KADIR HAS UNIVERSITY
SCHOOL OF GRADUATE STUDIES
PROGRAM OF MANAGEMENT INFORMATION SYSTEMS

PROPOSING A MODEL FOR PRECISION MANAGEMENT SUPERVISED WITH MACHINE LEARNING IN LIVESTOCK MANAGEMENT

BAHADIR BARAN ÖDEVCİ

PHD THESIS

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Submitted to the School of Graduate Studies of Kadir Has University in partial fulfillment of the requirements for the degree of PhD in the Program of Management Information Systems

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Director of the School of Graduate Studies

APPROVAL DATE: 27/07/2021

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LIST of ABBREVIATIONS

Abbreviations referred to in the thesis or dissertation should be displayed in the Abbreviations list in alphabetical order, together with its explanation/definition. Abbreviations should be used and typed taking into account the principles set out by the Turkish Language Association (TDK).

AD, Automatic drafter
ADW, Average Daily Gain Weight
EID, Electronic identification
MLA, Machine Learning Algorithms
M-SMS, Mobile Sheep Manager Software
PLF, Precision Livestock Farming
RFID Radio-frequency identification

PROPOSING A MODEL FOR PRECISION MANAGEMENT SUPERVISED WITH MACHINE LEARNING IN LIVESTOCK MANAGEMENT

ABSTRACT

The global demand for meat is predicted to rise by 40% in the next 15 years, owing to an increase in the number of people adopting protein-richer diets, and technology solutions in agricultural and livestock production systems are likely to play a vital role in addressing this issue. On the other hand, while expanding meat output, it will be critical to discover ways to reduce livestock farming's environmental footprint and assure high levels of animal care and health.

In this thesis, we aim to propose a model and approach along with a number of steps to follow for a livestock farm to adapt an information management system to attain optimum production efficiency. We are seeking answers to respond to the following research question: How can a livestock farm utilize information management systems for optimum efficiency? In order to expand the research on a specific livestock case study, we focus on intensively managed sheep for lamb production. However, the model and approach proposed in this thesis can be applicable to any livestock farming that aims to utilize information systems for precision management of farm operations. First, we reviewed scientific research related to long-standing, novel-technology, and data sensors with emphasis on data-information-knowledge-wisdom and decision-making processes and for intensively managed sheep for lamb production.

Secondly, we addressed what data elements exist in the context of a livestock farm and how data elements in the context of livestock farms are associated. Special attention was given to the data model of the farm context for managerial precision livestock farming (PLF) systems.

Thirdly, we proposed the decision-making points supervised by machine learning models in a PLF management information system for intensively managed sheep for lamb production. At this point, we developed and adapted a Mobile Sheep Manager

Software (M-SMS) for a commercial lamb production model using an appropriate cloud architecture that collects and utilizes farm data and responds to the farm management with respect to insights into the operational and financial aspects of the farm. The technology identifies real-time alarms pertaining to animal welfare, health, environmental effects, and production on the farm and provides troubleshooting recommendations. We also looked at its suitability for user experience as well as its impact on farm profitability and sustainability.

This research has shown that M-SMS combined with cloud services compounded with Predictive Analytics Services can fine-tune flock management and significantly improve operational excellence. According to the usability results, intensive sheep farmers had access to "point and click" solutions to keep legislative records, attain operational guidance and build flock performance data.

Finally, we propose a model and steps to follow to adapt the information management system to any livestock management system in order to attain optimum efficiency. It was concluded that the architecture of this application can be easily adapted to other intensively managed livestock if the steps in this study are followed precisely.

Keywords: Precision flock management, livestock, Predictive services, Sheep, Cloud architecture, machine learning, information systems

ÇİFTLİK HAYVANI YETİŞTİRİLİĞİNDE MAKİNE ÖĞRENMESİ DESTEKLİ HASSAS SÜRÜ YÖNETİMİ İÇİN MODEL ÖNERİSİ

ÖZET

Önümüzdeki 15 yıl içinde, proteince zengin diyetlerle beslenen insan nüfusunun artmasıyla küresel et talebinde %40'lık bir artış olacağı beklenmekte olup tarımsal ve hayvansal üretim sistemlerindeki teknoloji çözümlerinin bu zorluğun üstesinden gelinmesinde kilit bir rol oynayacağı düşünülmektedir. Diğer taraftan üretim verimi arttırılırken hayvancılığın çevresel ayak izini en aza indirmenin ve hayvanlar için yüksek düzeyde refah ve sağlık şartlarının sağlamanın yollarını bulmak önemli olacaktır.

Bu tezde bir çiftlik hayvanı üreticisinin, bilişim yönetim sistemlerinden istifade ederek üretim verimini optimize etmek için takip etmesi gereken adımları tanımlayan bir model önerisi sunmayı hedefledik. Şu araştırma sorusunu yanıtlamak istedik; Bir çiftlik hayvanı yetiştiriciliğinde, bilgi sistemlerini kullanarak nasıl optimum verimliliğe çıkılabilir? Bu araştırma sorusunu yanıtlayabilmek için örnek teşkil etmesi amacı ile çiftlik hayvancılığı olarak kapalı et koyunculuğu yetiştiriciliğine odaklandık.

İlk olarak, kuzu üretimi için entansif yöntemle yetiştirilen koyunlar için karar verme süreci ve veri-enformasyon-bilgi-bilgelik kavramları üzerinde durularak, uzun soluklu, yeni teknoloji ve veri sensörleri ile ilgili bilimsel araştırmalar gözden geçirilmiştir.

İkinci sırada ise, hayvan çiftlikleri bağlamında veri öğelerinin birbirleriyle nasıl ilişkili olduğu ele alınmış, hassas hayvan yetiştiriciliği (PLF) sistemleri için çiftlik yönetiminde veri modeline özel olarak odaklanılmıştır.

Üçüncü olarak, kuzu üretimi için entansif olarak yönetilen koyunlarda uygulanacak PLF yönetim bilgi sistemi için makine öğrenme modellerinin desteği ile karar verme noktaları önerilmiştir. Bu noktada, çiftlik verilerini toplayan ve kullanan, çiftliğin operasyonel ve finansal yönlerine ilişkin içgörülere göre çiftlik yönetimine yanıt veren bulut mimarisini kullanarak, Mobil Koyun Yönetici Yazılımı (M-SMS) ticari kuzu üretim modeli için geliştirilmiş ve bu tür bir üretim modeline uyarlanmıştır. Geliştirilen sistem, çiftlikte meydana gelen hayvan refahı, sağlık, çevresel etki ve üretim ile ilgili uyarıları gerçek zamanlı olarak algılamakta ve sorun giderme amaçlı önerilerde bulunmaktadır. Buna ilaveten, sistemin kullanıcı deneyimine uygunluğu, çiftlik karlılığı ve sürdürülebilirliği üzerindeki etkisi test edilmiştir.

Bu araştırma, tahmine dayalı karar destek hizmetleriyle bulut hizmetlerini bütünleştirilen M-SMS uygulamasının, sürü yönetiminde hassas yetiştiriciliğin yapılmasına yardımcı olduğunu ve operasyonel mükemmelliği önemli ölçüde iyileştirdiğini göstermiştir. Kullanılabilirlik sonuçlarına göre, koyun yetiştiricileri, yasal kayıtları tutma, operasyonel yetiştiricilik işlemlerinde rehberlik elde etme ve sürü perfomans verisi oluşturma konularında “göster ve tıkla” çözümüne erişebilmişlerdir.

