Mode for Integrated Poultry Supply Chain Model

Figure 6.19 is the complete picture of the SyntheSim mode (simulated) of the integrated poultry supply chain model. This figure shows the simulated behaviour of the model variables, including constants with the slide bar. This slide bar can be used for perceiving instant changes in the whole model due to altered value(s) for particular(s) variable. For example, the value for the 'initial parent chicks' variable is given as 120,000. When SyntheSim mode is active, then a slide bar will be available under the variable name. The slide bar will show the given value. If policy makers or farmers want to change the value to 150,000, at that point, associated variables will immediately show the behavioural changes. The SyntheSim mode works in this way on the model to do instant experiments until reaching the desired outcome or behaviour of the model variables.

Vensim's Synthesim mode provides an enormous facility where one can observe the whole model's behaviour. As is well-known, stock behaviour is the key for the system dynamics (SD) model to realize the trends. This model contains nine stock (level) variables which can be seen on Figure 6.19. Interestingly, miniature graphs for all stock variables appear to show similar behaviour. One can argue and question why this is so. The reason is very simple and can also be answered elaborately. Simply stated, a live business like poultry is completely dependent on production of eggs and chicks which guides the whole supply chain except for when disaster and calamities hit the chain (Rahman 2013a). Therefore, the poultry production process without calamities and disaster will behave consistently. For instance, 100 parents produce 70 eggs per day which will be forwarded to the hatchery after deducting damaged eggs. The rest of the eggs minus the unhatched eggs will then hatch in the hatchery.

Finally, chicks are delivered to the distributor to distribute to the ultimate farmers. If any disaster hits after accumulating the eggs, the policy maker may make the decision to hatch a certain proportion of eggs rather to hatch all of them. This decision may create behavioural oscillation rather than following the certain line. Figure 6.1 is an integrated model which consists of forward and reverse supply chains of the poultry industry. It is possible to view an instant result (behaviour) for both the supply chains based on the input value given to the 'parent chicks' and 'mature parent' variables and their capacity. If the input value exceeds the capacity value of these two variables, the model will not allow such values to be processed but instead will process the maximum value of capacity provided in the model. Therefore, integrated model is nothing but a combination of forward and reverse poultry supply chain for better productivity and efficiency. This chapter next discusses the reliability and validity of the simulation model.

6.6 RELIABILITY AND VALIDITY OF THE MODEL

Reliability and validity are an integral part of any kind of research and system dynamics (SD) research is no exception. The comparison between behaviour in the simulation and real-life data is important to justify the reliability and structure of the model. Most of the comparisons for key variables have been discussed above. All results were satisfactory as they closely matched each other. The next two sections discuss reliability and validity issues for the research model shown on Figure 5.8 in chapter 5.

6.6.1 Model Reliability

Model reliability is an iterative process to test policy (Sterman 2000). The refinement process continues until the model is able to satisfy requirements concerning its reality and robustness and reproduce the historical pattern (Jørgensen 2004; Forrester and Senge 1980; Homer and Oliva 2001). To test the reliability of the current model, the following matters were considered:

- ✓ Match the model-generated behaviour with real-life data;
- ✓ Observe model output by repeatedly changing over noise seed;
- ✓ Conduct multiple runs and observe results' similarity;
- ✓ Match between model behaviour and the real-life trend for different variables.

The model has accomplished above tests and found the results in favour of declaring the model as reliable. For instance, figure 6.3, 6.4, 6.6 and 6.7 tested the same.

6.6.2 Model Validity

According to Forrester (1980), Sterman (2000) and Barlas (1996), there is no unique way to claim model validity except by comparative views of real-life and model output, the extreme condition test, and dimensional and structural perfection of the model. Most SD scholars have agreed that model validation is only possible by those who know the real system accurately as an expert. Those experts are able to compare both the system dynamics (SD) model and real-life practice. If the simulation model reflects the reality, most experts express the opinion that 'half of the job is done' (McDoland 2013). Therefore, model outputs for key variables were compared with real-life outputs in the above section along with the key variables. Real-life and model data showed in comparison that they almost matched each other which assisted in comprehending the authentic structure and reliability of the model. Moreover, the model was tested by changing seed values for auxiliary variables and normal and expected behaviours were found. According to Peterson and Eberlein (1994), the following tests can be helpful to validate the model.

- ✓ Realistic behaviour under extreme or limiting conditions – consistency with actual data
- ✓ Conformance to thought experiments
- ✓ Plausible sensitivity to parameter changes over wide ranges

Apart from the key literature on SD model validation as discussed above, Qudrat-Ullah and Seong (2010) have exemplified six different validation tests based on Forrester and Senge (1980). Those tests can be done for structural validation of a system dynamics model. This validation tests are known as boundary adequacy, structure verification, dimensional consistency, parameter verification, extreme conditions and structurally oriented behavioural investigation (see 4.4.2.6). To build maximum confidence on current SD model, majorities of the above-mentioned tests were conducted to confirm the model validity. The following sections are describe the validation tests.

6.6.2.1 Boundary Adequacy

In boundary adequacy test, the model needs to elucidate whether the main influencing concepts and structures for addressing the policy matters are endogenous to the model (Qudrat-Ullah and Seong 2010; Forrester and Senge 1980). Figure 6.20 represents the exogenous and endogenous variables for the current poultry supply chain model. It is perceived that 'government policy', 'market demand' and 'competitors action' are the exogenous variables for the model. The case industry experts opined that market demand and competitors action can be driven from internal industry through implementing a visionary policy. A pragmatic policy implication will be followed by the competitors and consequently, market demand can be adjusted over the time. The model used standard and unchanged situation for exogenous variables. Those variables are deployed in the model to provide the facilities to experiments with the exogenous if needed.

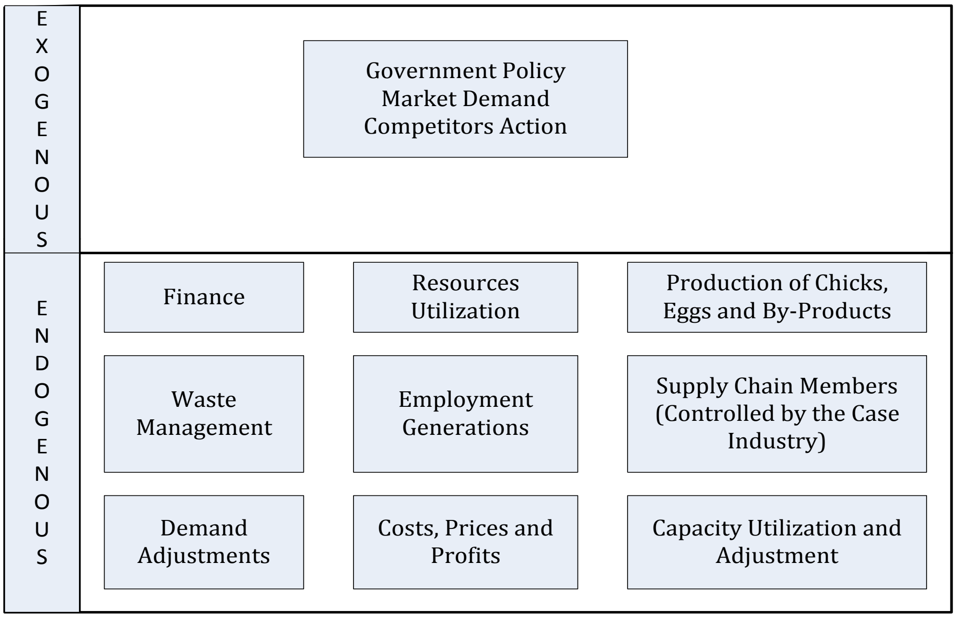

Figure 6.20: Summary of Integrated Poultry Supply Chain Model

On the other hand, finance, resources utilization, production, supply chain activities, waste management, demand adjustments, costs, prices and profits, and capital utilization are used as the endogenous variable in the model. These variables are suitable to measure and control by the respective industry and the researcher. Therefore, this model adopts adequate boundary to deal with poultry supply chain for a case industry.

6.6.2.2 Structure Verification

In structure verification test, the consistency of the model with relevant descriptive knowledge of the system is examined to validate its behaviour (Forrester and Senge 1980; Qudrat-Ullah and Seong 2010). Qudrat-Ullah (2005) has verified MDESRAP model using a case knowledge (where available knowledge about the real system) and constructed sub-model from the existing model domain for structural validation. Likewise, the current model constructed based on a real poultry industry where relevant information was crosschecked with the model equations and outputs. Figure 5.5 of chapter 5 presents a causal model on a real poultry supply chain industry. The causal relationship between the variables discussed under section 5.2. For example, parent chicks and mature parent dynamic structure in the causal model (figure 5.5). In this dynamic relationship, when parent chicks increase, mature parent will be increased with egg production. Consequently, parent chicks reduces and need to be filled with the day-old chicks to become mature parent in near future. It is a loop between these two variables with positive and negative feedback loop. Therefore, the causal relationships developed in the supply chain simulation model is validated based on real life knowledge in a poultry production system. Such kind of empirical structure validation (Zebda 2002) via real life knowledge can build confidence for the SD model. This model can be divided into forward, reverse and mainstream sub model from existing integrated model which will also serve as a 'theoretical' structural validation (Forrester and Senge 1980).

6.6.2.3 Dimensional Consistency

Dimensional consistency needs to test mathematical equation used in the model variables whether relevant equations are dimensionally resembled to the existent system (Forrester and Senge 1980; Qudrat-Ullah and Seong 2010). The present research has checked all the equations for constant, auxiliary and level variables to validate the model. For instance, the following equation represents one of the key variables (Decision to Purchase Parent Chicks) of the current model (figure 5.8, chapter 5):

Decision to Purchase Parent Chicks (Variable) = (Effect of the Ratio of Mature Parent to Capacity on New Orders*Gap in Desired to Mature Parent)/Time to Make Purchasing Decision, where,

- Effect of the Ratio of Mature Parent to Capacity on New Orders = Ratio of Mature Parent to Capacity [Dimensionless] of ([(0,0)-(1.25,2)],(0,1),(0.25,1),(0.5,1.1),(0.75,1.2), 0.85,1.1),(0.95,1.05),(1,1),(1.2,0.85))
- Gap in Desired to Mature Parent = [Desired Mature Parent-(Mature Parent), [Parent] and
- Time to Make Purchasing Decision = 8 weeks
- So, Parent/Week = (Dimensionless*Parent)/Week=Parent/Week

However, different variables (with different dimensions) are involved with the respective variables to make this dimension as 'parent per week'. Notably, the time unit for the current model is week (the input and output calculated in a weekly basis). Therefore, 'time to make purchase decision', 'mature parent capacity' and 'effect ratio' are not only carried from the real life knowledge but also equation is dimensionally consistent in the simulation model.

6.6.2.4 Parameter Verification

Academicians suggest to parameter verification to check the consistent parameter uses based on appropriate descriptive and numerical familiarity of the system (Forrester and Senge 1980; Qudrat-Ullah and Seong 2010). The current model (figure 5.8) deployed 145 variables of all kind and appendix C lists all of them with equations and units. Appendix C also provides parameters used in the model for each variable along with equation. Obviously, the knowledge of concern parameters has been obtained from real life practices.

6.6.2.5 Extreme Condition Tests

Academics and experts indicate that the model should be tested in extreme conditions so that it can be assessed as structurally valid for all circumstances. The extreme condition (indirect) test can be done by placing extreme values on the selected variables to comprehend the model-generated behaviour in order to detect the possible behaviour of the real system under similar circumstances (Balci 1994; Barlas 1996). It is necessary to test extreme condition using extreme values to ensure the logical behaviour in that unusual situation. A few circumstances were analysed below to test the current model in extreme conditions.

Extreme Condition for Parent Chicks

As shown in Table 6.2, extreme values were assigned to the associated variables of 'parent chicks' to comprehend the model behaviour. In reality, the case industry maintains approximately 120,000 initial parents with capacity for 200,000 mature parents. If a capacity gap arises, management is accustomed to spending eight weeks to make a decision to fill the capacity gap.

Table 6.2: Extreme and Normal Values for Parent Chicks

Variables	Normal Situation (Line 2)	Extreme Condition (Line 1)
Initial Parent Chicks	120,000	0
Policy Impact	0.15	0.3
Time to Make Purchasing Decisions	8	15
Initial Mature Parent Capacity	200,000	100,000

The purchase should have a visionary calculation to maintain optimum production. In addition, around 15% of the business is hampered due to policy barriers, sudden changes in the market situation, the government's uncooperative actions, etc. In an extreme condition situation, the value of 'initial parent' and 'mature parent' variables are provided as zero (0) and capacity of 100,000, respectively. In addition, policy had an assumed impact of 30% business losses, and the decision for purchasing new chicks was planned for 15 weeks' time. The model run with extreme values generated the simulated behaviour for parent chicks as shown in Figure 6.21. Line 1 on the graph revealed the behaviour over time for this particular variable in an extreme situation. The researcher later discussed the results with poultry experts and industry management to ensure the authenticity of the model behaviour in this extreme condition in which zero initial parent chicks was given as input. Logically, parent chicks will stream after 15 weeks after a 15 weeks' delayed purchase decision when there is a maximum capacity of 100,000.

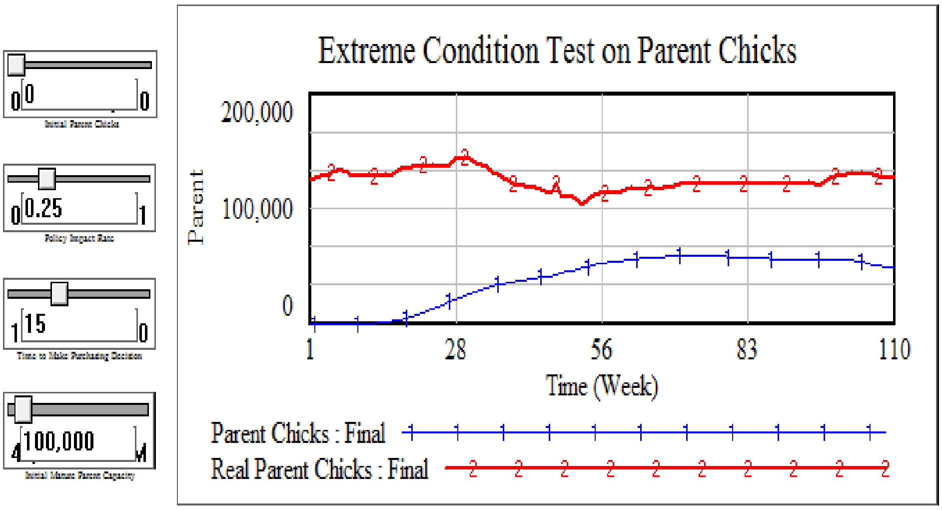

Figure 6.21: Extreme Condition Test for Parent Chicks

Extreme Condition for Mature Parent

As shown in Table 6.3, an extreme value was assigned to the connected variable of 'mature parent' to predict the possible simulated trend in comparison with reality. In normal practice, the case industry maintains a maximum capacity of 200,000 parents with 150,000 initial parents. At the same time, 10% deaths is treated as the normal situation with birds having the capability of remaining productive for 42 weeks. To set extreme values, the researcher considered a capacity of only 10,000 birds with 50,000 initial parents indicating quite abnormal thinking and circumstances. Realistically, the 'mature parent' variable should provide orders based on capacity but sometimes, mismanagement and the inability to forecast create such an uneven situation. In this case, the farmer would be forced to sell the parent birds to other parent firms and not have to cull these additional parents as poultry meat. In addition, death rates were considered to be 15% with a 25-week production life cycle both of which were also unusual. The model produced 312 weeks of behaviour but only two years of the variable's behaviour were chosen for Figure 6.21 to make the presentation more precise and clear.

Table 6.3: Extreme and Normal Values for Mature Parent

Variables	Normal Situation (Line 2)	Extreme Condition (Line 1)
Initial Mature Parent Capacity	200,000	10,000
Initial Mature Parent	150,000	50,000
Death Rate	10%	15%
Average Productive Life	42	25

It was indeed unusual for the case industry to maintain capacity of only 10,000 birds with 50,000 initial parent chicks. The graph in Figure 6.21 reflects the expected behaviour as it started from 50,000 but later reduced to less than 10,000 due to the maximum capacity barriers. The extreme value also considered the death rate as 15% and a production life cycle of 25 weeks, which are irregular occurrences in the real world except when strong calamities hit the industry. In Figure 6.22, line 1 reveals the behaviour over time for this particular variable in an extreme condition. Plausibly, the 'mature parent' variable behaved as anticipated compared to its input which was given extreme values.

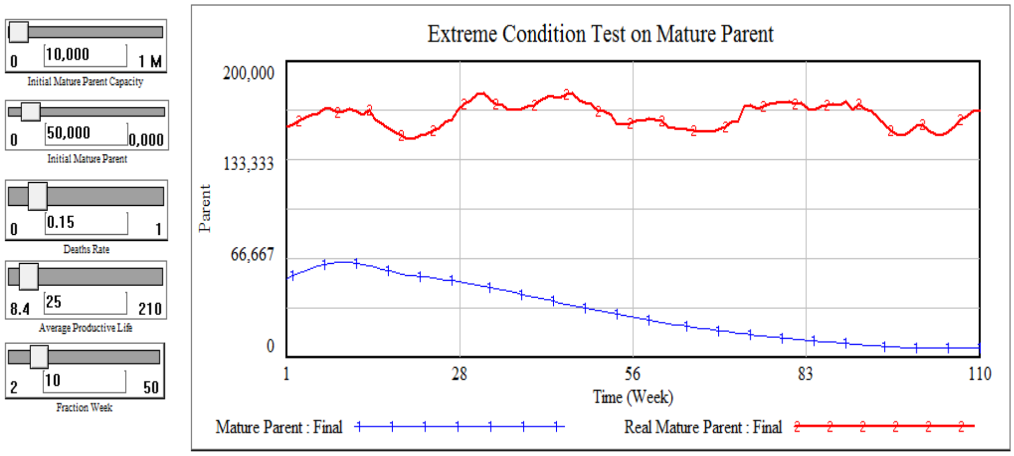

Figure 6.22: Extreme Condition Test for Mature Parents

Extreme Condition for Biogas

Biogas is a valuable by-product for the poultry industry as the case farm uses this in the gas brooder for baby chicks. Up to 70% of poultry waste (litter) is used to produce biogas in the case industry. The surplus production of biogas could be used in converting electricity. Normally, one tonne of poultry litter generates 71 cubic metres of biogas. In the extreme condition, 50% was used instead of 70% of total poultry litter and 40 cubic metres per ton was used instead of 71 cubic metres. Subsequently, the simulated model produced the desired result (as shown in Figure 6.23) for biogas production that had drastically fallen due to lower conversion and less litter collection compared to the normal situation.