Son olarak, bir model önerisi sunarak, farklı çiftlik hayvanı yetiştiricilik modellerinde de aynı adımlar takip edilerek bilgi teknolojileri sistemleri ile verimi optimize etmenin mümkün olabileceğini gösterdik. Bu çalışmada sunulan modeldeki adımlar sıra ile takip edilirse, hassas sürü yönetiminin entansif olarak yapılan diğer çiftlik hayvancılığı alanlarına da kolayca uyarlanabileceği sonucuna varılmıştır.

Key words: Hassas sürü yönetimi, tahmin servisleri, koyun, bulut mimarisi, makine öğrenmesi, bilişim sistemleri

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Bahadır Baran Ödevci

To My Dearest Family

1. INTRODUCTION

1.1. The subject matter

Information and communication technologies (ICT) have been used widely for the study and improvement of various aspects of livestock production. Basically, ICT has been playing a great role in livestock disease control, herd or flock management, livestock production and marketing of livestock and their products (Meena and Singh, 2013). Tiwari et al. (2010) argued that the livestock sector should come up with need-based, location-specific and local language content in the form of computer software and other electronic materials with regard to livestock production. ICT-based information delivery to the livestock sector can significantly improve the quality of decision-making in the livestock farming system.

A growing number of individuals are embracing protein-richer diets, which is predicted to increase the worldwide demand for meat by 40% over the next 15 years. The current growth trend in the livestock sector shows that, in order to meet the growing demand for livestock-based products in both domestic and global markets, the production system must be reoriented by increasing efficiency and raising quality awareness. Consumer worries about the safety of animal-based goods, according to Verbeke (2001), have led to a rise in demand for information and transparency in food chains, which has worked as a primary motivator for the creation of traceability systems. Farmers, according to Adhiguru et al. (2009), are seeking a variety of information sources not only to carry out their production and marketing activities efficiently, but also to ensure that consumers receive safe and high-quality products.

Technology solutions in agricultural and livestock production systems, according to the UN's Food and Agriculture Organization (FAO), will play a vital role in addressing this challenge and ensuring a sustainable food supply for a population of 9.7 billion people by 2050. (FAO, 2017). While expanding production, it will be critical to discover strategies to reduce livestock farming's environmental footprint and assure high levels of animal care and health. Decreasing farmers' workload and increasing the economic viability of farm operations are very important for sustainable production. This way, it will be possible for a farm to produce on a large scale and enable the farm to benefit from economies of scale. This is the way a farm can become more profitable. (Bettencourt et al., 2013).

Precision Livestock Farming (PLF) systems offer solutions to all the above challenges. PLF management tools provide real-time monitoring of animal welfare, health, environmental impact and production. PLF systems help farmers to collect and manage detailed information about their flock to ensure livestock production is sustainable and in compliance with health and welfare standards. Current PLF tools and technologies are mainly applied to the production of pigs, poultry and dairy cows. Small ruminants, which are mostly extensively raised animals, have been less subjected to PLF Technologies (Berckmans, 2014).

Berckmans (2017) stated that a major problem for the next 10 years is the continuous monitoring of animal health within the big groups of animals due to the increasing number of animals and the decreasing number of farmers. Thus, every farm will count more animals and infections in such big groups, which will be a big concern for animal health and welfare. This is a primary challenge since the development of vaccines will take time, and the efficiency of applying vaccines in big herds must be monitored to improve them. In addition to that, animal health is a top priority in relation to human health. In Europe, more than 25,000 people died due to not responding to antibiotics anymore while treatments cost €1.5 billion (Anne Mottet, FAO, unpublished). Another issue is the high risk of zoonosis diseases that can be transferred to humans due to the high density of animals living so close to humans in some countries. Thus, the safety and quality of the food products must be guaranteed at every part of the supply chain. Another huge problem to be solved is the environmental impact of the livestock sector. It was reported that (Anne Mottet, FAO, unpublished) more than 90% of the NH3, 37% of CH4, and 65% of N2O in the atmosphere come from the livestock sector, and up to 30% of all land and 8 to 15% of water resources are used by the livestock sector. A serious contribution to environmental impact would be to manage livestock in such a way that animal productivity is closer to the animal's genetic potential—less use of feeders, less manure, and higher productivity. In international competition, it is a challenge to keep farmers competitive, and animal productivity is a key factor. Therefore, the small ruminant industry has to lead the technology in precision livestock farming (PLF) due to several factors, such as increasing herd size, intensive management, lack of trained staff, public concern about animal wellbeing, increased cost of production, endemic diseases, and last but not least, new entrepreneurs without any experience with farm animals.

A University of Vermont project found that about 70 percent of the nation's private farmland will change hands over the next 20 years, and up to 25 percent of farmers and ranchers will retire (Parsons et al., 2010). "Farmer" and "entrepreneur" are not words normally seen next to each other. Entrepreneurial success stories tend to focus on shiny new technologies. Life on the farm attracts green-spirited entrepreneurs. In the 20th century, the concept of entrepreneurship was described as entrepreneurs as innovators who drive change in the economy by serving new markets or creating new ways of doing things (Trivedi, 2012). Śledzik, (2013) reviewed Schumpeter's view on innovation and entrepreneurship, who emphasized that the function of entrepreneurs is to reform or revolutionize the pattern of production in many ways: by exploiting an invention or, more generally, an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening up a new source of supply of materials or a new outlet for products, by reorganizing an industry, and so on (Joseph Schumpeter, Professor at Harvard Business School). Evidence indicates that for farmers to be successful as arbitrageurs, they need to possess most, if not all, of these characteristics or qualities. In any country or region, strategies for improving agricultural productivity or income of farmers, it is necessary to develop an entrepreneurial culture.

The definition of PLF is to manage the smallest production unit (the individual animal if possible) in order to deal with production performance on an individual basis rather than a herd basis. This approach is expected to improve animal health, wellbeing, and profitability of the farm operation. Sensors provide data about the individual animals in the herd. With proper physiological labeling and interpretation, this data can be translated into information which, in turn, can support management decision making at the level of the individual animal. The "smallest" unit can be the entire flock, a group of animals with common physiological and performance characteristics, or an individual animal. The "size" of this unit is determined by the sensors and facilities involved and the availability of automatic and easy operation.

A typical PLF system is constructed of the following components: a sensor that generates data, a model that gives a physiological interpretation of the data, a management decision making process, and finally, decision execution. PLF systems can be divided into two categories: those used for diagnostics and those used for management. The same sensor can serve both categories (Schulze et al., 2007). For example, a decline in pregnancy rate can indicate a reproductive health problem, but also a nutritional one. Nevertheless, for both categories, data has to be labeled and analyzed in order to convert it into meaningful information. Sensors are useless data generators unless there is a data model in the context of a farm that transfers this data to meaningful information (Singh et al., 2014). Both diagnostic and managerial PLF systems are designed to alarm or elucidate a physiological event or status which improves management decision making. The difference between diagnostic and managerial PLF systems is that the former has to alarm ahead or close to the event it is supposed to detect (estrous, lameness) and the latter can be more time tolerant. Most of the PLF appliances are of diagnostic nature related to health and reproduction, and the motivation for their development was to replace human senses as well as to economize on farm operations (Maltz, 2010).

1.2. Thesis aim

We aim to propose a model for a livestock farm that benefits from the merits of PLF and optimizes production efficiency. We devised a step by step approach, researched each step of the model and defined them, and eventually came up with and proposed a complete blueprint, which we intend for a livestock farm to implement and benefit from information systems and start optimizing for production efficiency.

In this thesis we review scientific research related to long-standing, novel-technology and under development sensors with emphasis on data-information-knowledge and decision-making processes and application possibilities for intensively managed sheep for lamb production.

Special attention will be given to the data model of the farm context as the starting point of the roadmap towards PLF. The data model might differ for each livestock under discussion. As stated earlier, we chose sheep breeding for lamb production. However, what is important here is the approach we use to implement a model for implementing a managerial PLF system, and how data elements are interrelated with each other. In terms of collecting the data on the farm, the following cloud-connected sensors will be in the focus; body weight scales, the machine learning algorithms (MLA) of the behaviors of the dam and her offspring for enabling high survival and growth rates of newborns, environmental factors affecting lamb survival will be tested under MLA. In addition to that, precision flock manager software and hardware will be tested for its fitness for user experience and its impact on farm profitability and sustainability will be discussed. This thesis will be based on case studies conducted as part of the project, which has been funded by Innovation for Sustainable Sheep and Goat Production in Europe (iSAGE-isage.eu).

1.3. Thesis outline

This thesis is composed of 6 chapters. The proposed model entails the critical steps, relationships among them, and the iterative flow of information and results can be seen in Figure 1.1.

The order of line of thought in the model we propose, Literature review on motivation, obstacles, and prospects of livestock farming, data model, tools, and technologies.

Chapter 1 is the introduction to the motivation for this thesis, accompanied by information about livestock production and the need for precision livestock systems.

Chapter 2 focuses on the research approach and design methodology that are employed throughout the thesis.

Chapter 3 defines the model of approaching PLF for any livestock. In this chapter the approach to defining the model and the guidance towards the steps taken to complete the model can be found.

Chapter 4 summarizes the papers published in the scope of this thesis.

Chapter 5 considers the findings from all preceding chapters and discusses the possibility and potential impacts of the model and approach we implemented for applying PLF to intensive meat sheep production and applying the same to any livestock farming.

Finally, Chapter 6 includes conclusion statements derived from this thesis.

2. RESEARCH APPROACH AND METHODOLOGY

2.1 Introduction

The purpose of this chapter is to describe and discuss the research approach and the methodology used in this thesis. The research approach has been given in the following section by addressing a PLF term and related technologies in different aspects of the sheep production domain. In the third part of the chapter, the detailed information concerning the methodology used has been provided by the underlying guidelines used for fundamental principles of design-science research. The following chapter, Chapter 3, will demonstrate how we applied the Design Science Research Methodology (DSRM) within the scope of this thesis.

2.2 Research Approach

One of the most important concerns of this thesis is to investigate precision livestock farming (PLF) and PLF related technologies in different aspects of the livestock production domain. The initial focus area of the thesis is to design a precision flock management (PFM) model for intensive sheep breeding and to develop machine learning algorithms (MLA) to be integrated into this model. However, this thesis aims to propose a model that defines how to apply PLF to any king of livestock. Development of PFM is a way of combining PLF hardware and software augmented with domain expertise in livestock. On the other hand, PFM will be enriched with MLA for a precise decision-making process. Software development will be based on intensive sheep production that aims at traceable lamb production in the sheep supply chain.

Figure 2.1 shows an example of a PLF model for biological processes. It is important to investigate a similar model to that of PLF for livestock as an approach because the concepts will be similar (Clarke, 1988; Aerts et al., 1998a, 2003c).

Farm animals are treated in groups by PLF, yet they are managed individually. The flock will produce outputs according to the inputs it receives. PLF is a generic strategy that can be used with any livestock. The PLF description of biological processes provides an understanding, particularly at a level where we recognize that controlling inputs to individual animals and measuring individual outputs is crucial. All of these measures will eventually feed into process models and, as a result, decision-making via predictive controller. We understand the significance of electronic animal identification.

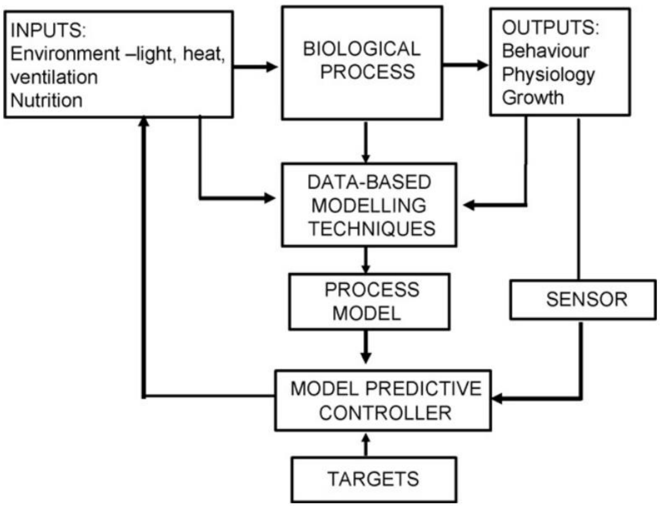

Figure 2.1 Overview of a PLF model for biological processes, which yields outputs such as behavior, physiology, growth (after Aerts et al., 1998a, 2003c).

2.3 Design Science Research Methodology

Information systems is an applied research discipline, in the sense that we frequently apply theory from other disciplines, such as economics, computer science, and the social sciences, to solve problems at the intersection of information technology (IT) and organizations (Peffers et al., 2007).

In recent years, several researchers succeeded in bringing design research into the information systems (IS) research community, successfully making the case for the validity and value of design science (DS) as an IS research paradigm (Hevner et al., 2004; March and Smith, 1995; Walls et al., 1992) and integrating design as a major component of research (Nunamaker et al., 1990). Despite these successful efforts to define DS as a legitimate research paradigm, DS research has been slow to diffuse into the mainstream of IS research in the past 15 years (Walls et al., 2004) and much of it has been published in engineering journals. A number of researchers, both in and outside of the IS discipline, have sought to provide some guidance to define DS research (Hevner et al., 2004). Work in engineering (Archer, 1984; Eekels and Roozenburg, 1991; Fulcher and Hills, 1996; Reich, 1994), computer science Preston and Mehandjiev, 2004; Takeda et al., 1990), and IS (Adams and Courtney, 2004; Cole et al., 2005; Hevner et al., 2004; March and Smith, 1995; Nunamaker et al., 1990; Rossi and Sein, 2003; Walls et al., 1992; Walls, et al., 2004) has sought to collect and disseminate the appropriate reference literature (Vaishnavi and Kuechler, 2005); characterize its purposes; differentiate it from theory building and testing research, in particular, and from other research paradigms; explicate its essential elements; and claim its legitimacy. However, so far this literature has not explicitly focused on the development of a methodology for carrying out DS research and presenting it.

Peffers et al. (2007) indicated that it was recently accepted the use of interpretive research paradigms, but the resulting research output is still mostly explanatory and, it could be argued, not often applicable to the solution of problems encountered in research and practice. While design, the act of creating an explicitly applicable solution to a problem, is an accepted research paradigm in other disciplines, such as engineering, it has been employed in just a small minority of research papers published in our best journals to produce artifacts that are applicable to research or practice.

The fundamental principle of design-science research from which our seven guidelines are derived is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact. Hevner et al., (2004) proposes seven guidelines with the aim of helping to improve practitioners' understanding with respect to the need for applying design-science effectively (Figure 2.2).

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

Figure 2.2 Design Science Research Guidelines

Peffers et al., (2007) developed a methodology for design science (DS) by introducing a DS process. Figure 2.3 illustrates each step of the DSRM process model.