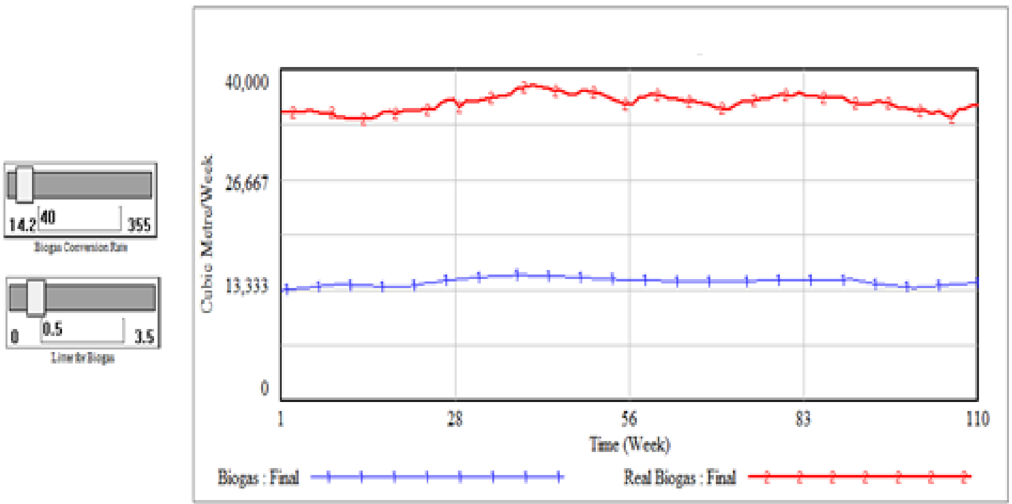

Figure 6.23: Extreme Condition Test for Biogas

Zero Capacities

As has been discussed, several key variables and their simulated behaviour were matched closely with the real-world data. The model was later verified in several extreme condition tests which also provided satisfactory results. At this point, the model was tested based on zero capacities. Zero capacities mean that all production stops: sometimes, models fail to pass this test. There are some other options such as one reality check being able to conduct this test for particular variables. However, a broader view of the model can provide wider visibility for the most important key variables and their instant impacts. As shown in Figure 6.24, the initial mature parent capacity used zero (0) instead of providing its normal capacity to test the impact on the whole model. Logically and as presumed, the model stopped at the first step as this model had no capacity to rear the chicks. This means that the model is working perfectly without having any structural errors. The relevant graph also shows yellow shading on all stock and rate variables that were represented in the zero process over time.

6.6.2.6 Sensitivity Analysis (Structurally Oriented Behavioural Test)

Sensitivity analysis is used to assist the modeller to understand the robustness and correctness of the model (Pannell 1997) as discussed in the methodology chapter (chapter 4). In addition, the behavioural sensitivity of SD model can be examined using a bounded values for a particular(s) variables to observe the behaviour over time (Qudrat-Ullah and Seong 2010). In fact, a range of numerical value is given as input for constant variables to see what can happen in the real system. Is this behaving logically? Positively, a numerical sensitivity analysis in line with projected estimated over time for a real system under the similar situations. Such kind of test can give more confidence on model structure to validate the system (Qudrat-Ullah and Seong 2010). This section describes the sensitivity test which was prepared based on five crucial variables. The sensitivity simulation analysis setup is shown in Table 6.4 and in the screenshot of the Vensim package. Five key variables were selected for the sensitivity analyses: initial parent chicks, initial mature parent chicks, time to make the purchase decisions, hatching percentage and policy impact over the system. The table also mentioned the type of distribution and the ranges used to analyse sensitivity. Importantly, the sensitivity simulation was run 200 times using 777 random noise seed to obtain rigorous test results. Figure 6.25 shows the sensitivity set-up window of the Vensim software package to acknowledge the way in which the analysis was conducted.

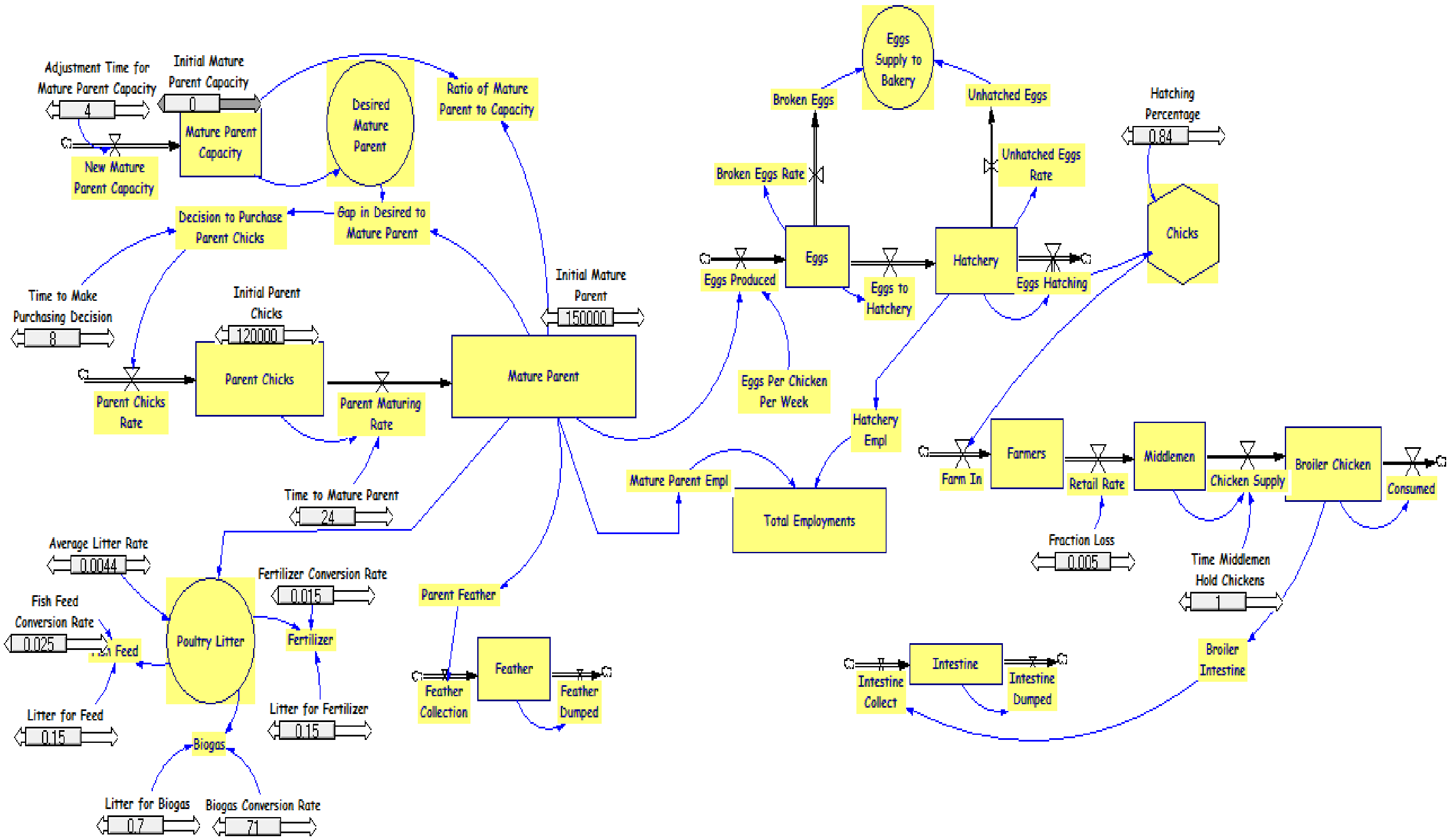

Figure 6.24: Zero Mature Parent Capacity

Table 6.4: Sensitivity Set-up

Variables	Distribution	Range
Initial Parent Chicks	Random Uniform	100,000 to 150,000
Initial Mature Parent Chicks	Random Uniform	120,000 to 200,000
Time to Make Purchase Decision	Random Normal	4 to 10 Week
Hatching Percentage	Random Uniform	0.78 to 0.87
Policy Impact	Random Uniform	0.05 to 0.20
Number of Simulation Runs	200, means that sensitivity analysis was run 200 times to check the model	
Noise Seed Used	777, Noise Seed Used 777 for Simulation Run	

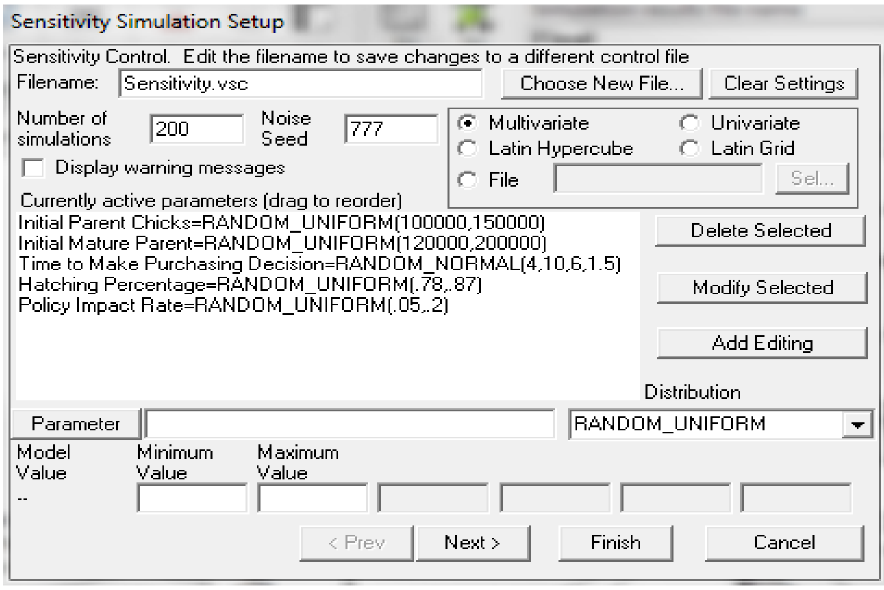

Figure 6.25: Sensitivity Set-up Window

(a) Sensitivity Analysis for Mature Parent

Figure 6.25 depicts the sensitivity results for the 'mature parent' variable which is the main variable of this model. The rest of this model's output depends on the 'mature parent' variable and its quantity. As shown in Figure 6.26, the result demonstrates its robustness and accuracy based on given input. The analysis was calculated with the confidence boundary used being 50% to 100%: confidence boundaries are indicated as shaded colour. The results are satisfactory as graph lines for 200 simulation runs are positioned within the confidence boundary.

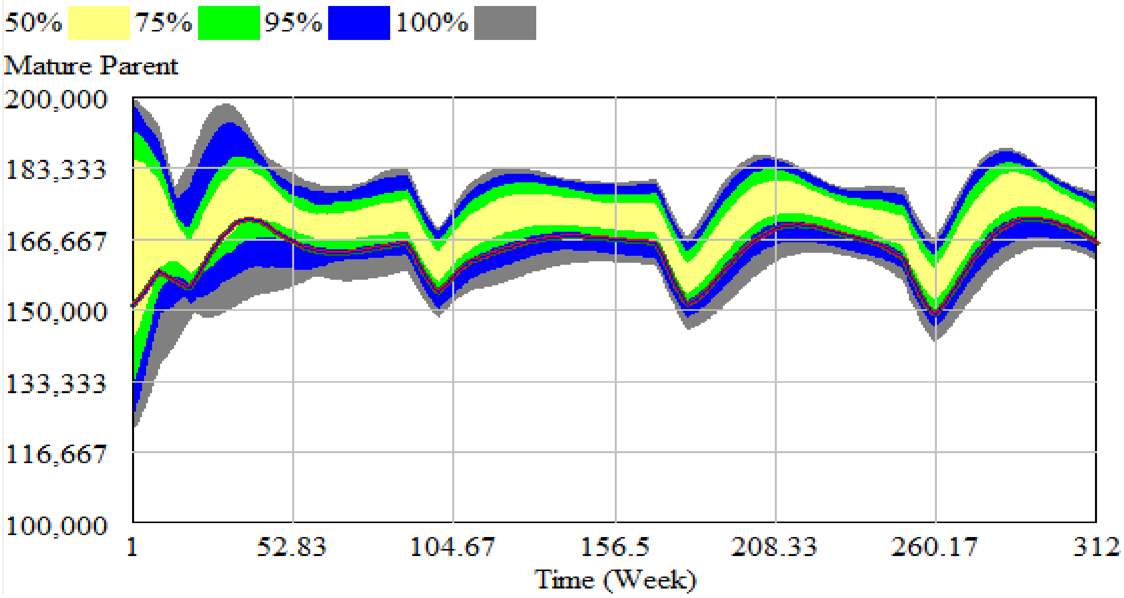

Figure 6.26: Sensitivity Results for 'Mature Parent' Variable

(b) Sensitivity Analysis for Chicks (Day-old Broiler)

Day-old broiler chicks are the main income-generating sources for the case industry. The sensitivity analysis for this particular variable also obtained satisfactory results in all confidence boundaries. The same criterion of the 'mature parent' variable was applicable for this analysis. Figure 6.27 depicting the sensitivity trends for 200 simulation runs did not expose any inconsistent or problematic behaviour over time.

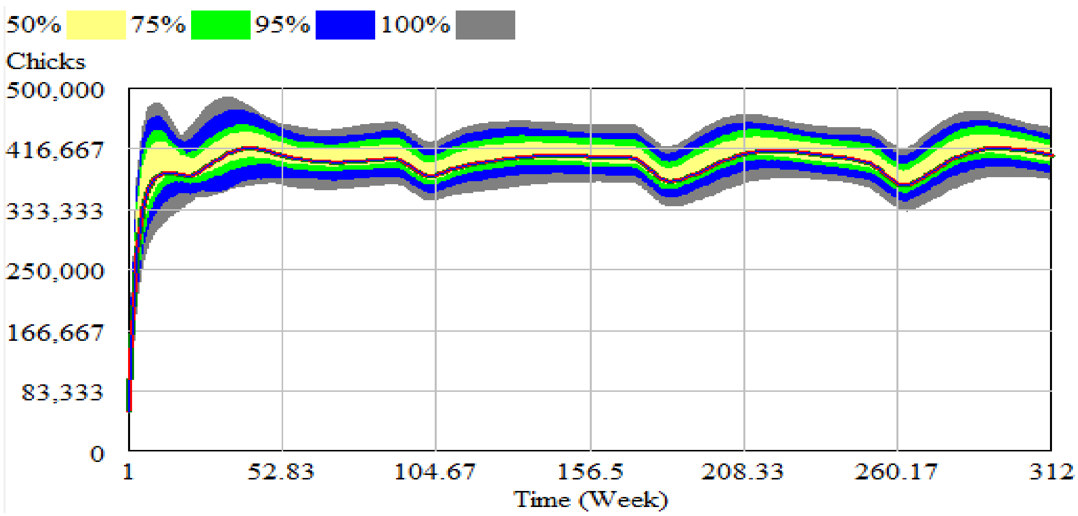

Figure 6.27: Sensitivity Results for 'Chicks' Variable

(c))Sensitivity Analysis for Biogas Production

Of the by-products, biogas is the most valuable. The case industry has massive plans to effectively reuse biogas in the near future. They are expanding their production and farm units which will help them to achieve doubled production of chicks and poultry wastes. Now, they are planning to convert this biogas for the sake of reducing their deficiency in electricity which incurs significant economic losses due to the need to maintain 24-hour standby diesel generators. New technological adaptation will help them to use biogas instead of costly diesel to run the generators. The sensitivity analysis for this particular variable provided reasonable outcomes in all confidence boundaries. Figure 6.28 represents the sensitivity graph for 200 simulation runs which maintained the confidence boundaries and perceived consistent behaviour over time.

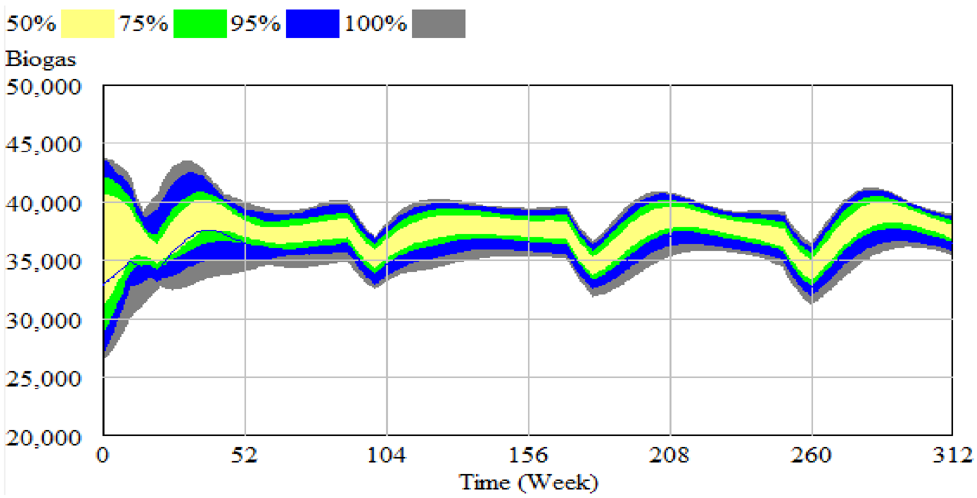

Figure 6.28: Sensitivity Results for 'Biogas' Variable

Above discussions analyse and explain sensitivity tests for the current model. Several individual sensitivity results are shown in the above sub-sections under the section 6.7. The objective of conducting such tests is to check model robustness and correctness in light of significant value changes for variables. The changes made over various distributions were mentioned in table 6.4 and figure 6.24. The sensitivity results are within the respectable range which suggests that the current model is working accurately even ranges of changes have been made.

Therefore, the discussions were made based on reliability and validity of the simulation model. First, the model tested reliability issues based on the criteria set in the section

6.6.1 based on literature. The model has passed all the relevant tests to declare it as a reliable model. It is noted that model generated behaviour is decently matched with the real data, model has given expected results having random changes of noise seed, gained expected output in multiple runs and find almost similar results between model and real data for different key variables. Second, the model has conducted several tests for validity as well. Several validity tests like boundary adequacy, structure, parameter, dimensional consistency, extreme condition, sensitivity tests were examined. The examined validity tests found the model as valid and workable in compare to real practice. Some of the scenario analyses discusses in the later section of 6.7.

6.7 SCENARIO ANALYSIS

When modellers confirm model reliability, authenticity, behaviour, structure, dimensions and extreme condition impacts, they usually do some policy tests to see how the current model structure functions (Postma and Liebl 2005; Hsia et al. 1994). To test this, an in-depth interview was undertaken with this case industry's owner to learn about their deliberate aims and if they will have scope to implement them. The owner indicated that he wanted to see his industry double mature parent capacity, increase parent chicks' capacity, increase hatching percentage, reduce disaster and calamity losses, reduce decision time, increase hatching capacity, etc. The main problem for the Bangladesh parent breeder industry is that the day-old broiler chicks do not obtain the desired price in comparison to costs in all seasons. The price fluctuates too frequently, and it is beyond the farmers' control to hold the minimum profit and avoid financial losses. The current model is unsuitable for testing the pricing issue as this depends on the nature of the market and seasonality. In fact, market price fluctuation was not included in the model except for showing its impacts through policy. The study tested three different scenarios which are as follows.

6.7.1 Scenario One: Increased Parent Chicks and Mature Parent Capacity with Reduced Decision Time

If parent stock industry wants to increase their initial parent significantly with the double increment of mature parent capacity and desire to reduce death rate and decision time into half than standard practice then what changes will be achieved? The inspiration of this test is to see the additional benefits through mentioned changes with various consequences. It was mentioned before that the 'mature parent' is the most considered variable with the highest influence in the current model. The model shows an immediate reflection on most variables if 'initial mature parent capacity" increases or decreases. The more parent chicks are reared, the more egg and chick production will flow towards the forward supply chain. At the same time, more poultry birds generate more poultry wastes which can be converted into additional by-products. In scenario one, the poultry owner wants to see his industry double mature parent capacity, increase parent chicks' capacity from 120,000 to 200,000, manage to reduce the death rate from 10% to 5% and reduce 'purchasing parent chicks' decision' from eight weeks to four weeks. Table 6.5 shows the possible changes for scenario one when four variables were considered in the policy test. These four variables are located on the top left side of the integrated model (Figure 5.8, chapter 5).