Their process model consists of the following six activities in a nominal sequence (Peffers et al., 2007):

- Problem identification and motivation: definition of the research problem and justification of a solution’s value.
- Objectives of a solution: inferring the purposes of a solution from the definition of the problem.
- Design and development: creation of an artifactual solution
- Demonstration: demonstration of the artifact’s efficacy for solving the problem
- Evaluation: Observing and measuring how well the artifact supports a solution to the problem

- Communication: Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences

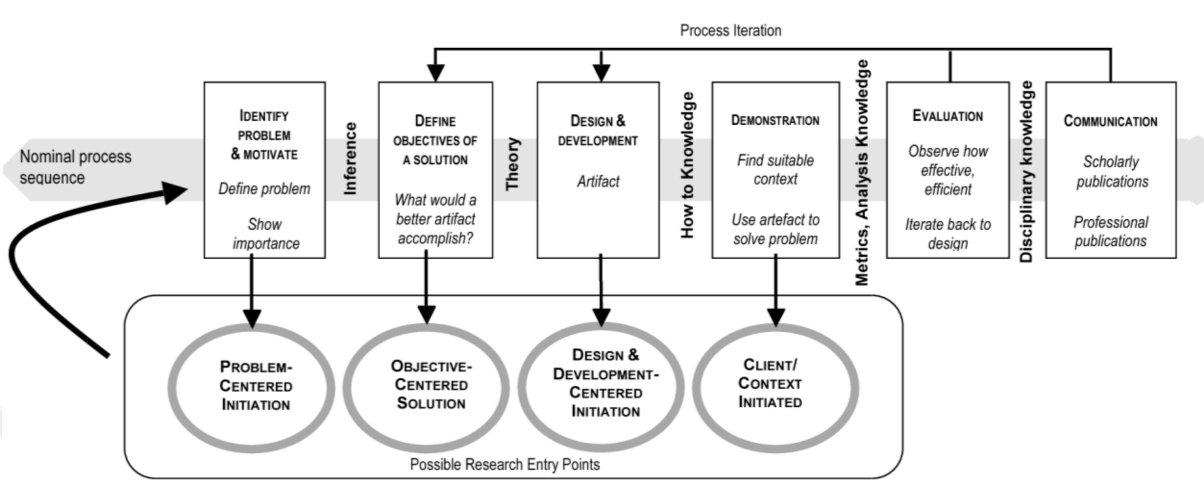

Figure 2.3 Design Science Research Methodology (DSRM) Process Model (Adapted from Peffers et al., 2007)

The DSRP model has been applied to this work because it is an explicit guideline for helping researchers while carrying out design science research in IS (Peffers et al., 2006).

The six-step process DSRM, which consists of problem identification and motivation, objectives for a solution, design and development, evaluation, and communication (Peffers et al., 2006) has been used to produce artifacts within the thesis. There are three different steps defined in the model proposed in this thesis. We created artifacts for each step as per the guidance provided by the Design Science Research Methodology. If one follows these steps for any livestock, one can implement PLF in the management of that livestock. The following chapter will provide details about the proposed model.

3. PROPOSING A MODEL TO IMPLEMENT PLF FOR A LIVESTOCK

Sheep livestock farming lacks precision livestock management practices in its current operations. That is why, in this thesis, we chose intensive sheep breeding for lamb production as the livestock. We follow steps to adapt PLF for intensive sheep breeding and define these steps as a model that will guide the PLF route for any livestock. Below is the figure that depicts the model proposed in this thesis.

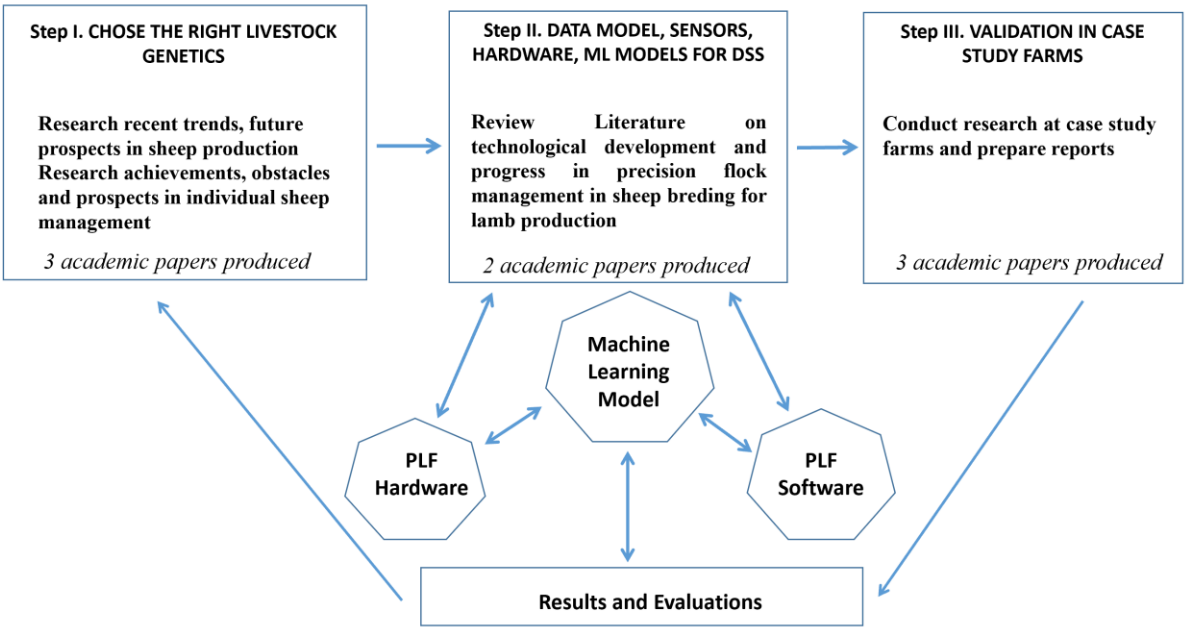

Figure 3.1 The proposed model entails the critical steps, relationships among them and iterative flow of information and results.

In this chapter, as the step 1, a literature review is conducted that explores key points namely: choosing the right sheep genetics for production according to the recent trends, achievements, obstacles, and prospects in the sheep breeding sector. Step 2 focuses on technological development and progress in precision flock management in sheep. Also, emphasis on existing PLF tools and software will be given and machine learning models that are used for decision support will be revised.

Step 3 in Chapter 3 describes the research settings, including the research findings at case study farms used for the majority of investigations and data collected in this thesis. This chapter also explores the feasibility, resources required and the impact on performance of a PLF compared to a conventional management approach.

The model entails the following critical steps:

Step 1: Chose the right livestock genetics that suit best for optimum production efficiency.

Step 2: Data model, sensors, hardware, ML models for decision support systems that constitute the components of precision livestock farming.

Step 3: Validation in case study farms.

There will be iterations over the steps proposed to fine tune the model. Iterations from step 3 back to steps 1 and 2, based on the evaluations of the results produced in case study farms. Based on the results, a modification might be made to the machine learning model, maybe a change in software or hardware specifications. However, if the variation in the expectations of the results is high, a change might need to be made in the genetics of the chosen livestock. Maybe the genetic composition of livestock characteristics did not prove to be profitable and sustainable, hence implementing PLF on that particular livestock will not be successful.

Figure 3.2, Figure 3.3, Figure 3.10 illustrate how to apply the DSRM process to Artifact 1, Artifact 2, Artifact 3, respectively. These figures can be found in this chapter, where we define the model proposed in this thesis.

3.1 STEP I: CHOOSE THE RIGHT LIVESTOCK GENETICS

PLF requires measuring data and extracting insight out of it. Livestock breeding should be implemented in a controlled, intensive environment, so that data can be captured through sensors and hardware. However, not every livestock breed provides environmental and economic sustainable business in an intensive system. One should research market needs and opportunities for that livestock and decide upon the right breed with the right genetics. Chosing the right livestock genetics that is profitable is, by definition, suitable for a precision livestock management system. Before even starting to contemplate a precision livestock management system for a livestock breed, one should screen for problems, obstacles, and prospects in that particular market. At this stage, in accordance with the design science methodology, we produce Artifact 1, and below is the process we follow for Artifact 1. A summary of each step can be found in the process.