Table 6.5: Changes for Scenario One

Variable Name	Normal Value	Expected Value for Scenario One
Initial Mature Parent Capacity	200,000	400,000
Initial Parent Chicks	120,000	200,000
Death Rate	10%	5%
Time to Make Purchase Decisions	8 Weeks	4 Weeks

Values were given to the input to see the changes that eventuated in comparison with the real-life situation of the model. The model ran under a different name as scenario one and results were compared with the standard output for the same model. After the run, the model with changed values was given different output than what was expected. The model was later tested by increasing the capacity to double as the case industry maintains capacity of 200,000 mature parent birds. The value of 400,000 mature chicks was given as input for the initial mature parent which started flowing to the forward and reverse supply chains of the model. Figure 6.29 shows the comparison between the real-life and standard model behaviour based on changed values for four different variables. The figure clearly shows that the model graphs are positioned at almost double production in the individual graph of the model variables. The graph is a shortened presentation of three key variables in comparison to the massive integrated model. The production will be almost double if the capacity can be set at double as in Figure 6.29. The graph considered the three key variables of 'parent chicks', 'mature parent' and 'day-old chicks'. The graph is also revealed that the death rate has been reduced which helped to increase the total number of 'mature parent' birds for a certain time. In contrast, the time taken for the parent chicks' purchase decision did not increase parent chicks to the same extent due to full capacity. Once capacity is full, new parent chicks cannot enter the system.

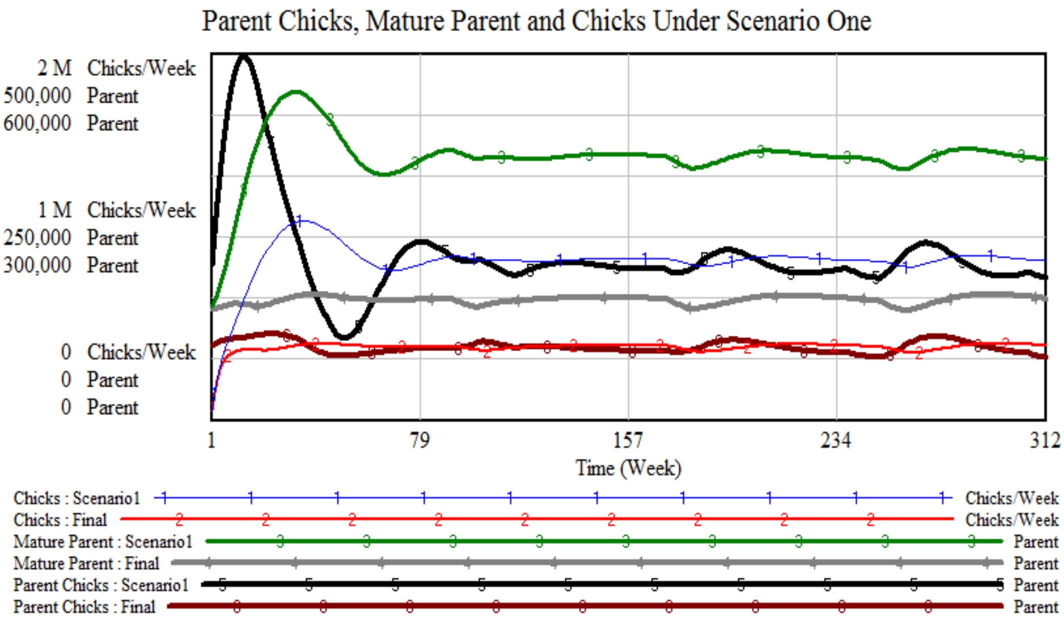

Figure 6.29: Simulated Behaviour of Parent Chicks and Mature Parent under Scenario One Test

The behaviour of poultry wastes under scenario one is revealed in Figure 6.30. The behaviour of various poultry wastes is shown on the same graph. As shown, production increased substantially more than the normal circumstances. The relevant graphs show the simulated behaviour for poultry litter, feathers and intestines. The lines are numbered in order to recognize and understand the changes in comparison to standard practices in real life. It is understandable that more capacity will lead to the production of more wastes to recycle and reuse. This recycling will obviously increase the opportunities to generate more by-products. More by-products will create the prospect of commercializing them to new market niches to gain supplementary financial benefits. Moreover, the further processing of wastes can employ additional employees, and establish family businesses and small and medium industries (SMEs) to handle such operations. The poultry industry can thus achieve maximum benefits if they are able to implement such policies in the near future.

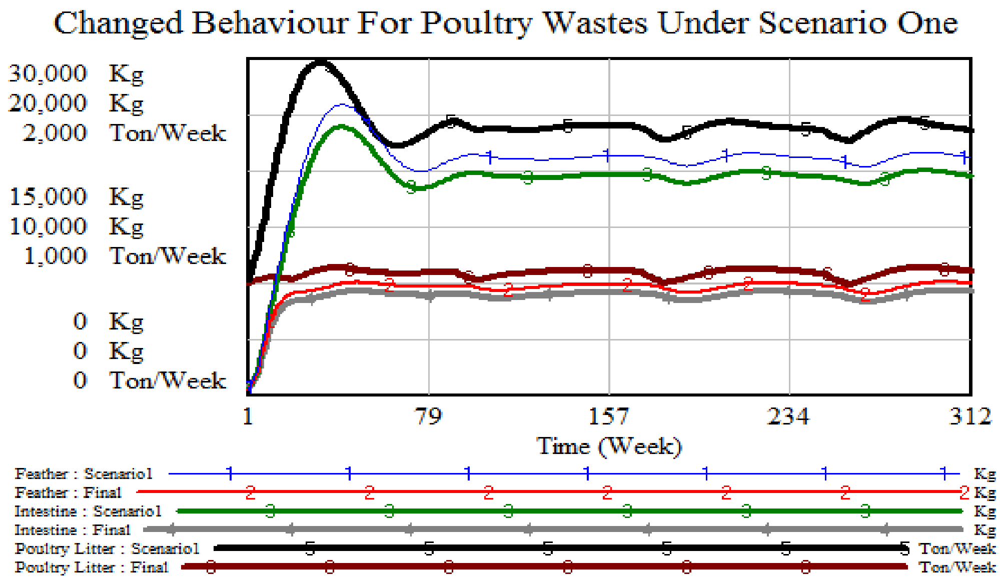

Figure 6.30: Simulated Behaviour of Wastes under Scenario One Test

6.7.2 Scenario Two: Consider Less Mortality and Maturing Time, Less Unhatched and Broken Eggs, Increased Hatching Percentage along with Doubled Rise in Hatchery Capacity

In scenario two, policy makers and the owner want to reduce mortality which is one of the major concerns of Bangladesh poultry. They also want to increase the hatching percentage and hatchery capacity in order to increase chicks' production. At the same time, they want to reduce the maturing time which would means that the mature chicken would go to market a little earlier to flow more chicken to the market. The changes made in the scenario two tests are shown on Table 6.6. As can be seen, the time for hatching eggs changed from three weeks to 1.5 weeks. Scientifically, it is not possible to hatch an egg in less time than three weeks or 21 days. Here, the time of 1.5 weeks denotes the doubled hatchery capacity so that the ultimate chick production will be twice the capacity in real-life practice. The maturing time for the chicken was 3.5 weeks instead of four weeks which means that the mature chicken would be ready to consume at a lower weight than in normal practice. For this, the poultry shed would be cleaned out four days earlier which may help them to rear three additional flocks a year. Therefore, the mobility and supply of chicken will be increased to a higher level than the real-life practice.

In addition, the chicken mortality rate was considered at 2% in comparison to the real-life practice of 4%, the hatching percentage was increased to 88% from 84%, the unhatched rate was reduced to 12% from 16% and, finally, broken eggs were courageously considered to be 1% compared to 3.5% in reality. The values were next given as input to perceive the deviations that were instigated in comparison with the standard values of the model. The model ran under the different name of scenario two and was compared with the standard output of the same model.

Table 6.6: Changes for Scenario Two

Variable Name	Normal Value	Expected Value for Scenario Two
Time for Eggs Hatching	3 Weeks	1.5 weeks x 2 (Double Capacity)
Time for Mature Chicken	4 Weeks	3.5 Weeks
Mortality Rate for Farmers	4%	2%
Hatchery Percentage	84%	88%
Unhatched Rate	16%	12%
Broken Eggs	3.5%	1%

Figure 6.31 displays the perceived changed model behaviour due to the changed values which created scenario two for specific variables. Simulated behaviour for broken, unhatched and hatching eggs is shown in the same figure to realize the expected positive changes for broken and unhatched eggs. One positive change was the increased number of hatching eggs which would guide a little more chick production within the limits. Increased hatching percentage helped to achieve more production than in the real-life scenario.

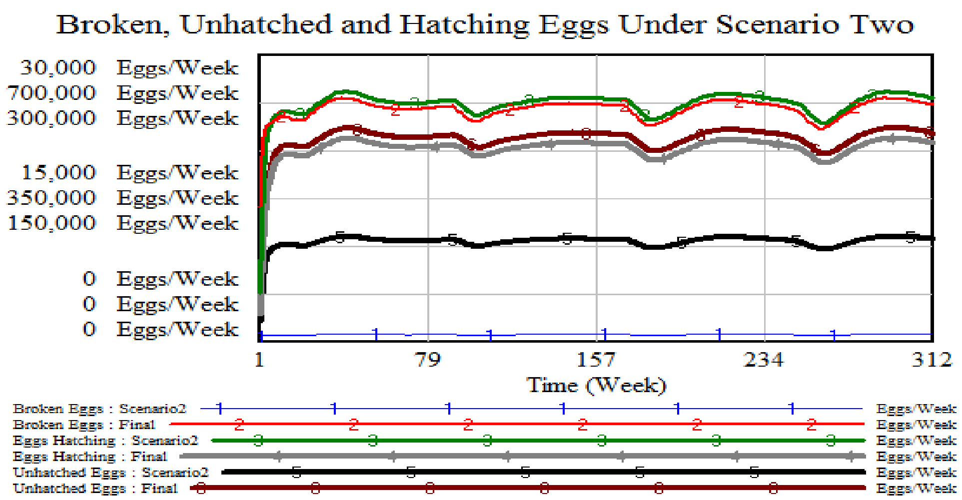

Figure 6.31: Simulated Behaviour of Reject and Hatching Eggs under Scenario Two Test

Simulated behaviour for farmers, chick production and mortality is shown in Figure 6.32. The graph lines demonstrate the comparison between real-life practice and the policy test. The graph lines reveal that mortality has been drastically controlled which helps the farmers to achieve more production. Clearly, chick production almost doubled as capacity increased. Thus, scenario two would be best applied by farmers, for chick production (hatchery) and to reduce chick mortality rates (by farmers) to achieve more sustainable benefits.

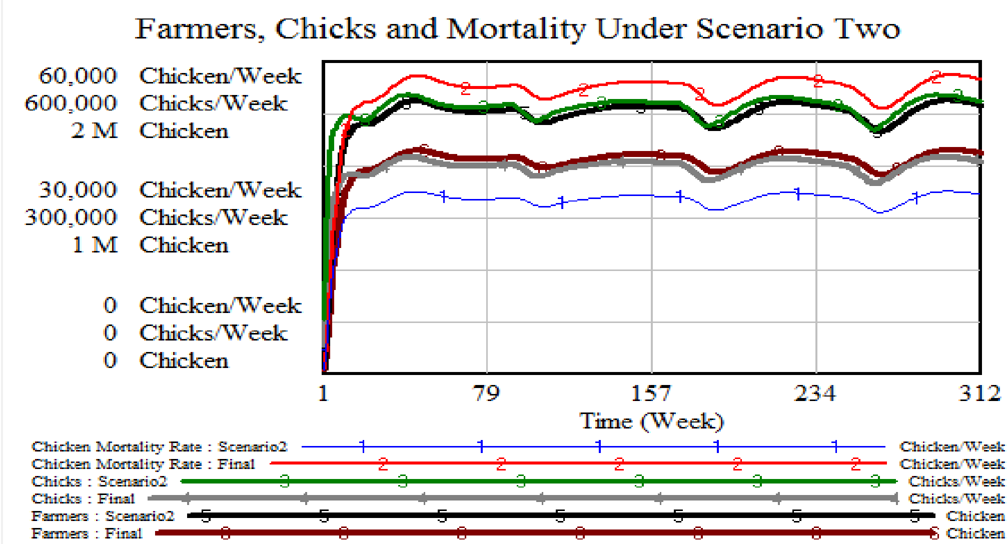

Figure 6.32: Simulated Behaviour of Farmers, Chicks and Mortality under Scenario Two Test

6.7.3 Scenario Three: Consider Reduced Cost per Parent and Other Costs, Increased Chicks' Price and Increased Biogas Production

In scenario three, policy makers and the owner want to increase profitability by reducing costs and expecting a better price for their day-old chicks. At the same time, they want to increase biogas production by increasing poultry litter input to the processing. Biogas is more profitable than the other types of by-products. The changes made for the scenario three tests are presented in Table 6.7. Higher costs are hindering the achievement of maximum profitability for Bangladesh poultry. At the same time, the industry is thinking of generating electricity from biogas which would be very useful and a cost saving method for them. In making this change, the average cost per parent per week would reduce to A$0.90 from $A1.10. Other costs per week would reduce to A$0.15 from A$0.25. The industry assumed that the sales price of day-old chicks would increase to A$0.75 from A$0.55. Figure 6.33 presents the changed simulation behaviour for costs, sales and profits over time. Importantly, profit would increase significantly which is the utmost desire of the policy makers. The per bird cost and other costs were given input values of A$0.20 and A$0.10 less respectively. As a consequence, profit was maximized in the simulated behaviour for the scenario three test. The final test was done for by-products manufactured from poultry wastes.

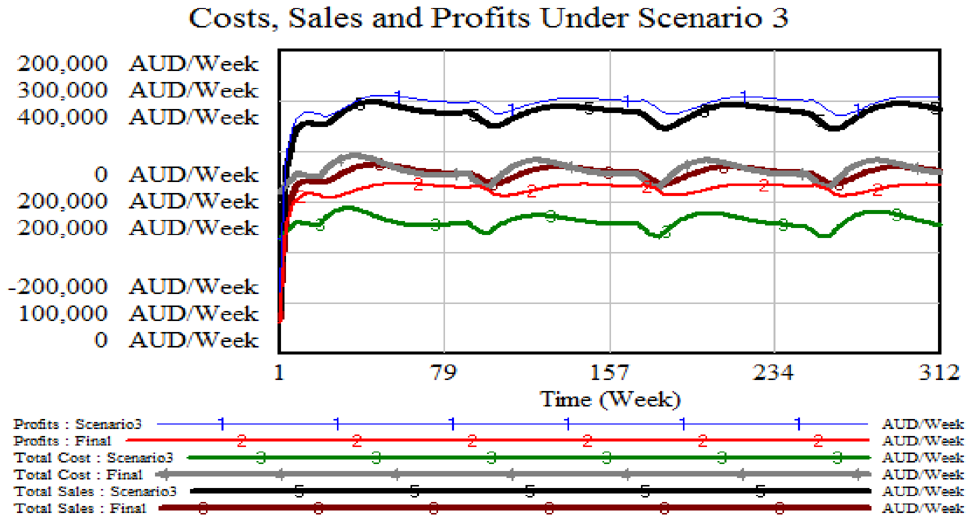

Figure 6.33: Simulated Behaviour of Costs, Sales and Profits

Figure 6.34 shows the simulated behaviour for the production of biogas, fertilizer and fish feed with real-life production. The graph also reveals that fertilizer and fish feed production were reduced due to the reduction of raw materials (poultry litter). Biogas production increases as expected due to 90% of total collected poultry litter being used instead of 70% of litter. Therefore, the scenario three tests were also more significant than the tests for the other scenarios for maximizing profits and utilizing poultry litter to produce economically viable by-products.

Table 6.7: Changes for Scenario Three

Variable Name	Normal Value	Expected Value for Scenario Three
Cost Per Parent Per Week	A$1.10	A$0.90
Other Costs Per Week	A$0.25	A$0.15
Average Chicks Price	A$0.55	A$0.75
Litter for Biogas	70%	90%
Litter for Fertilizer	15%	5%
Litter for Fish Feed	15%	5%

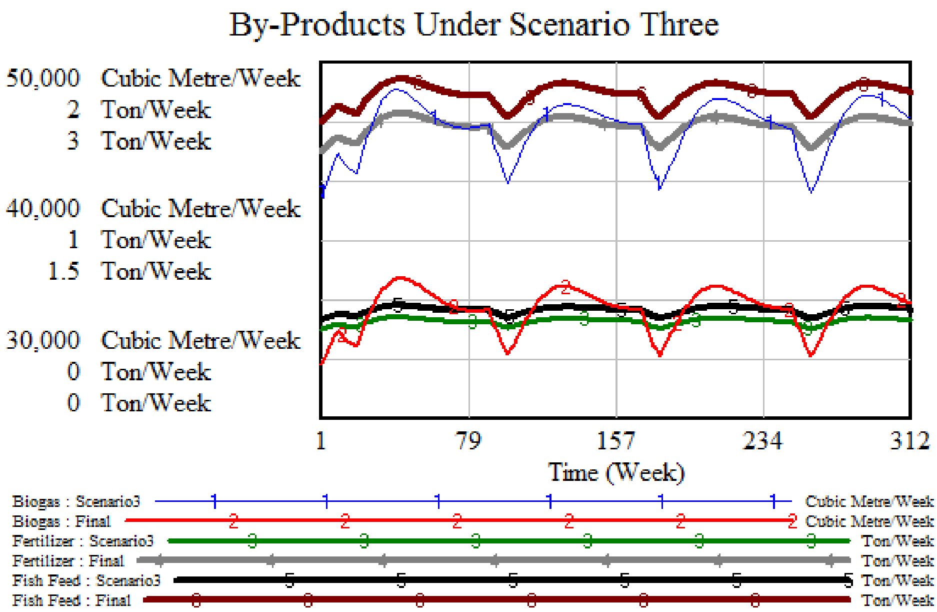

Figure 6.34: Simulated Behaviour of By-products

Above scenarios are focused, predicted and analysed based on three different situation of the poultry production process in Bangladesh. These scenarios are designed to demonstrate that the simulation model works perfectly grounded on requirements. In scenario one, the model dealt with double production of parent and mature chicks with reduced decision time which meet the efficient poultry production system for achieving sustainability. In scenario two, the model measured double hatchery capacity by reducing mortality, unhatched and broken eggs rate and standard chicks maturity time. By doing this test, the model controls recyclable wastes and can maintain double hatchery capacity to deal with more eggs flow from the parent farms. In scenario three, the model considered reduced costs and increased price for final products and better biogas production rate. Better price with the significant amount of by-products creation can be handled through scenario three. Aggregately, efficient productions with proper wastes handling can save the industry to manage to make more profits. At the same time, competent and sustainable process can bring more social, economic and environmental benefits which need to be examined to justify the research problem. It is now inevitably proven that the simulation model can predict the changed situation which can be applied in real-life situation.

6.8 SUMMARY

This chapter has discussed the findings based on the simulation results. The interpretations of the tables and graphs were carried out to show the opportunities that exist for integrating the poultry forward and reverse supply chains for the sake of better utility. The above discussions and presentations were based on the simulated output of the poultry supply chain model. The discussions were organized in light of the forward and reverse supply chains and the integration of the poultry supply chain for the case industry in particular and for Bangladesh in general. Each section exposed and discussed the simulated behaviour over time and undertook a comparison between simulated and real-life data. Structural validity, extreme conditions and statistical analysis for the main variables were later illustrated and thoroughly interpreted.