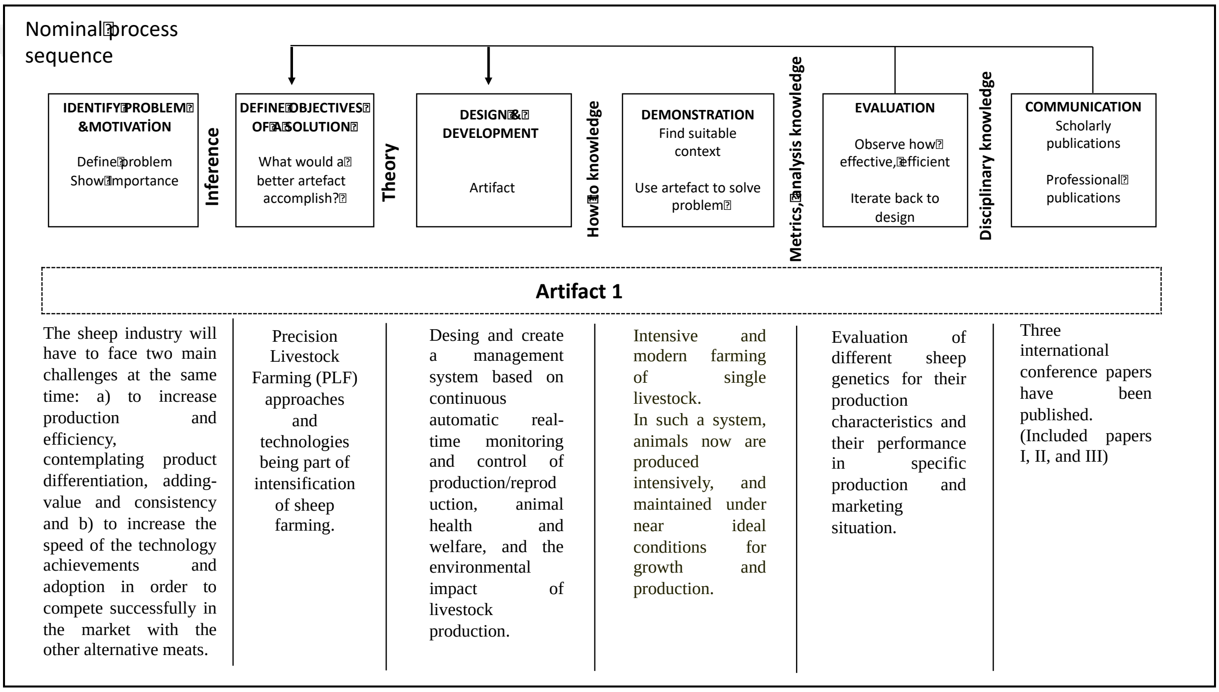

Figure 3.2 DSRM Process for the Artifact 1

Thornton (2016) wisely reviewed livestock production in the world in a holistic approach. There are strong remarks from his study which will be underlined within the scope of intensive sheep production in this text. In this review, it was stated that livestock systems occupy about 30 per cent of the planet’s ice-free terrestrial surface area (Steinfeld et al. 2006) and are a significant global asset with a value of at least $1.4 trillion. The livestock sector is increasingly organized into long market chains that employ at least 1.3 billion people globally and directly support the livelihoods of 600 million poor smallholder farmers in the developing world (Thornton et al., 2006).

Currently, livestock is one of the fastest growing agricultural subsectors in developing countries. Its share of agricultural GDP is already 33 per cent and is quickly increasing. This growth is driven by the rapidly increasing demand for livestock products. This demand is driven by population growth, urbanization, and increasing incomes in developing countries (Delgado, 2005). The combination of growing demand in the developing world and stagnant demand in industrialized countries represents a major opportunity for livestock keepers in developing countries, where most demand is met by local production, and this is likely to continue well into the foreseeable future (Thornton, 2016). East Asia will have shifted to negative population growth by the late 2040s (FAO 2010). In contrast, the population in sub-Saharan Africa (SSA) will still grow at 1.2 per cent per year. Rapid population growth could continue to be an important impediment to achieving improvements in food security in some countries, even when the world population ceases to grow at some point during the present century (Thornton, 2016).

Urbanization has a considerable impact on patterns of food consumption in general and on demand for livestock products in particular. Urbanization often stimulates improvements in infrastructure, including cold chains, and this allows perishable goods to be traded more widely (Delgado 2005), typically at rates ranging between 1.0 and 3.1 per cent (van Vuuren et al. 2009). Growth in industrialized countries is projected to be slower than in developing economies. Globally, however, between 2000 and 2050, the global cattle population may increase from 1.5 billion to 2.6 billion, and the global goat and sheep population from 1.7 billion to 2.7 billion (Rosegrant et al. 2009).

Even so, Van Dijk et al. (2010) have found evidence that climate change, especially elevated temperatures, has already changed the overall abundance, seasonality, and spatial spread of endemic helminths in the UK. This has obvious implications for policymakers and the sheep and cattle industries, and raises the need for improved diagnosis and early detection of livestock parasitic diseases, along with greatly increased awareness and preparedness to deal with disease patterns that are manifestly changing.

Montossi et al., (2013) expected growth in sheep meat production and consumption (22% in volume; 4% in price in real terms) between 2009–11 and 2021, will be driven mostly by developing countries. After the reduction in global supplies of sheep worldwide during the last decades, Rowe (2010) highlighted that sheep meat market share will be recovered, associated with price incentives in comparison with other meats.

The traditional importing markets (e.g. the EU and USA) will be expanded by increasing demand from developing countries with growth in income, such as China, Saudi Arabia, Jordan, the United Arab Emirates, India, Turkey, and Qatar (Food and Agriculture Organization of the United Nations (FAO), 2012). Rowe (2010) posed that sheep meat can not compete with poultry or pig meat in volume or price. Therefore, the alternative way is to focus more on differentiation based on quality and consistency.

Sheep are used extensively throughout the world to produce wool, meat, milk, and skins. The most recent estimate of the world's sheep population is 1.06 × 109 animals (FAO, 2001). The greatest numbers of sheep are found in Asia, followed by Africa and Oceania. Iran, Sudan, and Turkey are major producers of wool, meat, and milk, while Australia, China, India, New Zealand, and Syria are major producers of wool and meat. In many cases, the reason for this is that the sheep are used for their meat once their wool-and milk-producing lives have ended. The management of sheep will vary depending on the product to be harvested from the animals and the country in which they are raised. For example, milk sheep are managed so that they can be milked twice a day, whereas wool sheep only need to be shorn once per year. Within different countries, financial, cultural, and climatic differences affect such management factors as the number of animals supervised by one person and whether the sheep are kept outdoors all year round or spend some time indoors. Three major management systems used throughout the world for sheep production, namely, extensive production for wool and meat, intensive dairy production, and traditional pastoralism, were briefly reviewed by Kilgour et al., (2008) and they gave particular consideration to how these management systems affect the natural behaviour and welfare of the animals.

In the next 50 years, there is no doubt that research and innovation will play a key role in increasing food productivity by more than 100%. So, essentially, it looks like the sheep industry will have to face two main challenges at the same time: a) to increase production and efficiency, contemplating product differentiation, adding-value and consistency, and b) to increase the speed of technology achievements and applicability in order to compete successfully in the market with other alternative meats. This is not an easy competition given the size and type of business and capital investment of the poultry, pig meat and beef industries. Moreover, this will have to be done without decreasing the sensory quality of sheep meat (Montossi et al., 2013).