CHAPTER 7:

DISCUSSION OF RESULTS

7.1 INTRODUCTION

This chapter discusses the results analysed from the simulation model developed in this study. All of the results along with the tests of reliability and validity of the simulation model were shown in the previous chapter (see chapter 6). This particular chapter links the discussion of simulation results with the research objectives and questions. In support of this connection, additional tables and figures are presented. This chapter is structured as follows. The next section describes the appropriateness of a sustainable poultry process in light of the economic, social and environmental aspects which also addresses the first research question. This section includes subsections which specifically discuss the sustainable poultry production process followed by discussion on the specific economic, social and environmental benefits achieved from the poultry process. In response to the second research question, the following section discusses the forward supply chain and its consequences for societal changes such as creating employment and reducing poverty. The next section explores the reverse supply chain process for recycling poultry wastes in a profitable way. This section includes discussion on possible contributions gained through the reverse supply chain which includes answers to the third research question. In conclusion, a chapter summary is presented as well as an outline of the next chapter.

7.2 RESEARCH QUESTION ONE: WHAT IS THE MOST APPROPRIATE SUSTAINABLE POULTRY PRODUCTION PROCESS WITHIN THE BANGLADESH POULTRY INDUSTRY IN LIGHT OF THE ECONOMIC, SOCIAL AND ENVIRONMENTAL ISSUES?

The current study has focused on developing and designing an appropriate sustainable poultry production process for the parent stock (PS) industry which can be maintained for the aggregate and individual economy, society and environment. To do so, the study explored the forward and reverse supply chain operations of a specific poultry parent stock (PS) industry. Previous chapters have presented a number of tables and graphs to reveal the real facts of the sustainable poultry process and three aspects of benefits. This current section particularly addresses research question one which explored the sustainable benefits that can be achieved from the poultry supply chain process. The following discussion presents details of sustainable poultry production process followed by sustainable benefits from poultry activities that can bring economic, social and environmental benefits through an industry operation. Later, the literature in support of these activities will be presented, which claim the appropriateness of a sustainable process along with sustainable outcomes.

7.2.1 Sustainable Poultry Production

The main objective of this study was to develop a composite poultry supply chain model so that sustainability would be maintained. In reality, most of the poultry processes are existed in a scattered way. The current research put an effort to combine all fragmented processes under a single umbrella with minor extensions to develop an effective sustainable poultry production process. In the literature review (see chapter 2), sustainability and related terms were described with social, economic and environmental aspects having the highest priority. In fact, without this stability, the company cannot achieve sustainability. As previously mentioned, the Bangladesh poultry sector makes a significant contribution to society. Thousands of businesses and millions of workers are involved with this industry. Now, following discussion presents how the current poultry process can be achieved substantial sustainable outcomes in terms of economic, social and environmental sustainability perspectives.

Figure 7.1 is a simplified framework for a sustainable poultry supply chain process which has already been shown in a more complex form (see Figure 5.8 in Chapter 5). Moreover, Figure 3.8 in chapter 3 depicted the input and output of the poultry process supply chain for a parent stock (PS) company. With this Figure 7.1, it is clearly comprehended that forward and reverse supply chain integrates together to achieve more benefits. Better input can help to gain quality output. At the same time, it (Figure 7.1) shows poultry wastes can be collected through third party small-medium industry to reprocess them to make valuable by-products. The main purpose of this study was to develop smooth forward and reverse supply chains and then integrating them to achieve sustainable benefits (outcome) for the company and society. The model (Figure 5.8 of Chapter 5) was developed based on a case industry which is already operating and implementing many scientific processes to achieve sustainability. The case industry is a parent stock (PS) company in addition to which they maintain a hatchery, feed mill; day-old chicks supply chain network and by-product processing unit.

Notably, the supply chain length depends on the scope of the poultry business operation as there are so many varieties of operation that can be adopted. The operations may include grandparent, parent, ultimate farming, feed processor, feed supplier, chicks and chicken supplier, chicken processor and all the intermediary businesses. Poultry is a business which is completely dependent on input and a given input will drive the following supply chain operations for a particular period of time. There is no other way to increase the production or operation as it depends on the number of chicks or eggs available in the process. The possibility of decreased production can happen at any time due to calamities and disasters. Therefore, the main output (chicks and eggs) of the poultry operation is dependent on given input and, at the same time, the wastes generated are based on existing flock sizes.

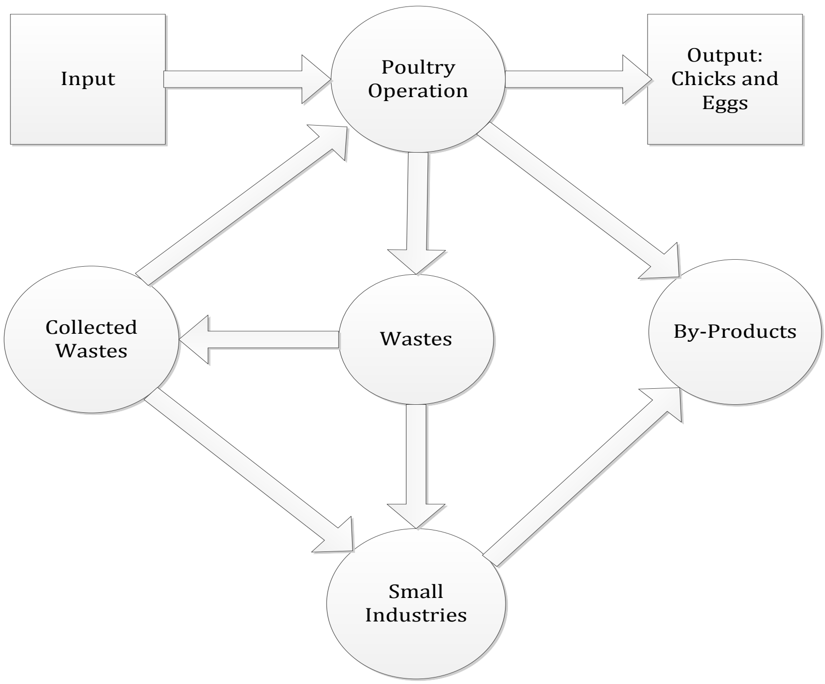

Figure 7.1: Sustainable Poultry Process

Usefulness of Poultry By-products

In addition, wastes are a foremost concern nowadays and scientists are putting their best efforts to finding ways to reuse or recycle wastes in a valuable way. Figure 7.1 also explains how poultry wastes can be reversed to the main operation to generate by-products. Alternatively, such wastes can be redirected to small and medium industries (SMEs) for further processing. In this way, SMEs will be established to process the economically viable by-products. These by-products can be consumed by different segments of customers and, perhaps, by the same industry. For example, biogas can be used for cooking burners, heating burners and generating electricity. The case industry uses biogas for warming the day-old chicks (brooding stage) and cooking for the large number of employees (cooking burners). The case industry has a minimum of 1,500 employees, and the industry canteen cooks for all of them. After using this quantity of biogas, a significant amount of gas remains as surplus. The surplus gas can be used for converting electricity as the power supply from the government authority is not enough for daily use. The case industry has already signed a contract with a foreign company to implement this strategy. Electricity scarcity is common in Bangladesh where it is expensive to buy from private and government power generating agencies. Moreover, the power supplying agencies are unable to provide continuous electricity to clients as supply is significantly less than the demand. Every day, the industry has to accept load shedding for at least six to eight hours (Rahman 2013b). As a result, they have to use a standby fuel generator to cover the gap which increases the chicks' cost. In a situation like this, they can use biogas as fuel for generating electricity which will benefit them financially. Therefore, most of the by-products are useful in Bangladesh context which will help the poultry industry to attain sustainability.

7.2.2 Sustainable Benefits (Economic, Social, and Environmental) from Poultry Activities

According to reports from the Global Reporting Initiative (GRI), Dow Jones and Association of Institution of Chemical Engineers (AICHE), sustainability has a number of indicators which they consider when making their reports to institutions. Considering these indicators, as shown on Figure 7.1, the poultry operational activities are disclosed which support the acquisition of sustainable benefits under sustainability theory. In the literature review (see Figure 2.8 in Chapter 2), a sustainable supply chain diagram was shown in order to understand the facts behind managing three-factor benefits. It was also disclosed that addressing any two of the three factors could be good for the industry supply chain operation. For example, better social and economic activities was called 'better', improved social and environmental or economic and environmental activities was 'good' and maintaining all three factors was 'best'. Table

7.1 describes all major poultry activities and the sustainable benefits that originate from them. The 15 main activities of the poultry operation were identified in the in-depth interviews and focus group discussion.

Eleven (11) of the fifteen (15) activities socially and economically benefit the industry and society, which was called 'better sustainability' by Carter and Rogers (2008). Rearing parent chicks and mature parents is of benefit to the society and economy. In terms of economic benefits, these two operations are seen to create employment, new ventures and earn financial returns while for social benefits they are observed to fulfil individual and industry needs, create value, reduce poverty and create entrepreneurs. In this way, the hatchery operation, chick production, chick supply for middlemen, agent and sub-agent activities, rearing broiler birds, supply to the distributor and profit making directly benefit Bangladesh society and the economy. Doubt may be expressed about profit itself being treated as a social benefit. The logic behind calling profit a social benefit is that society will be the beneficiary if an industry makes profit. The industry will spend some of their slice of profit for the sake of social and employee development (Friedman 2007).

Table 7.1: Benefits from Poultry Activities (Rahman 2013c, 2013b)

No.	Main Activity	Sustainable Benefits
1	Rearing Parent Chicks	Social and Economic
2	Rearing Mature Parent	Social and Economic
3	Hatchery Operation	Social and Economic
4	Producing Chicks	Social and Economic
5	Distributing Chicks	Social and Economic
6	Middlemen Operation	Social and Economic
7	Employ Agent and Sub-agent	Social and Economic
8	Creating Ultimate Broiler Farmers	Social and Economic
9	Selling Chicken to Middlemen	Social and Economic
10	Extend Farming Operation	Social and Economic
11	Making Profit	Social and Economic
12	Proper Dumping of Poultry Wastes	Social and Environmental
13	Using By-Products	Social, Economic and Environmental
14	By-Product Processing	Social, Economic and Environmental
15	Bakery Production	Social, Economic and Environmental

If social and environmental benefits can be achieved together, this is referred to as 'good' by Carter and Rogers (2008). The activity of appropriate dumping of wastes found in the poultry operation falls into this category. The poultry wastes generated from a poultry operation were discussed in chapters 3 and 5. Referring to the literature, it was revealed that some wastes were yet to be appropriately recycled and reused to generate extensive economic benefits for farmers. For instance, poultry feathers and intestines mostly remained unused for the case industry. They were selling poultry feathers for a lump sum price to third party companies for further processing (Chowan 2013; Rahman 2013a). However, the case industry personnel did not know the specific processes carried out by the feather processors. Some poultry intestines were supplied to fish farmers (Cobbler fish and catfish) and the remainder were dumped in an appropriate way. Some poultry processors are dumping these wastes in river and canal water which is suicidal for society, farmers and the surrounding community. This was why the case industry followed the appropriate environmentally friendly way of dumping such hazardous waste.

Three of the poultry activities in this study were directly achieving benefits for all three factors: social, economic and environmental. This triple bottom line success is recognized as achieving sustainability for a particular supply chain (Savitz and Weber 2006; Lee 2004; Carter and Rogers 2008). For example, processing by-products such as biogas, fertilizers and fish feed made from poultry wastes can achieve social, economic and environmental benefits. Recycling poultry wastes can keep the environment free from pollution, create small industries to process it and gain additional financial benefits by selling by-products. Even if the waste processors are using the by-products for their own consumption rather than selling them to the market, they are also saving money which is a direct economic benefit for them.

The earlier discussion on poultry activities and sustainability has revealed that sustainability theory and its components were covered by the activities operated by the case industry. Nevertheless, a particular point of concern was that some of the operations managed by third party companies were undertaken in an unorganized and unscientific way. The industry would be able to achieve all three aspects of sustainability if these operations or processes could function within an integrated model (see Figure 5.8 in Chapter 5).

7.2.3 Economic Activities in Poultry Farming

Economic gain is the main factor of concern in achieving sustainability. The company is always striving to reach its optimum targeted profit to accomplish other responsibilities such as social and environmental care. Three economic activities (table 7.2) were observed in the poultry industry in Bangladesh which are discussed in the following sections.

Table 7.2: Economic Activities in Poultry Farming

Indicators: Economic Factors	Poultry Activities
Financial Profitability (Dees 1998)	Making Optimum Profit
Value Addition (Ahmad and Seymour 2008; Acs and Armington 2004; Cobb et al. 2009)	Producing By-products and Chicken Processed Food
Sales and Cost of Goods (Cobb et al. 2009; GRI 2009)	Maximum Sales and Reducing Cost

7.2.3.1 Financial Profitability

The main inspiration for operating a business is to make a profit even it is a social business for eradicating poverty (Seelos and Mair 2007; Dees 1998). Without profit making, no business can be sustained to achieve its short- and long-term objectives: the poultry business is no exception to this motivation. The main product of the case industry is day-old chicks. Chicks' price in the current market determines their ultimate profit. Although the chicks' market is vulnerable in nature, the company can manage to earn an attractive profit at the end of the year. Figure 7.2 shows the inconsistency of the profit curve but that the company still manages to retain the expected average level of profit.

7.2.3.2 Value Addition

Value addition offers more resources and activities than a main product alone in order to provide additional facilities to customers (Cobb et al. 2009; Grönroos 1997). In this poultry process, by-products are generated in addition to the main product of day-old chicks. Poultry meat processing units produce many varieties of value-added products such as chicken nuggets, samosas, etc. which are beyond the research boundary. In the input–output poultry model (see Figure 3.8, Chapter 3), value-added chicken foods and by-products from wastes have been shown in order to comprehend the level at which these can be processed.

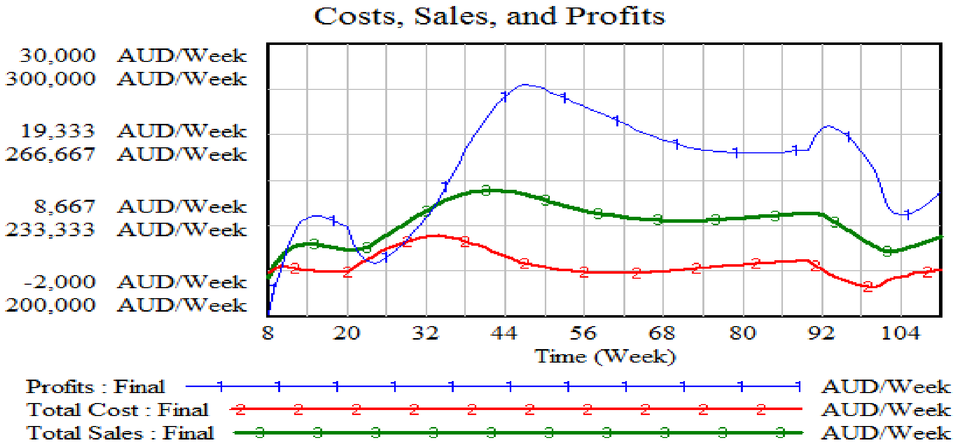

Figure 7.2: Simulated Behaviour of Costs, Sales and Profits

7.2.3.3 Sales and Cost of Goods

Sales and cost of goods are important indicators for assessing the presence of sustainability in a company (Cobb et al. 2009; GRI 2009). Sales are the heart of a business while cost of goods always influences sales and profit. For instance, the case industry produces chicks a certain amount of which needs to be sold in the market, otherwise they cannot minimize the cost of goods and manage optimum profits. At the same time, minimizing cost is the burning issue for the company as it helps to achieve additional profit. The case industry has taken many relevant steps to reduce their cost of goods by utilizing indigenous raw materials from its own sources. For example, the industry is using biogas to generate heat for brooding the chicks and is also using bamboo slats instead of costly imported plastic slats. This is how the industry is saving costs in its aim to make extra profit to cover all the necessary expansions and incentives for its employees and society.

7.2.4 Social Activities in Poultry Farming

Social benefits are one of the components for sustainability which are mostly a concern for society and community. Social indicators in sustainability concepts are listed in the various reports of GRI, AICHE and Dow Jones. A number of direct and indirect social benefits can be gained through a sustainable poultry supply chain process. Table 7.3

shows the social indicators that match the real-life poultry supply chain operation. Some direct social gains from the poultry processes are discussed below.

Table 7.3: Social Activities in Poultry Farming

Indicators: Social Factors	Poultry Activities
Employment Creation (Reynolds et al. 2001; GRI 2009; Cobb et al. 2009; Knoepfel 2001)	Parent Stock Farming, Hatchery, Middlemen, Ultimate (Broiler) Farming
Poverty Reduction (Yunus 2007; Krantz 2001; Coulthard, Johnson, and McGregor 2011; Rhyne 1998)	Farming, Working, Participating as Supply Chain Member
Create Self-employed Young Entrepreneurs (Wagner 2003; Freytag and Thurik 2010; Lazear 2003; Åstebro and Thompson 2011; Lynch 2004; GRI 2009; Cobb et al. 2009; Knoepfel 2001)	Farming, Distributor, Agent, Sub-agent, Supplier of Raw Materials, Middlemen (Chicks and Chicken Sellers), By-Products Processor, Ultimate Farmers
Creating New Ventures and Family Business Creation (Stock and Watson 2003; Dyer and Chu 2003; Heck and Stafford 2001)	Small and Medium-scale Farming, By-Products Processor, Sub-agent
Social Welfare and Care (Seelos and Mair 2005a; Hall, Daneke, and Lenox 2010; Sundin 2011)	Gaining Profit, Recycle and Reuse of Poultry Wastes

7.2.4.1 Employment Creation

Employment creation is one of the main concerns for research question one as it explores whether or not the forward supply chain of a poultry process creates employment. Employment generation is a major indicator of the social aspects of sustainability (Reynolds et al. 2001; GRI 2009; Cobb et al. 2009; Knoepfel 2001). The more employment generated, the more social contribution can be made by an industry. An employment opportunity denotes the capability of a person to steer one's family. Therefore, it has a tremendous positive impact over a society in acknowledging an industry for its contributions. For example, parent farming and broiler farming contribute the most in terms of creating employment opportunities. Notably, the employment of one person is required to rear 500 parents while broiler farming needs one person per 1,000 birds. In addition, the hatchery unit and role of the middlemen also create significant employment. Importantly, as more and more poultry birds are reared in a farm unit, more opportunities for employment will be created.

7.2.4.2 Poverty Reduction

Poverty reduction is an immense anxiety for the Bangladesh economy as more than 40% of its people are living under the poverty level (BBS 2010; Yunus 2007). Most businesses do not even know how they can contribute to eradicating poverty (Hancock 1992; Yunus 2007). It is not considered necessary for an industry to track how it contributes to addressing social issues. However, this can be assessed easily by the government or non-government agencies based on product turnover, people involvement, supply chain networks, etc. The poultry sector contributes significantly to the rural and urban economy. People are involved with the supply chain network of the case industry participating as a worker, agent and middleman, etc. For instance, workers of the participating farms eliminate their poverty by doing their jobs at a standard level of performance. Moreover, significant numbers of people are involved as workers for supply chain members. The case industry maintains its supply chain networks for distributing day-old chicks covering 70% of the country. Such a network creates better scope for eliminating poverty especially for the significant number of people living in the rural area.

7.2.4.3 Create Self-employed Young Entrepreneurs

Creating self-employed young entrepreneurs is stimulating for a society as it provides the opportunity for young people to be self-employed: sustainability performance can be judged based on how many entrepreneurs are involved within a business network (Wagner 2003; Freytag and Thurik 2010; Lazear 2003; Åstebro and Thompson 2011; Lynch 2004; GRI 2009; Cobb et al. 2009; Knoepfel 2001). There are many young unemployed people in the rural and peri-urban areas in Bangladesh. They are searching for suitable employment and small businesses so they can maintain their livelihoods. The prospect of tempting young entrepreneurs is relatively high within the poultry supply chain network. For instance, ultimate (broiler) farming is an opportunity for young entrepreneurs to become involved due to the low capital and space required. According to the poultry owner, one young entrepreneur can start rearing 1,000 day-old chicks with an investment of approximately A$3000 which is remarkably low in terms of investments required for other businesses. If they are maintaining 1,000 birds efficiently, it is expected that they can maintain their livelihood along with that of their family. Obviously, they have to consider various types of calamities, disasters and market fluctuations in maintaining their self-employed small poultry farming business. Similar opportunities for creating self-employment are available at the levels of distributor, agent, sub-agent, supplier (raw materials), middlemen (chicks and chicken sellers) and by-products processor.