From the consumer side, there is an increasing concern about the sustainability of the intensification of animal industries and its potential damage to the environment, human health, and animal welfare. In some segments of consumers, extrinsic factors (e.g. product origin, general production practices, animal welfare, social and religious values, climate change, water and air pollution, and human health) appear to be important clues in consumer purchasing decisions (Font i Furnols et al., 2009, Font i Furnols et al., 2006, Garnier et al., 2003, Grunert, 2006, Saunders et al., 2010, Tilman et al., 2002, Troy and Kerry, 2010). The need for more global sustainable agriculture has been strongly addressed in the past, but it has to be applied specifically to local values and constraints (Tilman et al., 2002).

Between 2001–2011, Turkey became one of the leading emerging economies in the world with an 8.9 percent growth rate in 2010. Agricultural income increased from 23.7 to 62.0 billion dollars. Government subsidies on agricultural activities increased by 255%. Agriculture credits provided to farmers were 30 times higher with an interest rate of 5%, which used to be 59%. Considering agricultural production value, Turkey's agriculture placed first and seventh among European countries and in the world, respectively. Growth in economic terms in the country led to an increase in per capita, which yielded an increase in demand for red meat. More demand results in higher meat prices. As long as economic growth continues, one might expect that there will be more meat production due to more demand. Farmers and the market link become more important and the region of the farm impacts prices and farm profitability. Forecasting these impacts is critical for policy makers for better decision making for the sector.

Compared to the beef price to the mutton price in the USA and EU, the price of mutton is lower, while the price of mutton is higher in Turkey. Looking at the prices, it could be said that Turkey is having fewer problems competing with the EU and USA because of the increasing gap between the prices of mutton rather than beef (Yavuz et al., 2013). It was forecasted that trends in meat marketing margins for the 2013–2024 period and reported that meat production and yield for cattle are expected to increase due to increasing red meat demand, while mutton yield is expected to decrease because of the production problems faced by farmers. According to the analysis, mutton yield increased by just 2 kg per head, reaching from 19.8 to 21.8. That is above EU but below USA figures. In this study, the Turkish meat sector showed that, considering current trends in their own country, economic growth would cause meat demand and consequently meat prices to increase, resulting in rising meat yield per head and an increase in production if the number of animals remains stable. But the prices of meat are still high because of trade interventions and increasing demand due to an increase in per capita income. That would lead to the sector not being competitive under free trade conditions (Yavuz et al., 2013).

3.1.2 Individual sheep management: achievements, obstacles and prospects

Precision livestock farming is a multidisciplinary science that requires collaboration among animal scientists, physiologists, veterinarians, ethologists, engineers, information and communication technology (ICT) experts, etc. (Berckmans, 2017).

All livestock systems have evolved and adapted over time to benefit from advances in scientific knowledge and technology development (Burgess and Morris, 2009). Farming is currently going through a digital or technological revolution (Bronson and Knezevic, 2016; Gallardo and Sauer, 2018; King, 2017), with the increase in Precision Livestock

Farming (PLF) approaches and technologies being part of this. PLF is an approach to managing livestock systems with the potential to improve productivity, economic viability, sustainability, and welfare, and reduce labour (Banhazi et al., 2012b; Berckmans, 2017, 2004; Wathes et al., 2008). PLF research has largely focused on, and applied to, intensive livestock systems (Norton and Berckmans, 2017; van Hertem et al., 2016; Xin and Liu, 2017). application to specific geography and breeds, such as KuzuFab (case study of this thesis), could provide a new approach to tackling the difficulties they face, as well as provide a model for similar geography and breeds.

The European Union (EU) has lately committed significant funds to the Welfare Quality® initiative, which intends to develop a methodology for assessing farm animal welfare (www.welfarequality.net). The EU intends to put this into practice through new directives (EFSA, 2012). However, implementing a significant number of new directives is likely to be prohibitively expensive for farmers. Farmers, who are already subject to a slew of restrictions and legislation, will be wary of this strategy until it yields demonstrable benefits. It is no longer easy to make a living from cattle husbandry due to so many intricate issues. Farmers must balance feed and energy costs against financial rewards for their animal-based goods in a difficult position. Furthermore, they are expected to manage a variety of process outputs, such as animal health and welfare, product quality, and environmental effects, all while attempting to make a reasonable profit (Berkmans, 2014).

Year after year, the number of farmers raising animals decreases, but the global demand for animal products rises. As a result, livestock farms will continue to grow in size, as will the number of stock units on them. As a result, there is less time available to attend to individual animals, making proper monitoring and management of the animals more difficult. This is a significant issue because the modern farmer, who is frequently seated at a computer, is becoming increasingly detached from the most important component of the biological process under management, namely the animal. As a result, the number of farm animals is unlikely to decrease. Product quality control, animal health and welfare, and biosecurity are all challenges that even small farms must deal with. Many stakeholders are now active in the cattle production industry. As a result, farmers all around the world are grappling with how to combine all of the needs of the individual animals under their care into long-term production methods (Berkmans, 2014).

The goal of precision livestock farming (PLF) is to build a management system based on continuous automatic real-time monitoring and control of production/reproduction, animal health and welfare, and livestock production's environmental impact.

3.2 STEP II: DATA MODEL, SENSORS, HARDWARE, ML MODELS FOR DECISION SUPPORT SYSTEM

This is the stage where we model data in an intensive farm, deciding on the sensors and hardware that will be used to capture the intended data. Decision support systems are an essential part of PLF systems. This is the stage where we develop machine learning models to support decision making on the farm. Our aim is to develop a multi-task tool based on PLF hardware and software. At this stage, in accordance with the design science methodology, we produce Artifact 2, and below is the process we follow in Artifact 2. A summary of each step can be found in the process.

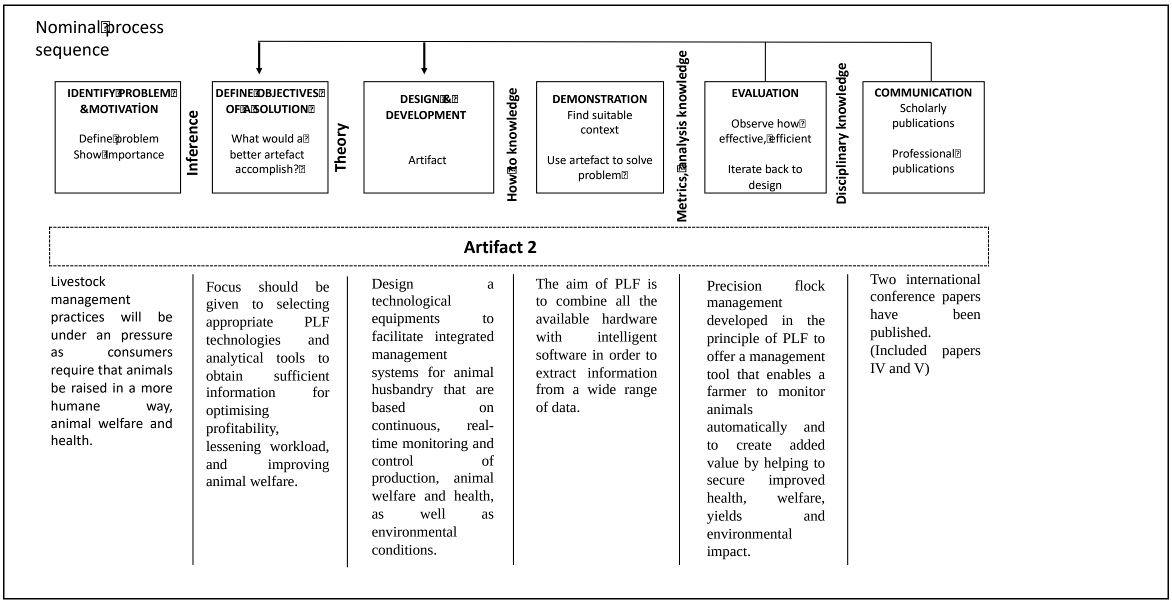

Figure 3.3 DSRM Process for the Artifact 2

Before the industrial revolution 4.0, livestock management decisions were mostly based on the observation, judgement, and experience of a human in a traditional way. The last decade has witnessed a great metamorphosis and brought a novel concept named "Precision livestock farming (PLF)," which is a digital management system that periodically or continuously measures production, reproduction, health and welfare of animals, and environmental impacts of the herd through a "per animal" approach by using monitoring tools, mainly the internet of things (IoT), and controlling all stages of the production process (Banhazi and Harmes, 2018; Berckmans, 2017).