7.2.4.4 Creating New Ventures and Family Business Creation

Creating new ventures is vital for a society as it expands the opportunities to involve more people and entrepreneurs (Stock and Watson 2003; Dyer and Chu 2003; Heck and Stafford 2001). At the same time, new ventures can be formed within a family. Even the case industry initiated their business in 1986 as a small farmer under the family business. They later expanded their business and converted it to a joint-stock company. They are continuing to operate their business under a family umbrella of three members. The case industry is a role model farm for the surrounded community due to their tremendous success in the past two decades. The difference between family businesses and other types of business is that it can be operated by family members with or without help of additional workers. For example, one person can maintain a 2,000-bird capacity in a small farm with assistance of other family members. Similarly, poultry by-product processing and sub-agents of day-old chicks' supply can be maintained within a family boundary. These initiatives can form more and more new ventures with so many opportunities to involve other people from within a society.

7.2.4.5 Social Welfare and Care

Social welfare and care are an ultimate responsibility for the company that makes substantial profits from an economy (Seelos and Mair 2005a; Hall, Daneke, and Lenox 2010; Sundin 2011). Social benefits are a kind of indirect 'payback' to society by the industry concerned. For instance, the case industry was established a primary school and a mosque and provides charity for disadvantaged people in the surrounding community.

7.2.5 Environmental Activities in Poultry Farming

Environmental management within the supply chain domain has been gradually building but remains scarce (Vachon and Klassen 2008). Environmental activities have become important for manufacturers as they face intense pressure from supply chain members (Henriques and Sadorsky 1999). The poultry industry is no exception as it generates a number of wastes which need to be appropriately dealt with. Otherwise, they will damage the environment in many ways. Table 7.4 presents the environmental indicators along with poultry activities in Bangladesh. The following sections discuss some direct environmental issues that the poultry industry needs to consider and is addressing.

7.2.5.1 Waste Recycled or Reused

Poultry wastes are no longer considered as something worthless to dump without recycling or reusing as they can be converted into valuable by-products (Sikdar 2007; Gertsakis and Lewis 2003; Tipnis 1993; Edwards and Daniel 1992). In the literature review section (chapter 2), the usage of various poultry wastes to make different by-products was discussed. This study has specifically focused on poultry waste management which relates to the reverse supply chain process of poultry operation. 'Recycle' and 'reuse' are separate terms with different meanings. Recycling is a procedure to convert waste into new products to prevent the potential harmfulness of waste (Elfasakhany et al. 2001; Murphy, Mueller, and Gowda 1993). For example, poultry litter (excreta) is converted into valuable by-products of biogas, fish feed and fertilizer. The case industry follows particular procedures to convert its poultry wastes into such valuable products. On the other hand, reuse means that something is used again after it has already been used (www.recycling-guide.org.uk). In a poultry operation, the products are perishable and cannot be stored for long time. Moreover, there is almost nothing to get back from customers after they have consumed the products. On the other hand, poultry litter is converted to biogas. After producing biogas, a certain percentage of wastes need to drain out which can then be used for making fertilizers. This is how the reuse concept is used in a poultry operation.

Table 7.4: Environmental Activities in Poultry Farming

Indicators: Environmental Factors	Poultry Activities
Waste Recycling or Reuse (Sikdar 2007; Gertsakis and Lewis 2003; Tipnis 1993; Edwards and Daniel 1992)	Reuse and Recycle Poultry Wastes
Reducing Environmental Degradation (Dean and McMullen 2007)	Reuse and Recycle Poultry Wastes, Using Biodegradable Chicks' Packaging
Biofuel (Biogas) (Hill et al. 2006)	Producing Biogas and Artificial Firesticks

Environmental Certification (GRI 2009)	Maintain Environmental Certification under Department of Environment, Bangladesh Government

7.2.5.2 Reducing Environmental Degradation

Environmental degradation is the decline of the environment through diminution of resources (air, water and soil), ecosystem and wildlife (Johnson et al. 1997). Nowadays, any kind of disturbance to the environment is not acceptable and it should be controlled from the source (Dean and McMullen 2007). The poultry industry generates a number of wastes which may cause biodegradation. Moreover, the poultry operation as a whole uses many raw materials to procure its feed and products which can cause the same degradation. For example, 40-50 day-old chicks are packaged in a box which can be made from plastic material which is hazardous to the environment. To protect against such damage, the case industry is making their chicks' packaging from cardboard and bamboo materials rather than using plastic or synthetic components. In fact, the farm needs to watchful over its whole operation to find out the risks of environment degradation and should take appropriate measures to control it. The poultry operation needs to track its wastes flow towards particular destinations such as canals, rivers and ponds and then address the potential consequences before they occur. For instance, the hatchery unit of the poultry operation uses highly corrosive cleaning materials to clean their incubators after hatching a batch of chicks. The case industry is specifically using a pond area into which corrosive water flows where it is contained: thus, the industry does not allow it to flow to another destination. This is how the industry can protect against environmental biodegradation to safeguard people and wildlife.

7.2.5.3 Biofuel (Biogas)

Biogas is an environmentally friendly renewable energy as are solar and wind energy that is produced from recycled wastes (Picken and Strub 1983; Deublein and Steinhauser 2011). Environment damage can be prevented through converting wastes into biofuel and biogas with this process aiming to reuse the wastes for a different purpose (Hill et al. 2006). As discussed earlier, poultry litter waste is converted to biogas which can be used for operating electric generators, heaters, burners, etc. The case industry is even considering converting biogas into electricity through a high-tech converter. For example, the case industry is currently using 70% of its poultry litter for converting into biogas. If they did not process such a quantity of waste to produce biogas, they would potentially dump it on vacant land, or into canals and rivers. By converting the wastes, they are saving the environment to a great extent.

7.2.5.4 Environmental Certification

Environmental certification is required for a company to be considered as having an eco-friendly operation (GRI 2009). In Australia, planning and environmental conditions are designed for poultry growers which are regulated by the government authority (GOWA 2004). Similarly in Bangladesh, the environmental agency under the concerned ministry provides environmental certification by observing the poultry operations and the surrounded atmosphere. The research case industry has retained this certification since the regulation was imposed on poultry farmers. This means that they are maintaining their operation in an environmentally friendly way.

Figure 7.3 depicts a sustainability diagram based on the research model shown on Figure 5.8 (Chapter 5). Using arrows, it clearly marks the benefits flowing from stock variables to sustainability indicators. This figure also points out the number of bakery items that can be produced from the unhatched eggs that flow from the hatchery and farms. At the same time, the number of employment opportunities is also measured through this model. The same effect has been shown in number nine (bakery items) on Figure 5.8. In addition, Figure 7.3 reveals the number of entrepreneurs that can be created at the distribution level which was also shown in number eight on Figure 5.8. Workers (additional employment) need to operate the small businesses of sub-agent and bakery unit which is also shown on the model.

As shown on Figure 7.2, mature parent, chicks, bakery items, biogas, fertilizer, intestines, fish feed and feathers are providing economic benefits. Mature parent, chicks, employment, middlemen, bakery and biogas processes are benefiting society. Notably, fish feed, intestines and feathers can also provide social benefits subject to small businesses being involved by the third party company. Lastly, environmental benefits can be achieved from profit and processing of bakery items, biogas, fertilizer, fish feed, intestines and feathers. Profit can also help to maintain the contribution to the environment. For instance; if the company made additional profit above the expected level, it will spend some proportion of profit to restore the environment or prevent environmental degradation for the sake of the surrounding community.

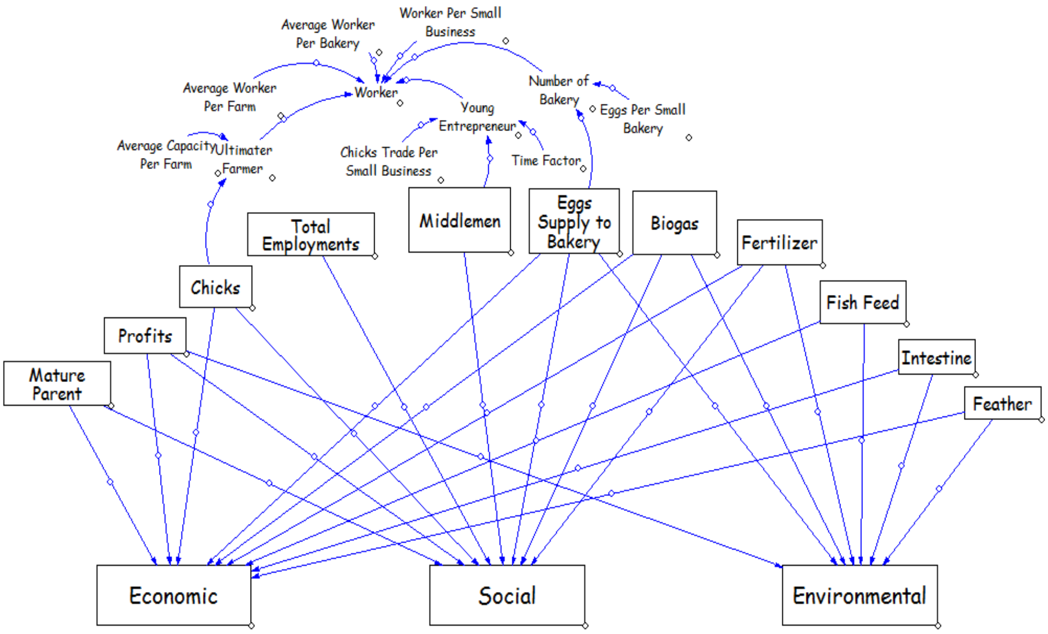

Figure 7.3: Poultry Process and Sustainability

The above discussion provided details about sustainability and its components in the supply chain of the case poultry industry. The discussion was based on economic, social and environmental aspects of sustainability. The case industry supply chain operation was found to bring economic, social and environmental benefits for the country. The impacts of such components are influential contributing to Bangladesh society to a great extent. Thus, the above-mentioned process can be regarded as an appropriately sustainable poultry production process that meets the purpose of achieving sustainability. The above sections therefore reviewed the first research question.

7.2.6 Summary

The motive of first research question is to quest the most appropriate sustainable poultry production process in light of triple bottom line of sustainability. Above discussions (see section 7.2) is tried best to defend the first research question. To support this question, above sections elucidates sustainable poultry production process (section 7.2.1) followed by sustainable benefits (economic, social, and environmental) from poultry activities. Later, economic, social, and environmental activities within the poultry process have been discussed to support this model as sustainable in nature.

7.3 RESEARCH QUESTION TWO: IN WHAT WAYS CAN THE POULTRY FORWARD SUPPLY CHAIN (FSC) BRING SOCIAL CHANGES LEADING TO EMPLOYMENT GENERATION AND, THEREBY, REDUCING POVERTY?

The second research question investigated the forward supply chain (FSC) process and its role in bringing positive social changes. The forward supply chain is a process which initiates from the raw material and progresses through to the ultimate consumption of a product (Bowersox 2011; Rogers et al. 2002; Poirier and Reiter 1996). The poultry forward supply chain is an extensive network starting from the pure line breed through to the final consumption of meat and eggs. However, this study has limited its research boundary to parent stock farming through to broiler meat consumption. This study has only considered broilers bred for meat supply and consumption. Within the research boundary, parent stock rearing, hatchery operation, chicks' distributors, agents and sub-agents under distributors, broiler farmers and middlemen selling mature chickens are involved. Therefore, a long supply chain exists within the forward channel which can contribute to social changes. The following sections deals with various social changes through poultry forward supply chains.

7.3.1 Forward Supply Chain and Various Social Involvements

Table 7.1, as described in subsection 7.2.1, lists the kinds of activities involved in the forward supply chain. Table 7.1 also shows that the first 11 activities involve sustainable social and economic benefits. Figure 5.5 and Table 5.5 (see chapter 5) previously mentioned the main areas (as a number) of the integrated model highlighting the number and title in a box. There were 10 different main areas identified and discussed in chapter 5. Within these areas, number one (parent stock), four (eggs and hatchery) and five (farmers and middlemen) are directly involved with the forward supply chain. In addition, capacity decision (area two) and profit and loss (area three) are also related to the forward supply chain but do not contribute social benefits instead computing and managing desired parents for future flocks and profits and costs.

Figure 3.9 (see Chapter 3) presented the forward supply chain process starting from the pure line poultry mother breed and finishing with customers. The case industry starts their operation from parent stock and maintains the rest of the processes in their forward supply chain. Operationally, parent stock day-old chicks initially come to the breeder farm and are reared for 22-24 week to become mature and are then named as mature parent. The mature parent is then reared for 42 weeks for hatcheable eggs collection. The hatchery unit starts by preserving eggs in scientific cold storage for a certain period. This unit again tests and examines hatchable eggs before setting eggs into hatching incubators. The eggs stay in hatching incubators for 18 days and are then transferred to the hatcher machine for the remaining three days. Finally, the chicks are ready to travel to the distributor for delivery to the final broiler farmers. The hatchery must establish the grade for their chicks with this recorded and acknowledged on the chicks' box. Normally, four grades are available in Bangladesh poultry, named as A, B, B+ and C. B+ and C grade chicks are not sold by the case farm to maintain goodwill. The healthy chicks are then distributed to the ultimate farmers through distributors, agents and sub-agents. Farmers rear these chicks for around four weeks to the maximum six weeks. Within four weeks, broiler chickens can be sold at weights of 1.2-1.5 kg while six-week-old chickens are expected to be more than 2.2 kg. Then, farmers sell their mature chicken to the middlemen at the different levels of wholesalers, retailers and chicken food processors of value-added product. Finally, consumers consume fresh and delicious chicken meat from open markets and processors.

Above involvements helps to create employments, involves the poor workers, invites young entrepreneurs to deal with fragmented business operation, includes various agents and sub-agents for supplying and distributing poultry feed and chicks. Every step of the poultry processes are somehow involved with the society in terms of accommodating people. Accommodating people as business owner, entrepreneur, worker and some other means is ultimately creating social gains. In this way, poultry forward operations are keeping tremendous contribution to the society in various ways.

7.3.2 New Ventures (SME) and Employments

Above discussions is spoken the story of social involvements with the poultry industry in Bangladesh. Now, table 7.5 revealed the numerical figure (from simulation results) of the number of bakery (new venture), distributing house (new ventures), employments, ultimate farmers and ground level workers. Young entrepreneurs can establish a small new venture based on participating in a poultry supply chain operation For instance; a small bakery can utilize unused eggs where 8-10 thousands of eggs flows from the farm as raw material for making bakery products. Each bakery can accommodate around 3-6 employees. Yet again, 2000-5000 chicks per week can be distributed through an agent (middlemen). A sub-dealer can survive by distributing even less than 1500 chicks per week. In fact, dealers and sub-dealers are also involved with feed selling to the farmers and act as middlemen of final product of chicken and eggs. This is how; they introduced themselves as a small business owner with accommodating around ten employees. Like this, the ultimate farmers' rear day-old chicks as the table 7.5 shows more than four hundreds farmers can accommodate with such productions. Ultimate farmers are involving the additional workers if they are rear greater than 2000 birds in a flock. Practically, small farmers (who rear around 2000 birds) manage their farming by their own with the help of other family members. If they failed to get help from family members then they need to involve permanent or part-time workers to manage daily farming works. Furthermore, more than 1400 workers can be involved throughout this poultry process while total employment is over two thousands. All of them can maintain their families by involving with these activities. Therefore, the social impact is huge in considering managing individual livelihood.

Table 7.5: Social Impacts through Poultry Rearing

Time (Week)	**50**	**100**	**150**	**200**	**250**	**300**
Number of Bakery	62	57	61	60	60	62
Young Entrepreneur	89	84	88	85	86	89
Total Employments	2,489	2,328	2,440	2,407	2,398	2,475
Ultimate Farmer	416	380	407	403	400	414
Worker	1,465	1,349	1,433	1,409	1,408	1,456

The above section describes the forward supply chain process and reveals the significant parties involved with this chain. The forward supply chain starts from parent stock farming and finishes with chicken consumption. This network maintains its contribution to society while it processes the product as it flows towards its final destination. The social gains are specifically concerned with poverty eradication, employment generation, and entrepreneurship development. Poverty eradication is accomplished by providing suitable jobs to the poor people. Again, Figure 7.4 presents the sources of employment generation at various levels of the forward supply chain. As shown, the levels of parent chicks and mature parent farm, hatchery unit, chicks' distribution units, broiler farms and middlemen create most of the employment. Figure 6.10 in chapter 6 also illustrated the simulated behaviour of employment generation from different sources. The number of bird transactions determines the ultimate amount of employment creation in the forward supply chain of the poultry process. Section 7.2.4.1 discusses how employment can be generated from the different processes of the supply chain. In addition, Figure 7.3 supports a similar understanding of the mechanism of employment generation. Thus, poultry forward supply chain process is helping to establish small ventures with thousands of employment opportunity.

7.3.3 Poverty Alleviation

Poverty is defined as being without capability to possess the basic human needs including food, water, sanitation, clothing, shelter, health care and education (Uchitelle 2001; INE 2009; Cowell 1995). One of the major goals from research question two was to detect how poverty could be eradicated through participation in a poultry supply chain network. Section 7.3.3.2 discusses poverty reduction at different levels of the poultry supply chain. It was acknowledged in the in-depth interviews that skilled poultry workers are in tremendous demand much more so than unskilled workers. In Bangladesh, a daily worker (casual) is paid from BDT 150 to BDT 250 (equivalent to A$2.15 to A$3.60) per day (Rahman 2013c). A casual poultry worker is paid more than BDT 350 (A$5) per day which is moderate for a poor worker. Moreover, a full-time worker is paid on a monthly basis: the minimum monthly payment is around BDT 10,000 with free housing facilities. Permanent workers also enjoy annual and sick leave on a pro rata basis. Notably, the more experience a poultry worker gains, the more payment they earn. The case industry has many experienced good workers who receive lump sum payments of around BDT 30,000 (A$428) per month. The wages paid to the workers seems like nominal in compare to developed country wages. However, such amount is sufficient enough for them as living expenditure is reasonable in contrast of advanced countries. In practice, it is possible to accommodate more than fourteen hundreds people as the skilled, semi-skilled and unskilled workers to maintain their family with modest lifestyle.