The tools used for PLF are quite species specific, since every farm animal has its own physiological routines. However, tools tested and validated for a farm animal could be adapted for another farm animal. The development of PLF was driven by a number of variables in the care of livestock, such as the growth of herd size, and the resulting inability of farmers to care for individual animals, the economic efficiency of farming, and increasingly environmental factors, such as many other developments in the fields of agriculture, computing, and engineering. As these variables create more considerable complexity in farmers' work, it has become necessary for farmers to be able to monitor variables related to basic livestock production processes (Banhazi and Harmes, 2018).

Thus, the use of automated measurement methods to monitor animal behavior has become increasingly widespread, and a number of models have been introduced that can distinguish reasonably accurate traits of daily physiological routines.

Frost et al., (1997) indicated that the elementary principle for the emergence of PLF tools is to provide accurate and relevant information to take decisions as a farmer. But farmers have a challenge to meet productivity demands, sustainability and welfare of animals. Such a challenge offers unique opportunities for innovative technologies to be tested and applied. Therefore, the definition of the PLF technology was that the combination of computers and ICT is used to make the production chain more efficient due to the increased control it affords, resulting in improvement in animal welfare and benefits in using resources, resulting in decreased environmental pollution (Banhazi and Black, 2009). The introduction of process control procedures has resulted in significant improvements in other industries (Wathes, 2009).

PLF is a management system which uses sophisticated intelligent software and systems to combine a variety of data from different sources of hardware for monitoring. This data-driven system enables improved health, welfare and production along with minimized undesirable environmental impact through complex monitoring mechanisms such as tele-surveillance.

Pedersen (2005) underlined that the future demand for livestock production will be met through intensification, resulting in larger farms because the number of farms is decreasing. On the other hand, livestock management practices will be under additional pressure as consumers require that animals be raised in a more humane way, improving animal welfare and health. To meet consumer demands for efficient animal production and also their concerns regarding animal welfare, there is a need for modern livestock facilities to not only monitor environmental conditions but also animal behaviour and health (Banhazi and Black, 2009; Koenders et al., 2015).

The current availability of technological developments such as smart sensors, detectors, cameras, and microphones can facilitate integrated management systems for animal husbandry that are based on continuous, real-time monitoring and control of production, animal welfare and health, as well as environmental conditions. These management systems help farmers to instantaneously detect climate effects on animals and take immediate actions in response. Precision livestock farming (PLF) represents a system as a set of interconnected processes.

These processes include animal growth and behaviour, product yield, endemic disease, and the physical environment of livestock buildings, which includes their thermal microenvironment and the emission of gaseous pollutants (Banhazi et al., 2012; Berckmans, 2014; Groot Koerkamp, Bos, and van Henten, 2007; Lehr, 2014; Naas et al., 2006).

Therefore, precision livestock farming technologies (sensors, detectors, cameras, microphones, etc.), should enable the automatic monitoring of environmental, physiological, and behavioural variables, and can be used to continuously assess not only livestock performance but also their well-being in relation to their environment.

Black and Banhazi (2013) claimed that PLF is equally necessary for economic and social value. To achieve this target, focus should be given to selecting appropriate remote electronic measurements, computer technology, and analytical tools to obtain sufficient information for optimizing profitability, reducing workload, and improving animal welfare.

Modern technology allows for the placement of cameras, microphones, and sensors close enough to replace the farmer's eyes and hearing in the monitoring of individual animals. PLF's goal is to use all available technology in conjunction with clever software to extract information from a wide range of data. Precision livestock farming can provide a management tool that allows a farmer to automatically monitor animals and contribute value by assisting in the improvement of animal health, welfare, yields, and environmental effects (Berkmans, 2014).

3.2.1 Precision Livestock Farming Hardware

As stated by researchers, the aims of precision sheep production are: to accurately select and run sheep that best fit production goals and market signals; and to manage key inputs such as genetics, nutrition, and parasite control to match the needs and potential of each animal.

Technology currently available and possible ways of its commercialization and readiness will be summarized here. Implementing precision sheep production requires some capital investment and significant practice change for most producers. It is essential to know which sheep in the flock contribute to enterprise profit. This involves measurement of the basic characteristics. Manual data recording and record management is largely overcome by electronic tags and automated data entry. Electronic tags are therefore regarded as a fundamental component of precision sheep production.

Electronic tags are not only an easy, cheaper and more accurate way of data collection, but they also allow easy re-use of data throughout the life of the animal and facilitate automatic drafting and more sophisticated management techniques dependent on this technology. When it comes to automated data entry, data management, and decision support systems, these technologies are currently available and are becoming more powerful and easier to use. One of the most cost and labor-effective tools is automatic drafting, which is based on electronic tags and decisions based on an index or single parameter allow precise management of culling, joining, and marketing. PLF technologies collect data in a stress-free manner that does not include animal discomfort or handling (Scott and Moran, 1993; Hamilton et al., 2004). Advanced aspects of precision sheep management, according to Rowe and Atkinks (2006), include continuous or regular weight monitoring and remote drafting devices that respond to weight change and/or indexing instructions. These sophisticated features are currently being researched and developed, and they are likely to be commercially available in the near future. Commercialization and widespread adoption necessitate the establishment of proper infrastructure and data management support.

Atkins and Richards (2007) underlined the weakness of simple and traditional guidelines for selection and genetic improvement in most sheep flocks. They emphasized visual classing in selecting maiden ewes and wethers entering the flock and exiting the flock as complete age groups. However, it was documented (Rowe and Atkins, 2006) that the production potential and management needs of individual sheep vary significantly within a single flock and approximately 20% of sheep in any flock contribute little to the profitability of the enterprise. At this point, breed differences and management systems should be considered as important determinants for setting up a precision sheep production approach.

At present, integration of the necessary data/information and coordinated actions are carried out manually by farm workers (stockmen) in Turkey. However, the supply of stockmen with the necessary management skills is limited and the profit margins of livestock farming are very slim. We propose that livestock farming, like manufacturing industries, will have to adopt computer-based methods of process management to overcome these constraints. This, then, is the background against which the development of precision livestock farming is taking place.

1.2.1.1 Weighing

The weight of an animal is an important indicator of the wellbeing and value of an animal. There are several reasons why weight is crucial in livestock animals; 1) weight is very effective in assessing reproductive efficiency and growth performance in animals; 2) it can be used in determining the health status of an animal when measured in relation to its age. For example, an animal losing weight is an indication of poor health and, on the contrary, gaining weight shows that the animal is in good health. 3) In addition, weight can also be used in measuring the correct dose of therapeutic pharmaceuticals to treat animal diseases, to avoid the risk of underdosing or overdosing. 4) Weight can be used to determine the correct amount of feed an animal can get, to avoid underfeeding or overfeeding. 5) It also allows one to determine the possible value of the live animal in relation to the market price. 6) Weighing also helps in determining the weaning time of an animal.