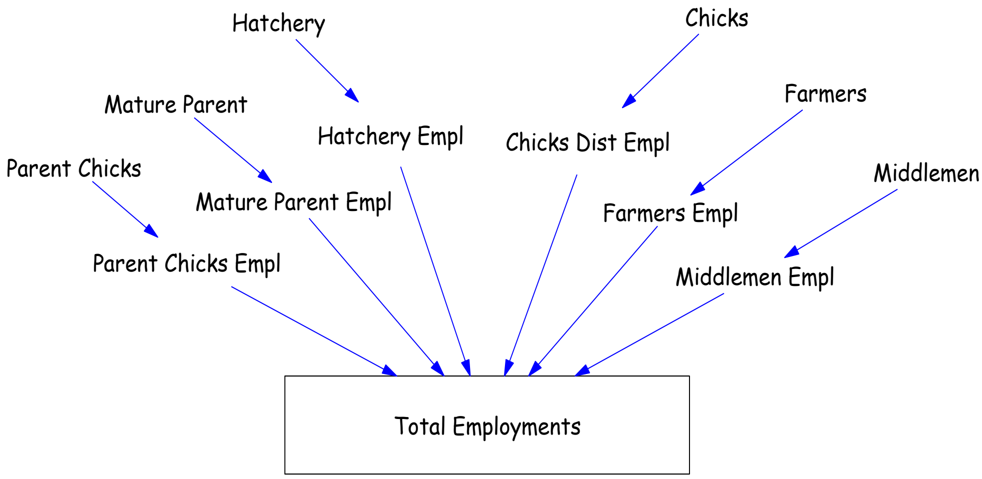

Figure 7.4: Employment from Forward Supply Chain

7.3.4 Summary

Sections 7.2.4.3 and 7.2.4.4 discussed the creation of self-employment and family ventures. The poultry sector has tremendous scope to expand its operations and production as per capita chicken and egg consumption is remarkably lower than the standard level in nearby countries. The protein deficiency in Bangladesh is significantly greater than expected which has been discussed in chapters 2 and 3. Every new venture, including self-employment and family businesses, helps to mitigate the poverty of individuals and groups such as families. This is how; the poultry forward supply chain is helping to change society in terms of providing social benefits. Social benefits include eradicating poverty, and creating employment and new entrepreneurs and ventures which appropriately responds to research question two.

7.4 RESEARCH QUESTION THREE: HOW CAN THE PRINCIPLES OF THE REVERSE SUPPLY CHAIN (RSC) BE USED TO RECYCLE POULTRY WASTES EFFECTIVELY?

The third research question examined the reverse supply chain (RSC) processes that recycle poultry wastes thus creating additional by-products for further use. The reverse supply chain is a modern concept which includes the activities of retrieval, utilization of used or unused products, appropriate disposal, reuse and recycling (Guide and Van 2002; Nagurney 2005; Dowlatshahi 2005, 2000; Kopicki, Berg, and Legg 1993). Most reverse logistics studies have highlighted reprocessing materials that come back from customers after a certain period of usage. However, recycling can be a part of the reverse supply chain (Dowlatshahi 2000, 2005; Tibben-Lembke 2002; Tibben-Lembke and Rogers 2002; Kopicki, Berg, and Legg 1993; Nagurney 2005; Hoek 1999). All of these studies have mentioned that recycling work can flow along the reverse chain of a process. Most of these studies also mentioned recycling after product use. In this study, the poultry industry has been taken as the case study which involves a live bird and is therefore a perishable business. It would be difficult to find similarities to product return after use with chicken products. The logic behind considering the reverse supply chain is that it can recycle its wastes to convert them into valuable goods. In a sense, poultry feed is used as intake and wastes come out as output which can also be compared to the reuse concept. At the same time, wastes from by-product processing can be used to make other types of products such as fertilizers and firesticks for rural household usage. Such uses can be compared with typical reverse supply chain theory of product return and reuse. Obviously, the study claims here that these processes comprise the poultry reverse supply chain. The next few sections discuss the effectiveness of usage of poultry wastes in accordance with reverse supply chain (RSC) principles.

7.4.1 Poultry Litter

The literature on poultry litter has been covered under the section on poultry waste management in the literature review discussion (see chapter 2). Table 5.11 (see chapter 5) presented the purpose and calculation of poultry litter from the poultry process. Chapter 6 (see Figure 6.11) described the simulation model behaviour of poultry litter and its by-products. Later, section 7.2.5 discussed poultry by-products and their economic benefits under the sustainability domain. These discussions and presentations focused on poultry litter and its by-products in order to understand its value and impact on the farm and society. Figure 7.5 displays the reverse supply chain process of poultry wastes in which poultry litter makes a significant contribution in terms of value addition. In this figure, poultry litter processing can be tracked in the upper-left corner of the split presentation of the integrated poultry supply chain model (see Figure 5.8 of chapter 5). In the integrated poultry model, poultry litter inflow comes from the maiden source of the mature parent. Broiler farms can be an additional source of poultry litter as they produce thousands of tonnes of litter. Unfortunately, the Bangladesh poultry industry still lacks of coordination between the different members of the supply chain. Such a relational gap hinders the achievement of overall sustainability. This study suggests forming collaboration between broiler and parent stock farms so that benefits can be maximized.

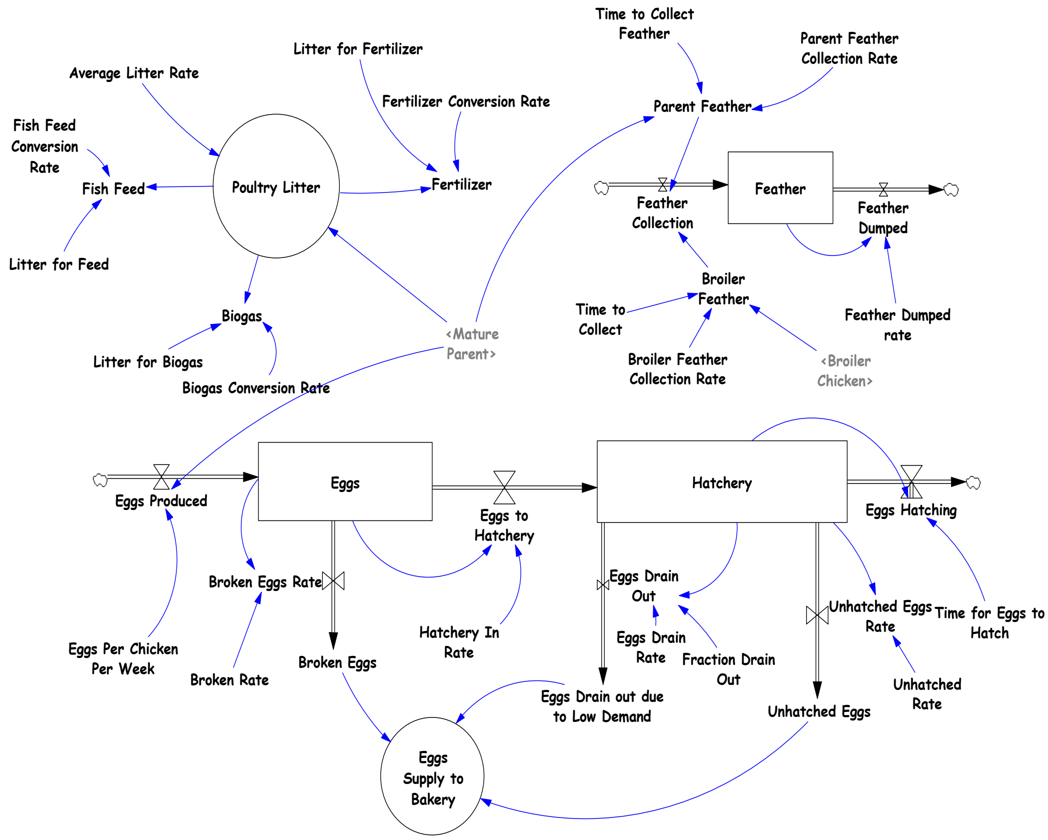

Figure 7.5: Poultry Wastes Usage under Reverse Supply Chain Process

7.4.2 Hatchery and Eggs

The hatchery unit deals with hatchable eggs from the parent mother from which day-old chicks are hatched. Significant numbers of eggs remain unhatched and are rejected at different stages of the hatching unit process. Chapter 5 (see Table 5.14) described the purpose and quantifying techniques of unused eggs from the poultry process. Chapter 6 (see Figure 6.15) depicted the simulation and real behaviour of waste eggs supplied to bakeries. This particular waste (unused eggs) is shown in Figure 7.4 (positioned in the bottom of the split model). As shown on Figure 7.4, there are three different sources from where waste eggs flow to bakeries. These three sources are, namely, broken eggs, unhatched eggs and drained out eggs. Absolutely broken eggs are supplied to fish farms rather than bakeries due to the hygiene issue. This portion of the model is an extended version developed by observing real-life practice. The objective of forming an integrated model was to maximize the benefits from its own sources. In practice, eggs are supplied to bakeries but the poultry processor never thought to incorporate such a unit within their operation. This study has highlighted the benefits that could come from this particular source which needs to be part and parcel of the poultry supply chain.

Table 7.6: Unused Eggs

Time (Week)	50	100	150	200	250	300
Broken Eggs	24,869	22,985	24,791	24,433	24,142	25,295
Eggs Supply to Bakery	244,731	227,619	242,481	236,779	236,971	247,772
Unhatched Eggs	219,862	204,634	217,690	212,345	212,829	222,476

7.4.3 Poultry Feathers

Poultry feathers are one of the wastes from which valuable by-products can be made. Unfortunately, a significant quantity of feathers remains unused. Chapter 5 (see Table 5.12) described the purpose and measuring methods for poultry feathers within the poultry process. Figure 6.13 of chapter 6 showed the simulation and real-life behaviour of poultry feathers flowing to the third party industry of making beds and pillows. Poultry feathers are shown in Figure 7.4 above in the top-right side of the split model. As shown on Figure 6.14 (see chapter 6), a significant quantity of poultry feathers can be collected from mature parent and broiler birds. This part of the model is also an extension from real-life practice where a proportion of the total collected feathers is supplied to bed and pillow producers. Nevertheless, a noteworthy percentage of feathers is yet to be collected and recycled or reused to receive maximum utility from it. The bed and pillow industry requires a certain amount of feathers based on their demand. The case industry collects that amount of feathers and rest remain unplucked from the poultry birds.

Table 7.7: Feather Production

Time (Week)	50	100	150	200	250	300
Feather (KGs)	10,060	9,477	9,874	9,492	9,702	10,002

The integrated model (Figure 5.8) modelled feather collection, the dumped rate and stock. The result (on Figure 6.13) showed approximately the amount of feathers that could be collected and used for further processing. Policy makers and poultry owners can now receive help from this research model which acknowledges the possible benefits of feather collection. They could establish additional businesses that process feathers which would bring economic benefits. At the same time, dumping poultry feathers is hazardous for the environment which could be protected by reusing feathers. Thus, the current integrated simulation model could assist farmers to quantify the total collection of feathers so that they can plan to obtain maximum benefits from it themselves.

7.4.4 Poultry Intestines

Poultry intestines are an almost untouched waste during the poultry process in Bangladesh. There is a little usage by fish farmers and the rest is dumped into the environment. In such a way, the environment is being polluted and poultry and human diseases are carried to the surrounding communities. Figure 6.16 from chapter 6 presented the simulated behaviour of intestine collection from broiler and aged parent birds. In real practice, above 90% of the intestines are dumped on low-lying land, and in canals and rivers which is injurious to humans and wildlife (Rahman 2013a). The integrated poultry supply chain model has extended this object to investigate the quantity of intestines that could be collected from the poultry operation. By using this model, policy makers and poultry owners can consider reusing and reprocessing this valuable waste. If they could use such a large quantity of poultry intestines, farms and society could benefit in various aspects. At the same time, they could benefit economically increasing their profitability.

Table 7.8: Intestine Production

Time (Week)	50	100	150	200	250	300
Intestine (KGs)	6,200	5,837	6,085	5,853	5,979	6,164

Above discussion of the reverse supply chain and poultry waste management, deep insight into and an acknowledgment of the opportunities in poultry waste recycling, reuse and reprocessing have been achieved. Research question three is thus appropriately answered by the above discussions. In addition, discussions in previous chapters have also supported the research objectives of the study. Specifically, the present status of the poultry industry in Bangladesh was discussed in chapter 3. Later, a sustainable poultry supply chain model was developed in chapter 5. Discussion of this model covered the qualitative and quantitative aspects of system dynamics (SD). At the same time, discussions addressed environmental matters within the poultry production processes in order to manage poultry wastes. The reverse supply chain along with the environmental issues was reviewed in chapters 2, 3, 6 and 7. The model was effectively designed as 'know-how' and a guideline for poultry waste management for the sake of protection of the nearby environment while retrieving valuable by-products for further benefits. Finally, chapters 2, 6 and 7 discussed how to gain maximum social benefits through structuring the poultry forward chain.

7.4.5 Summary

The main purpose of research question three is to identify the recycle and reuse of poultry wastes effectively. At the same time, the research looked at the possibility of creating additional economic and environmental values from the wastes through making valuable by-products. Section 7.4.1 discussed about poultry litter which is the most important concern for the poultry farmers. The research model (figure 5.8 of chapter 5) was shown the opportunities to convert the poultry wastes into valuable products which can be used in the same industry or to the surrounded farmers and community. Again, unused farm and hatchery eggs can be established small bakery industry with further employment opportunity (according to section 7.4.2). At the same time, wastes procuring are keeping social contribution through establishing small business with new employment opportunities. Once more, the extended model is considered poultry feather and intestine that can be used for making valuable by-products of synthetic plastics and fish feed respectively. Last but not the least; poultry waste management can keep surrounded environment clean and hygiene that is expected to the farmers for disease management. Therefore, above discussions are attempted to defend research question three by showing the opportunities to manage poultry waste management for the sake of availing sustainable benefits.

7.5 SUMMARY

This chapter has provided a discussion on the findings based on the combination of literature review, simulated behaviour analysis and the integrated poultry supply chain model. The clarification of the findings has been carried out to support the research questions. It is acknowledged from the discussion that the real-life poultry supply chain could achieve sustainability if supply chain members follow the integrated simulation model (chapter 5). The model can be used to observe the consequences of expansion, increased and decreased production, calamities and disaster situations, etc. Importantly, the model could be used to measure the quantity of wastes, by-products and unused wastes. This information will help the relevant authorities to take appropriate action on changes needed in their existing supply chain operation. Thus, this chapter has provided some essential lessons and strategies for the poultry supply chain in the Bangladesh context. The following chapter provides concluding remarks and future directions arising from the current research.

CHAPTER 8:

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

8.1 INTRODUCTION

System dynamics (SD) and the application of simulation modelling techniques are not easy-going methods for the poultry executives and policy makers of Bangladesh. System dynamics (SD) has made it possible to model a typical business supply chain process along with its diverse members and interactions between many key players in a useful and realistic manner (Maliapen 2003). Once a practical model is developed in a simulation environment, it is then easy to experiment with various inputs, rates and scenarios. By observing different scenarios, policy makers can adopt the best changes into their real business operation. The creation of the poultry simulation model in the supply chain context has provided insights for decision makers and managers about far-reaching goals. The first part of this chapter identifies whether the poultry case industry could use a structured simulation model with SD methodology to implement a visionary plan, for competitive advantage and for achieving sustainability in light of the economic, social and environmental benefits. Subsequently, the chapter summarizes the entire research and highlights the key findings from previous chapters. Relevant issues revealed during the study, including study limitations and implications for future research, are identified and recommendations suggested.

8.2 SUMMARY OF THE RESEARCH

The Bangladesh poultry industry has not received much attention from academics and Bangladesh government policy makers in the years since 1990. Until now, few studies have been conducted on the basic components of the poultry industry in Bangladesh. In the earlier literature, discussions were confined to the poultry production system (Das et al. 2008a, 2008b; Bessei 1993), scavenging backyard farming (Nielsen, Roos, and Thilsted 2003; Askov H. Jensen 1996), economic and social issues of rural poultry farming (Guèye 2002; Danish Ministry of Foreign Affairs 2003; Jabbar and Seré 2004; Fattah 2000) and small poultry model (Dolberg, Mallorie, and Brett 2002; Islam and Jabbar 2005; Ahmed 2000). In the last two decades, the poultry industry has developed significantly in terms of its systematic (scientific) production process within a commercial environment. The poultry industry then started to contribute significantly towards the country's GDP, directly and indirectly creating increased employment through millions of jobs, providing social and economic contributions, etc. This was discussed in chapters 2 and 3. Sustainable poultry production along with structured supply chain networks has recently been addressed in the contemporary literature. This particular study is a continuation of the current research trend which intends to fill the research gap. This study is unique in terms of its development of an integrated process in which forward and reverse supply chains function together. It was assumed that such integration would create more opportunities to benefit the economy, society and environment. This current research has proved the assumptions made at the beginning of the research in its research questions. The final summary of the existing research is discussed in the following sections.

Chapter 1 expressed the intention and uniqueness of conducting the present research based on its importance and the research gap in the current literature and practice. The focus and scope of the research were discussed in order to understand the boundary of the present research. Research objectives and questions were stated in the same section to understand the reasons for the direction of this research. The complete outline of the thesis, including key terms, was provided to add depth to the discussions. This particular chapter worked as a guideline for conducting the rest of the research as well as outlining the construction of the thesis. The relevant literature was next reviewed in chapter 2 to identify the appropriate research gap. At the same time, the worthiness and suitability of the current research was discussed in light of the research gap and future prospects. Continuing this discussion on the literature, chapter 3 described two aspects: the Bangladesh poultry operation and the case industry operation. To find the answer for the first objective, the discussion was compiled based on the Bangladesh poultry operation, including products, middlemen, supply chain networks, contribution to the rural and national economy, typical poultry rearing systems, calamities and disaster faced by the farmers, etc. In the latter section of this chapter, the case industry was described in light of its mission, vision, production, products, supply chains, strategies at times of calamities, and other aspects. This description introduced the Bangladesh poultry operation and case industry operation to this thesis. chapter 3 was the foundation for understanding the existing process of the Bangladesh poultry industry thus making it easier to identify the possible areas that need to be developed.

A rigorous research process was designed to undertake the current research. Consequently, chapter 4 discussed the research design and process for the current study. Notably, the current research followed design science methodology under the positivist paradigm. At the same time, this research employed a system dynamics (SD)-based quantitative approach to construct and analyse the poultry supply chain model. The system dynamics (SD) approach combined qualitative (causal loop diagramming) and quantitative modelling. In qualitative modelling, the causal loop diagram was developed based on real-life relationships among the variables. Later, the causal diagram was converted into the quantitative model by adding the necessary stocks (levels), rates (flows) and auxiliary variables. Complete methodological flowcharts were discussed in this chapter, which also addressed the issues of reliability and validity. A research process with such rigorous methodology had not previously investigated the poultry supply chain in the Bangladesh context.

To answer research question one, the causal loop diagram (qualitative) was developed in chapter 5. Key variables were identified to build the complete causal model. Later, the stock and flow model was developed based on the causal diagram model. Consequently, appropriate rates, formulae and equations were used to run the model in the virtual world of the simulation environment. In addition, the model was extended into the field of waste reversal to compare this with real-life poultry supply chain practice. This is an area to which the study given much emphasis when exploring how to combine supply chains and achieve sustainable benefits. In addition, the model's cause (cause–effect) trees were shown and discussed to perceive the internal relationship between and among the variables. The term 'multi-effect condition' was used to describe the relationship in which more than one variable was influenced by and from other variables. The model contained many complex relationships which involved more than 20 loops and each loop consisted of a number of variables which influenced one another. Chapter 5 focused on 10 major areas which were discussed one after another with related equations and formulae. The plotted areas in the model were discussed which indicated the purposes for their involvement in the model and how and why they work in real life.

Research is normally tested through results and outcomes from analyses and the current research is no exception. Most of the simulation-based analyses and results were presented in chapter 6. In this connection, simulation analysis was used which is a form of analysis mainly focused on behaviour over time for a particular(s) variable(s). The results were analysed in the aspects of forward, reverse and integrated supply chains. Key variables were considered to present the behaviour over time for a period of six years (312 weeks). Within these six years, the first two years' outputs were considered in comparison with reality and remaining four years involved projecting future outputs. To check for structural accuracy, the model was compared with real-life behaviour for the first two years with real-world data collected from the case industry to match with model (simulated) data. At the same time, results were examined again and again for consistency and accuracy to verify the reliability of the model in comparison with real-life practices. The validity issue was then discussed to prove that the model was valid in comparison with the real-life process. In addition, the model was checked under all possible extreme conditions to find the optimum and desired outputs. The model results responded very well in the context of proving that it was a valid model. At the same time, sensitivity analyses were conducted to cross-check the validity and reliability of the model which is important to the modeller. In addition, sensitivity analysis took place to confirm model robustness and all tests were passed successfully. To that end, three scenario analyses (see section 6.8) were conducted based on the goals of policy makers and farmers. All the tests were given expected outcomes in a situation which was in line with their goals.

The discussion of the results in chapter 7 was based on analyses of all results in the study and their impact on decision making. Decision making can influence the future behaviour of the industry. Any logical and substantial changes might be welcomed by the industry personnel comprised of decision makers and policy makers. The research questions were responded to in this particular chapter by referring to the main components of the research model. It was also evident from this discussion about the kind of positive changes that could be achieved if the model were to be adopted. The forward supply chain in terms of social changes and the reverse supply chain in terms of waste management were later discussed. Both these discussions were confined to the achievement of more economic, social and environmental benefits, which was named as sustainability. The current research model and its outcomes can be used in the real supply chain to attain a sustainable poultry production process with sustainable benefits.

8.3 CONTRIBUTIONS OF THE RESEARCH

The findings from this study reveal that this research has made a valuable contribution to both theoretical and practical points of view. The study has also provided an insight into the sustainable supply chain process of the Bangladesh poultry industry. Specifically, the study has successfully integrated both the forward and reverse supply chains in order to achieve sustainable benefits. The following sections discuss both contributions.

8.3.1 Theoretical Contributions

The leading theoretical contribution of this study was to develop a system dynamics (SD)-based integrated supply chain model in the Bangladesh poultry industry. No evidence to date was found of research conducted on this issue which had considered both the aspects of forward and reverse supply chains along with the use of DSR and SD methodology. The model is an extended version of real-life practice which involves sustainable benefits for the farmers, society and the environment. This extension incorporated scattered processes into one framework for the sake of better productivity.

Secondly, the study also contributed by revealing the positive social benefits that could be achieved through a specific forward supply chain. The forward supply chain consists of a number of trading partners involved in processing the poultry products of eggs, day-old chicks and mature chicken. The trade journey between the poultry parent farm and consumer is associated with various processes of parent farming, hatchery operation, middlemen activities, broiler farming and distributing mature chicken to consumers. Within the process, a number of social contributions can be made such as employment generation, entrepreneur development, poverty reduction and environmental care for human hygiene and health. This massive interaction between the poultry process and social benefits had not been dealt with by the previous research. This specific contribution enriches the relevant theory of the Bangladesh poultry supply chain.

Thirdly, the study profoundly considered environmental and waste management issues based on various wastes created from the poultry operation. Bangladesh is a small country having hundreds of million people living amidst a number of environmental hazards. The poultry industry is escalating such hazards in various ways by inappropriate dumping of wastes on vacant land and in canals and rivers. This research has developed a model in which poultry waste management has been considered not only as a way to reduce environmental degradation but also for economic and social gains. There are a very few previous research studies that have mentioned waste processing but no study to date has shown the benefits that can be derived. Obviously, this particular aspect of the study fills the existing literature gap on the environment, poultry wastes and sustainability.

Finally, the decision support system (DSS) in a system dynamics (SD)-based simulation model is an exclusive model that has been developed in order to consider the future behaviour of the poultry supply chain and its model behaviour. At the same time, a qualitative system dynamics (SD) model was developed to understand the linkage between variables for the poultry supply chain. This important diagram can handle future assumptions regarding facing various calamities and disaster. This model also explicitly considers calamities and disaster which is an integral part of the poultry process in Bangladesh. This kind of dynamic model development can track possible disasters in time to prepare to face them. By doing so, the poultry industry can prevent economic losses and acquire knowledge on upcoming market trends. Thus, the DSS based model was examined to enrich the theoretical gap about the 'things to do' in an unpredictable situation.

8.3.2 Practical Contributions

The case parent stock (PS) farm is planning to implement and put into practice the outcomes of the study. The following sections discuss the study's specific contributions for the real-life practice for the poultry industry in Bangladesh.

Firstly, the integrated supply chain model has become the highest priority for the case industry to implement in their supply chain network. The simulation model is a useful tool to analyse and track the supply chain variables to measure their performance. Before putting the model into practice, the industry needs to amend the model based on its own operational boundaries. In this situation, they may need to hire an expert with the required knowledge on modelling to operate the simulation model. The industry can track the possible time-based behaviour of the main products of eggs and day-old chicks by implementing the research model. Such a facility will help the industry to achieve sustainable growth.

Secondly, the model can be practised in the forward supply chain of the poultry operation. There are a number of processors involved in the forward chain who make social contributions in terms of employment, poverty reduction, etc. The model and study outcomes will help entrepreneurs to develop possible changes in the forward supply chain which will increase the economic and social contribution to the industry and society respectively.

Thirdly, implementation based on the research output will help to reduce and reuse poultry wastes by recycling them to produce valuable by-products. This particular practice could bring sustainable benefits to farmers, society and the environment. Previously, the industry was not too concerned about recycling their poultry wastes with a few exceptions. With this study, they are clear about the recycling processes under the reverse supply chain which will support them to attain multi-faceted sustainable benefits.

Fourthly, the industry would be able to practise the standard management of employment, hatching, distribution and farming through implementing the research output. The study revealed the standard process units for every processing level which will assist them to measure the actual requirement. Importantly, appropriate management will save them costs and time to implement timely and targeted production.

Finally, the research model can generate production behaviour over time for as many years as the industry wants to foresee. The decision making will be smooth once the model is applied in practice. Thus, futuristic assumptions can assist them to prepare for high and low demand and supply from and to the market, respectively. For example, the industry can track the high demand and times of disaster so that they can regulate their production to adjust to the market which is important for the poultry operation. Most of the time, Bangladeshi poultry farms are victimized due to fluctuations of supply and demand. More supply at times of low demand will be disastrous for the company. From this day forwards, the industry can protect against such uncertainties by using the predicted model behaviour over time for that particular variable.

8.4 IMPLICATIONS FOR POULTRY INDUSTRY AND POLICY MAKERS

The implications are derived from the integrated poultry model being adopted to create a sustainable production process with effective supply chains. The integrated poultry supply chain can bring more sustainable benefits than what would be achieved by participating as a fragment of a whole operation. The implications for the case industry are as follows.

8.4.1 Using Simulation as a Decision-making Tool

The proposed model, which is simulation-based analysis, demonstrated an easy procedure to select the best alternatives from various conflicting criteria. Using the simulation tool supported with software applications such as Vensim may help poultry management to evaluate their decisions more efficiently and effectively as compared to the traditional method. Simulation is the most updated application to experiment the real-life case over a computer screen which is very effective. Industry personnel can simulate their process changing possible values for what they want to implement. The results will help them to ensure whether or not their goals are acceptable. Outcomes from the simulation analysis can be compared with the experience of decision makers providing insight into the differences. Finally, they can conduct sensitivity analysis to test for different scenarios and the conditions of various problems.

8.4.2 Using System Dynamics as a Decision-making Tool

System dynamics (SD) is challenging tool but is useful in terms of being more applicable in solving various problems and in more closely reflecting reality. Using system dynamics as a decision-making tool for problem solving helps the relevant farms to perceive holistic and dynamic aspects of a problem rather than a static snapshot. Decision makers and policy makers are able to accommodate more variables, provide interrelationships among variables, and minimize time delays in problem solving. Using a structured model simulating key variables can test policies that may be used as a warning sign to detect unintended outcomes and generally improve system behaviour.

8.4.3 Decisions Relating to Business Expansion

The simulation model for integrating the poultry supply chain can also assist to calculate the economic returns. Such economic benefits rely upon the number of birds that are transacted in a supply chain. The more birds that are transacted in a system, the more chances there are of gaining profits: the risk of losses is higher as well. Profits and losses depend on successful production and optimum market prices of ultimate products. The case industry has the vision of increasing their production capacity and market extension in terms of chicks' production. Now, they can utilize the model to perceive alternative tests of increased capacity with fluctuating prices to consider whether or not expansion will gain addition profits. If it is not profitable, then they should not reconsider the initiative for expansion: otherwise, expansion should proceed.

8.4.4 Improvements on Existing Situation

The simulation study can suggest the possible changes needed within an unchanged situation. This can improve existing process management to achieve better efficiency with no changes of finance and resources. Sometimes, a company cannot make changes and undertake expansion even it is worthwhile to do so due to financial inability. In such circumstances, the company can use a simulation tool to conduct experiments on existing resources to find out ways to achieve better productivity. For example, the following things could be addressed:

- ✓ Managing existing resources for better efficiency and productivity;
- ✓ Restructuring the relationship between the supply chain members and stakeholders to gain maximum benefits;
- ✓ Managing existing risk (calamities and disaster situation) by taking appropriate measures;
- ✓ Extending markets through effective relationships with supply chain members;
- ✓ Forecasting the future market trends through simulated behaviour over time so that they can prepare themselves for upcoming rises or falls in the market situation;
- ✓ Ensuring sustainable benefits in society in terms of creating entrepreneurs, employment, poverty reduction, social care, etc.;
- ✓ Maintaining a hygienic environment through timely poultry waste management;
- ✓ Measuring the production of economically feasible by-products from poultry wastes to create economic, social and environmental benefits.

8.5 RESEARCH LIMITATIONS

The limitations of this research comprised constraints in the following matters:

Firstly, the simulation model is suitable for the process from the parent stock (PS) farm through to the broiler chicken consumer. The study did not consider the preceding breeds of grandparent (GP), great grandparent (GGP) and pure line (pedigree). Thus, it is sometimes difficult to predict the quantity from the initial parent breeder as there should be a strong relationship between the number of GGPs and GPs. The number of GPs will measure the appropriate number of PS. The research considered the parent breeder as the initial breeder for the model with no link to the preceding breeder other than assumptions based on the in-depth interviews. Therefore, the model may not provide accurate forecasting because of the potential dissimilarity in the provision of input parent chicks.

Secondly, the model was developed according to the available information derived from in-depth interviews, focus group discussion and observation. Any misleading information may lead to results that are dissimilar from what they should be. The standard production guideline from the mother breed company does not match the Bangladesh perspective due to the involvement of several calamities and disasters. The current research has taken only a case farm to simulate the model which is slightly unreliable in authentication of the whole scenario. If it was possible to cross-check with few companies, then this would potentially be treated as more accurate. However, the current research has been cross-checked through the observation technique to validate the information that came from in-depth interviews and focus group discussion.

Thirdly, the research has taken the Bangladesh poultry industry as its field rather than considering other countries. The model may not work from the perspective of a different country. For example, the calamities and disasters considered in this model occur in the Bangladesh context but may have no similarity with other environments.

Lastly, if the poultry industry needs meticulous prediction, accurate information between the model analyst and stakeholders is a mandatory requirement. Nonetheless, the current research model and its analyses are useful as straightforward strategies and policies. They provide knowledge and understanding to support poultry executives to test models based on input, rates, influenced objects, assumptions, etc. which they feel fit the proposed industry.

8.6 FUTURE DIRECTIONS

The knowledge gained from conducting this research relating to sustainability, supply chain; simulation and the Bangladesh poultry industry can be further expanded to address various prospects.

When a simulation model is developed in a specific type of industry for a particular country, it may not be appropriate for the same operation in another country. However, the study has taken the first step using a specific environment which can be extended through incorporating different environments. In disseminating the outcomes of the current study, more countries might show their interest in incorporating the present research knowledge into their operation. To do so, the research model needs to be adjusted based on the prospective supply chain operation to work appropriately. At the same time, the current research model can be experimented with and utilized by a similar kind of industry in Bangladesh. To do so, no changes would be incorporated as the client would have the same pattern of operations as the existing research's case industry.

This is the first instance of carrying out this kind of study on Bangladesh and its poultry parent stock (PS) farms. It would be stimulating to carry out longitudinal research because long-term research could reveal the true necessity of system dynamics (SD) applications and whether or not they contribute to the success of policy and decision making in the same type of industry. Practical benefits through simulation-verified policy would inspire farmers and policy makers to undertake more research. More research efforts will definitely help farmers to achieve better productivity while ensuring maximum sustainable benefits.

The current research is mainly centred on a case parent stock (PS) farm and its supply chain network. Future research could be directed to each individual supply chain member on their distinctive operations. If research on distinctive operations could be conducted for each supply chain member, then every single party of the supply chain network would be assisted to structure their operation, including ensuring and forecasting benefits that would arise from their operations.

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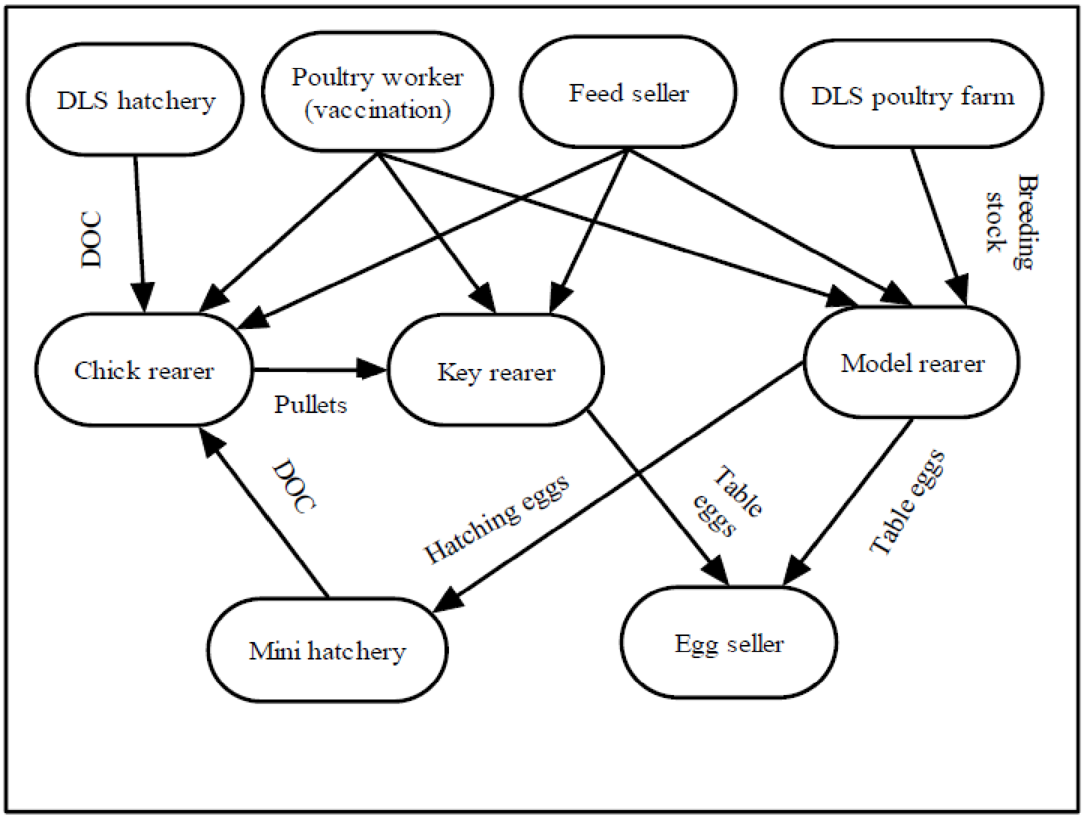
APPENDICES

Appendix A: The Bangladesh Poultry Model in SLDP (Dolberg, Mallorie, and Brett 2002)



Appendix B: System Dynamics Modelling Approach in "SD-based" Research

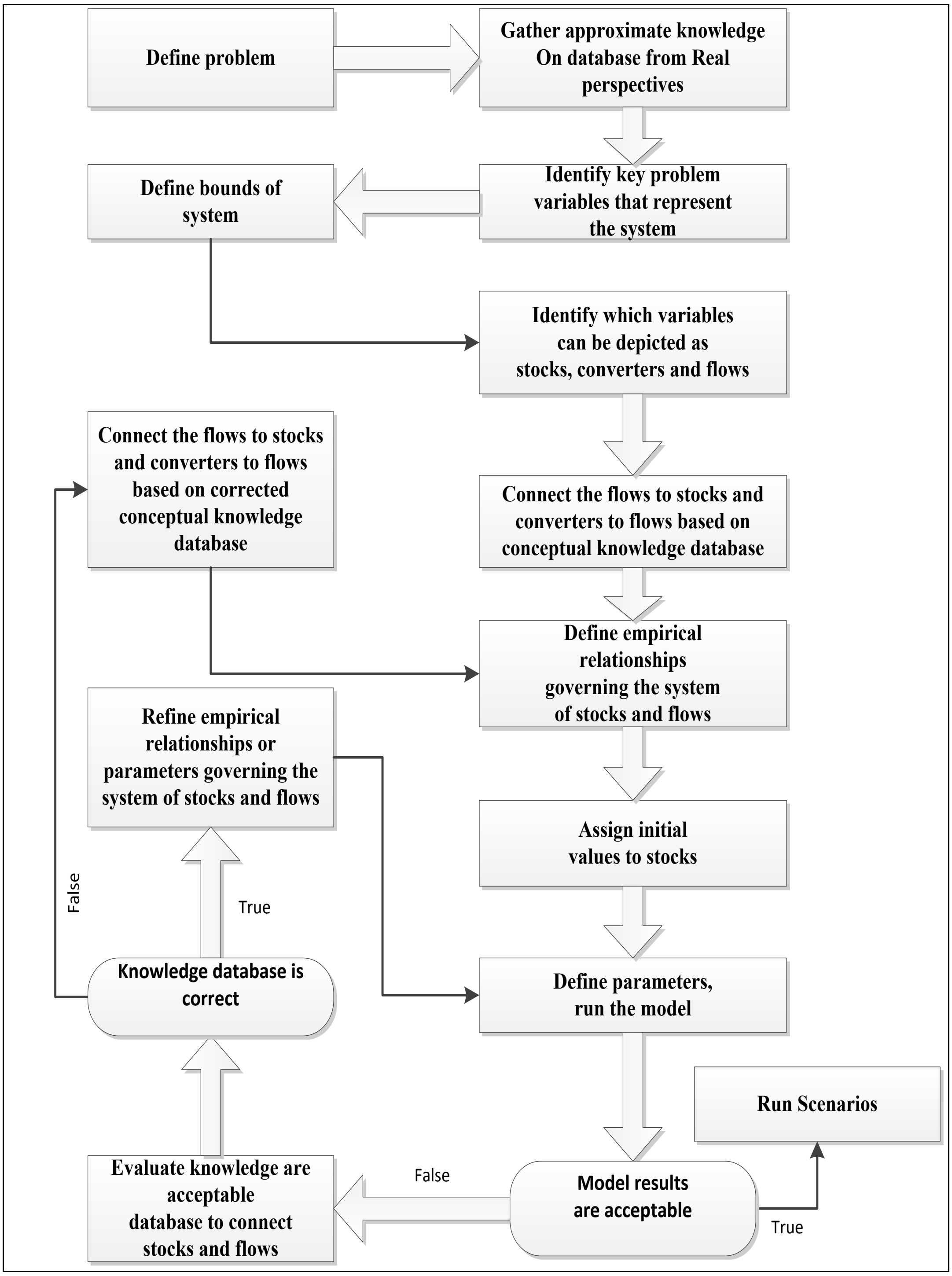


Figure: System Dynamics Modelling Approach (Jutla, Elshorbagy, and Kells 2006)

Appendix C: List of Variables with Units and Equations Used

Level Variables

1. Broiler Chicken = INTEG (Chicken Supply-Consumed, 0), Units: Chicken
2. Eggs = INTEG (Broken Eggs Rate + Eggs Produced - Eggs to Hatchery-Broken Eggs Rate, 0), Units: Eggs
3. Farmers = INTEG (Farm In-Chicken Mortality Rate-Retail Rate, 0), Units: Chicken
4. Feather = INTEG (Feather Collection-Feather Dumped, 0), Units: Kg
5. Hatchery = INTEG (Eggs to Hatchery-Eggs Hatching - Eggs Drain Out-Unhatched Eggs Rate, 0), Units: Eggs
6. Intestine = INTEG (Intestine Collected-Intestine Dumped, 0), Units: Kg
7. Mature Parent = INTEG (Parent Maturing Rate - Culled Parent Rate-Deaths - Parent No Longer Productive, Initial Mature Parent), Units: Parent
8. Mature Parent Capacity = INTEG (New Mature Parent Capacity, Initial Mature Parent Capacity) Units: Parent
9. Middlemen = INTEG (Retail Rate-Chicken Supply, 0), Units: Chicken
10. Parent Chicks = INTEG (Parent Chicks Rate - Aggregate Policy Impact-Parent Maturing Rate, Initial Parent Chicks), Units: Parent
11. Total Employment = Max (1500, (Farmers Empl + Biogas Empl + Middlemen Empl + Fertilizer Empl + Fish Feed Empl +Hatchery Empl + Mature Parent Empl + Parent Chicks Empl + Chicks Dist Empl)), Units: Persons/Week

Auxiliary, Constants and Data Variables

12. Adjustment Time for Mature Parent Capacity = 4, Units: Week, RANDOM NORMAL (3, 4, 3.5, 0.1, 100)
13. Age and Culled Parent = (Aged Parent + Culled Parent) * "Intestine/Parent", Units: Kg/Week, Intestines from Aged and Culled Birds
14. Aged Parent = Parent No Longer Productive, Units: Parent/Week
15. Aggregate Policy Rate = (Policy Variable * Policy Impact Rate/Tenure) * PULSE TRAIN (34 , Tenure , 68, 1000), Units: 1/Week
16. Average Chicks Price = 0.75, Units: AUD/Chicks, 50 taka = 1 chicks * 7 days/70
17. Average Cost Per Week = 0.9, Units: AUD/Parent/Week, 900 taka/23 weeks + 3000/42,RANDOM UNIFORM (1, 1.2, 1000)

18. Average Litter Rate = 0.00441, Units: Ton/Parent/Week, Daily=0.00063, Weekly = 0.00063 * 7 = 0.00441
19. Average Meat Price = 3.5, Units: AUD/Parent, AUD 1 equals to 70 BDT (Approximately), RANDOM UNIFORM (3.2, 3.8, 1000)
20. Average Parent Chicks Costs Per Week = 0.325, Units: AUD/Parent/Week, RANDOM UNIFORM (0.3, 0.35, 1000)
21. Average Productive Life = 42, Units: Week, Maximum time of laying eggs is 40 weeks, Average Productive Life of Mature Parent
22. BGER = 0.0001, Units: Person/Cubic Metre, Biogas Employment Rate
23. BICT = 4, Units: Week, Broiler Intestine Collection Time
24. Biogas = Poultry Litter * Litter for Biogas * Biogas Conversion Rate, Units: Cubic Metre/Week
25. Biogas Conversion Rate = 71, Units: Cubic Metre/Ton
26. Biogas Empl (Employment) = Max (5, (Biogas * BGER)), Units: Person/Week
27. Broiler Chicken = INTEG (Chicken Supply-Consumed,0), Units: Chicken
28. Broiler Feather = (Broiler Chicken * Broiler Feather Collection Rate)/Time to Collect, Units: Kg/Week
29. Broiler Feather Collection Rate = 0.102, Units: Kg/Chicken/Week
30. Broiler Intestine = (Broiler Chicken*"Intestine/Broiler")/BICT, Units: Kg/Week
31. Broken Eggs = Broken Eggs Rate, Units: Eggs/Week
32. Broken Rate = 0.035, Units: 1/Week, RANDOM UNIFORM (0.03, 0.04, 1212)
33. CDER = 0.0002, Units: Persons/Chicks, Chicks Distribution Employment Rate
34. Chickens Maturing for Market = Farmers/Time to Mature Chicken, Units: Chicken/Week
35. Chicks = Eggs Hatching * Hatching Percentage, Units: Chicks/Week
36. Chicks Dist Empl = Chicks * CDER, Units: Person/Week
37. Chicks enter to Broiler Farms = 0.995, Units: Dmnl, RANDOM UNIFORM(0.995,0.997, 1212)
38. Competitor Action = 1, Units: Dmnl
39. Consumption Rate = 1, Units: 1/Week
40. Cost of Parent Chicks Per Week = Parent Chicks * Average Parent Chicks Costs Per Week, Units: AUD/Week
41. Cost Per Mature Parent Per Week = Mature Parent * Average Cost Per Week, Units: AUD/Week
42. Culled Parent = Culled Parent Rate, Units: Parent/Week

43. Culled Per Week = 0.005, Units: Dmnl/Week
44. Deaths Due to Disaster = Natural Disaster*PULSE TRAIN(0,0,0,1000), Units: Dmnl
45. Deaths Rate = 0.1, Units: Dmnl
46. Deaths Rate due to Disease = (Deaths Rate/Fraction Week)*PULSE TRAIN(10, Fraction Week , 80 , 1000), Units: 1/Week
47. Decision to Purchase Parent Chicks = Max(0,(Effect of the Ratio of Mature Parent to Capacity on New Orders * Gap in Desired to Mature Parent)/Time to Make Purchasing Decision), Units: Parent/Week (Max(0,(Effect of the Ratio of Mature Parent to Capacity on New Orders * Gap in Desired to Mature Parent)))/Time to Make Purchasing Decision
48. Desired Capacity = Mature Parent Capacity * Effect of Profits Ratio on Capacity, Units: Parent
49. Desired Mature Parent = Mature Parent Capacity, Units: Parent
50. Desired Profits = 150000, Units: AUD/Week
51. Effect of Profits Ratio on Capacity= WITH LOOKUP (Ratio of Profits to Desired Profits, ([(0,0)-(3,2)],(0,1),(1,1),(1.2,1.1),(2,1.2))), Units: Dmnl
52. Effect of the Ratio of Mature Parent to Capacity on New Orders = WITH LOOKUP (Ratio of Mature Parent to Capacity, ([(0,0)-(1.25,2)],(0,1),(0.25,1),(0.5,1.1),(0.75,1.2),(0.85,1.1),(0.95,1.05),(1,1),(1.2,0.85))), Units: Dmnl
53. Eggs Drain out due to Low Demand = Eggs Drain Out, Units: Eggs/Week
54. Eggs Drain Rate = PULSE TRAIN(0, 0 , 0 , 1000), Units: Dmnl
55. Eggs Per Chicken Per Week = RANDOM UNIFORM (4.1 , 4.3 , 1212), Units: Eggs/Parent/Week, 175 to 182 Eggs in 42 Weeks, RANDOM UNIFORM(4.1 , 4.3 , 1212)
56. Eggs Supply to Bakery = Broken Eggs + Unhatched Eggs + Eggs Drain out due to Low Demand, Units: Eggs/Week
57. FAER = 0.001, Units: Persons/Chicken/Week, Farmers Employment Rate
58. Farmers Empl = Farmers*FAER, Units: Person/Week, Farmers Employment
59. Feather Dumped Rate = 1, Units: Dmnl/Week
60. FER = 0.0002, Units: Persons/Ton, Fertilizer Employment Rate
61. Fertilizer = Poultry Litter*Litter for Fertilizer*Fertilizer Conversion Rate Units: Ton/Week
62. Fertilizer Conversion Rate = 0.015, Units: Dmnl, Fertilizer Conversion Rate

63. Fertilizer Empl = Max (3, (Fertilizer * FER)), Units: Person/Week
64. FFER = 0.01, Units: Persons/Ton, Fish Feed Employment Rate
65. Finance = 1, Units: Dmnl
66. Fish Feed = Poultry Litter * Litter for Feed * Fish Feed Conversion Rate Units: Ton/Week
67. Fish Feed Conversion Rate = 0.025, Units: Dmnl
68. Fish Feed Empl = Max (2, (Fish Feed * FFER)), Units: Person/Week
69. Fraction Drain Out = 1e-007, Units: 1/Week
70. Fraction Loss = 0.005, Units: Dmnl
71. Fraction Mortality = 0.04, Units: Dmnl/Week, RANDOM UNIFORM(0.03,0.06, 1012)
72. Fraction Week = 10, Units: Week
73. Gap in Desired to Mature Parent = Desired Mature Parent - (Mature Parent), Units: Parent, Max(25000,(Desired Mature Parent - (Mature Parent))) or Desired Mature Parent - (Mature Parent)
74. Gap in Mature Parent Capacity to Desired Parent Capacity = Desired Capacity-Mature Parent Capacity, Units: Parent
75. Govt Policy = 1, Units: Dmnl
76. Hatchery Empl = Max(100,(Hatchery * HER)), Units: Person/Week, Hatchery Employment
77. Hatchery In Rate = 0.99, Units: Dmnl/Week
78. Hatching Percentage = 0.84, Units: Chicks/Eggs, RANDOM UNIFORM (0.84, 0.87, 1212)
79. HER = 0.00015, Units: Persons/Eggs/Week, Hatchery Employment Rate
80. Initial Mature Parent = 150000, Units: Parent
81. Initial Mature Parent Capacity = 200000, Units: Parent
82. Initial Parent Chicks = 120000, Units: Parent
83. Intestine Dumped Rate = 1, Units: 1/Week
84. "Intestine/Broiler" = 0.062, Units: Kg/Chicken
85. "Intestine/Parent" = 0.088, Units: Kg/Parent
86. Litter for Biogas = 0.9, Units: Dmnl
87. Litter for Feed = 0.05, Units: Dmnl
88. Litter for Fertilizer = 0.05, Units: Dmnl
89. Market Demand = 1, Units: Dmnl

90. Mature Parent Empl = Mature Parent * MPER, Units: Person/Week, Mature Parent Employment
91. MER = 0.0002, Units: Persons/Chicken/Week, Middlemen Employment Rate
92. Middlemen Empl = Max (100,(Middlemen * MER * Staff Per Middlemen)), Units: Person/Week, Middlemen Employment
93. MPER = 0.002, Units: Persons/Parent/Week, Mature Parent Employment Rate
94. Natural Disaster = 1, Units: Dmnl
95. Other Costs = 0.15, Units: AUD/Week
96. Parent Chicks = INTEG (Parent Chicks Rate - Aggregate Policy Impact-Parent Maturing Rate, Initial Parent Chicks), Units: Parent
97. Parent Chicks Empl = Parent Chicks * PCER, Units: Persons/Week
98. Parent Feather = (Mature Parent * Parent Feather Collection Rate)/Time to Collect Feather, Units: Kg/Week
99. Parent Feather Collection Rate = 0.145, Units: Kg/Parent/Week
100. Parent Intestine = ("Intestine/Parent" * (Mature Parent/PICT)) + Age and Culled Parent, Units: Kg/Week
101. PCER = 0.001, Units: Persons/Parent/Week, Parent Chicks Employment Rate
102. PICT = 65, Units: Week, Parent Intestine Collection Time
103. Policy Impact Rate = 0.05, Units: Dmnl
104. Policy Variable = Competitor Action * Govt Policy * Market Demand * Finance, Units: Dmnl
105. Poultry Litter = Mature Parent * Average Litter Rate, Units: Ton/Week
106. Profits = Total Sales-Total Cost, Units: AUD/Week
107. Ratio of Mature Parent to Capacity = Mature Parent/Mature Parent Capacity, Units: Dmnl
108. Ratio of Profits to Desired Profits = Profits/Desired Profits, Units: 1
109. Sell Parent as Meat = (Aged Parent + Culled Parent) * Average Meat Price Units: AUD/Week
110. Staff Per Middlemen = 4, Units: Dmnl, RANDOM UNIFORM (4, 10, 50)
111. Tenure = 12, Units: Week
112. Time for Eggs to Hatch = 3, Units: Week
113. Time Middlemen Hold Chickens = 1, Units: 1/Week, RANDOM UNIFORM (0.995,0.997, 1212)
114. Time to Collect = 4, Units: Dmnl
115. Time to Collect Feather = 26, Units: Dmnl

116. Time to Make Purchasing Decision = 8, Units: Week
117. Time to Mature Chicken = 4, Units: Week
118. Time to Mature Parent = 24, Units: Week, How long it takes for chicks to become Mature Poultry
119. Total Cost = Cost of Parent Chicks Per Week + Cost Per Mature Parent Per Week + Other Costs, Units: AUD/Week
120. Total Parent = Mature Parent + Parent Chicks, Units: Parent
121. Total Sales = Chicks * Average Chicks Price + Sell Parent as Meat, Units: AUD/Week
122. Unhatched Eggs = Unhatched Eggs Rate, Units: Eggs/Week
123. Unhatched Rate = 0.15, Units: 1/Week, RANDOM UNIFORM (0.15, 0.16, 12)

Rates

124. Aggregate Policy Impact = Parent Chicks * Aggregate Policy Rate, Units: Parent/Week
125. Broken Eggs Rate = Eggs * Broken Rate, Units: Eggs/Week
126. Chicken Mortality Rate = Farmers * Fraction Mortality, Units: Chicken/Week
127. Chicken Supply = Middlemen * Time Middlemen Hold Chickens, Units: Chicken/Week
128. Consumed = Broiler Chicken * Consumption Rate, Units: Chicken/Week
129. Culled Parent Rate = Mature Parent * Culled Per Week, Units: Parent/Week
130. Deaths = Deaths Rate due to Disease * Mature Parent * Deaths Due to Disaster, Units: Parent/Week
131. Eggs Hatching = Hatchery/Time for Eggs to Hatch, Units: Eggs/Week
132. Eggs Produced = Mature Parent * Eggs Per Chicken Per Week, Units: Eggs/Week
133. Eggs to Hatchery = Eggs * Hatchery In Rate, Units: Eggs/Week
134. Eggs Drain Out = Fraction Drain Out * Eggs Drain Rate * Hatchery, Units: Eggs/Week
135. Farm In = Chicks * Chicks enter to Broiler Farms, Units: Chicken/Week
136. Feather Collection = Broiler Feather + Parent Feather, Units: Kg/Week
137. Feather Dumped = Feather * Feather Dumped Rate, Units: Kg/Week
138. Intestine Collect = Broiler Intestine + Parent Intestine, Units: Kg/Week
139. Intestine Dumped = Intestine * Intestine Dumped Rate, Units: Kg/Week

140. New Mature Parent Capacity = Gap in Mature Parent Capacity to Desired Parent Capacity/Adjustment Time for Mature Parent Capacity, Units: Parent/Week
141. Parent Chicks Rate = Decision to Purchase Parent Chicks, Units: Parent/Week
142. Parent Maturing Rate = Parent Chicks/Time to Mature Parent, Units: Parent/Week
143. Parent no Longer Productive = Mature Parent/Average Productive Life Units: Parent/Week, Number of Mature Poultry who age out, die, or are no longer productive.
144. Retail Rate = Chickens Maturing for Market * (1-Fraction Loss), Units: Chicken/Week
145. Unhatched Eggs Rate = Hatchery * Unhatched Rate, Units: Eggs/Week

Appendix D: Some Pictures from the Case Industry

Picture 1: Sign Board for Nahar Agro Group

Picture 2: Industry Main Gate with Bio-security Precaution

Picture 3: A snapshot of Poultry Shed from Roof Top

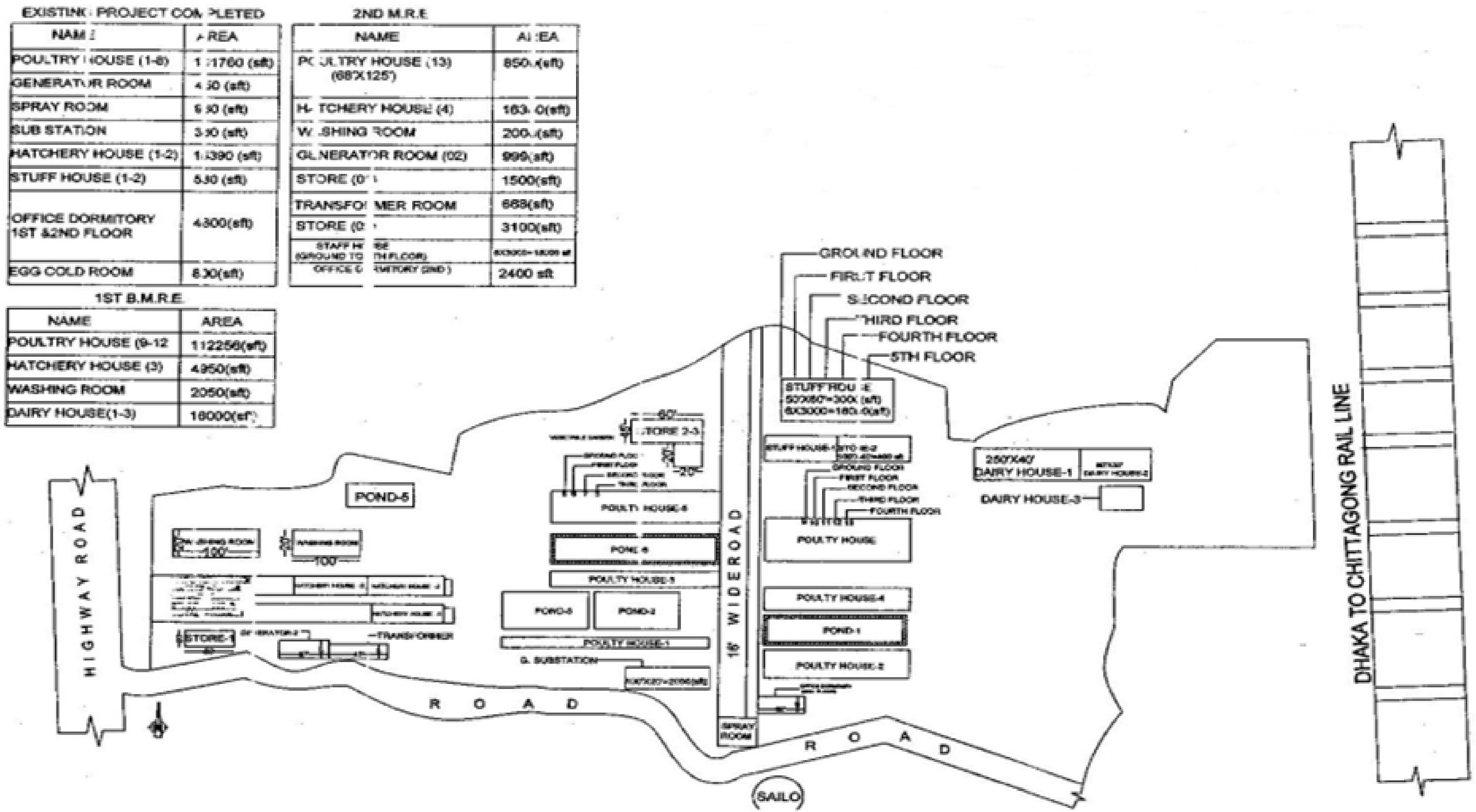
Picture 4: Mother Parent Stock under Scientific Control Shed

Picture 5: Day-old Chicks Grading before Travel to The Ultimate Farmers

Picture 6: Day-old Chicks in a Scientific Packaging System

Picture 7: Eggs Queued up for Hatching

Picture 8: Biogas Plant



Picture 9: Engineering Layout for Case Industry (Particular unit)