However, very few livestock producers weigh their animals frequently. This is often due to the lack of convenient weighing equipment. For sheep, walk-over weighing (WOW) shown in figure 3.5 is an emerging alternative to conventional static weighing and the subjective appraisal of sheep flocks for nutritional management decision-making purposes (Richards et al., 2006). It is a method of automated live weight data collection whereby sheep are encouraged to traverse a strategically placed weighing platform within a paddock as part of their daily routine. The resultant sheep-weights are collected and interpreted by livestock managers to make management decisions for the flock. This system was developed for an extensive sheep breeding system and it is hard to adapt it to an intensively housed sheep flock. Mob-based walk-over weighing (MBWOW) is similar to the original concept of RFID-linked WOW, but without the capacity for individual identification provided by the RFID technology. The use of MBWOW (Figure 3.4) technology on a whole-flock basis means that the RFID component can be omitted, and consequently, application is simpler and lower in cost (Brown et al., 2012). However, an inferred compromise is that MBWOW does not offer any opportunity for differential management within the flock.

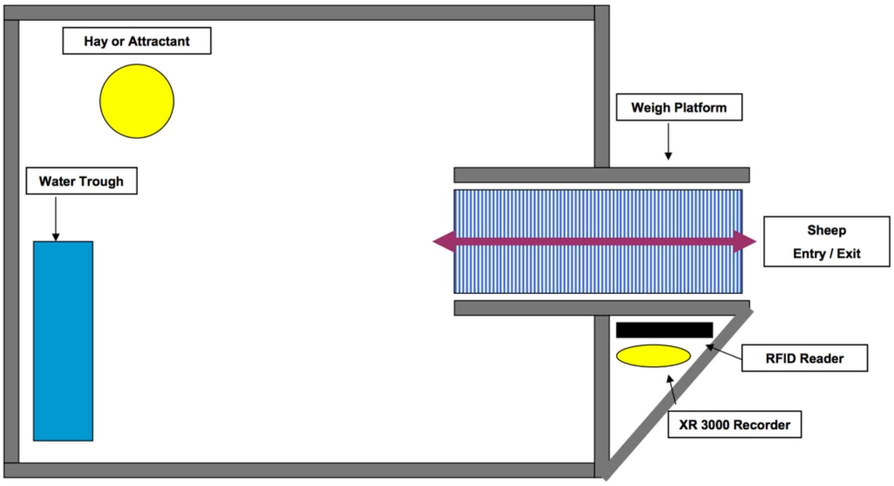

Figure 3.4 WOW design

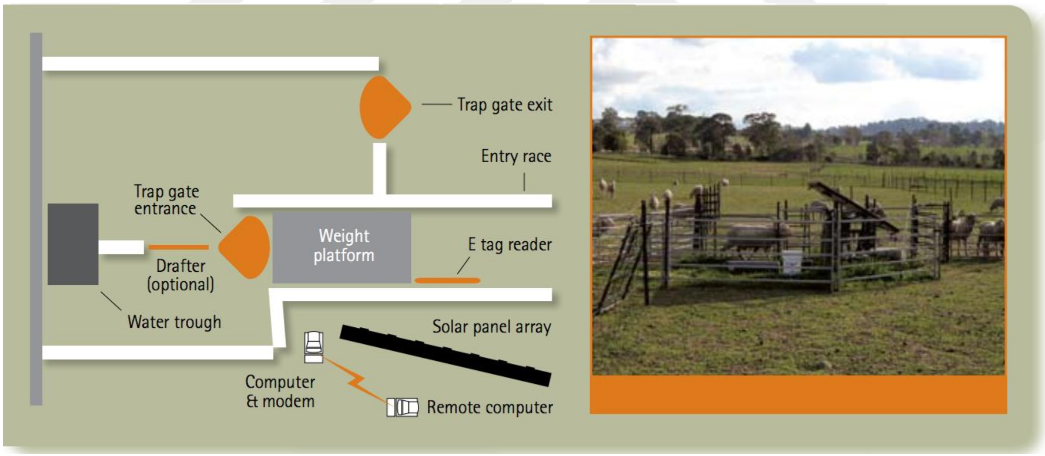

Figure 3.5 Mob-based walk-over weighing

3.2.1.2 Behavior

The behaviour of an animal can be used as an indicator of its physiological state. Since, a diseased animal may be more, or less, active than a healthy one; animals suffering from a cold environment may huddle together for warmth; an animal's activity level may be linked to its stage in the reproductive cycle (Frost et al., 1997).

Various methods have been used in the manual recording of behavior. Automated recording of animal behavior offers several advantages over manual observation; automatic systems allow measurements to be taken from more animals, for greater periods of time, and are less prone to human error. Rest and activity are fundamental components of animal behavior, and there are many situations in which records of body position and movement of animals, on pasture or indoors, are required.

The New South Wales Department of Primary Industries (NSW DPI), in collaboration with the University of New England Precision Agriculture Research Group and CSIRO, is conducting research using sensors on sheep to gather behavioral and location data to establish metrics on individual animals. Sheep wear a sensor either on an ear-tag or collar that sends continuous, real-time data that researchers analyze to determine key animal welfare, health, productivity, and environmental indicators. The aim of this program is to identify critical control points in the production system early enough so that producers can implement corrective measures to prevent negative health, welfare, and sustainability impacts. (Rural Industries Research & Development Corporation, 2016).

The data collected from each sheep will eventually evolve into information and tools that producers can use to evaluate a range of factors contributing to on-farm efficiency, including intake and feed efficiency at pasture, behaviour, disease susceptibility and health, reproduction and welfare status, and into applications that improve whole farm profitability, risk management and compliance. Researchers are performing extensive field tests of available technologies with a view to developing sensors and networks for commercial application on farms (Figure 3.4).

Figure 3.6 Sensors for supply chain integration

3.2.1.3 Controlled environment sheep housing

Livestock housing in temperate climates falls into two types, controlled environment and climatic buildings in which the physical environment mirrors that outdoors. This distinction is based on the desirability of control or modification of the physical environment. In general, climatic buildings are more for ruminants and horses. Typically, air temperature is measured with thermistors, compared against a set target, and the rate of (mechanical) ventilation is adjusted to raise or lower ventilation heat losses and thereby cool or warm the building (Randall and Boon, 1994). The lack of control of other factors, such as air quality, arises either from an inability to engineer a workable system through lack of sensors or control mechanisms, or from ignorance of the effects of each factor on animal health and performance and hence of control targets.

The term "context" refers to information that can be used to characterize the situation of an entity, which is a location, person or object. The environmental parameters such as temperature, humidity, and light as a context element, associated with appropriate control equipment, can range from specific sectors of the farm. Thus, the location is interrelated with context-related concepts.

3.2.1.4 Sensors to collect data

Stockmen collect auditory, olfactory, and visual data from their animals on a regular basis to assess their health, welfare, and productivity. Because of the (r) evolution in sensors and sensing techniques, such as improvements in micro-and nano electronics, new technologies can help with this task, even with big flocks or herds (Frost et al., 1997; Berckmans, 2004). Furthermore, sensors are not limited to the stockman's sensory modalities: infrared thermography, for example, can provide fresh information regarding animal temperature. Continuous, simultaneous measurement of a large number of units with analysis of temporal patterns as well as point statistics are frequent aspects of sensors used in PFM.

Low-cost cameras combined with image analysis techniques can be used to assess an animal's activity, size, form, and weight (De Wet et al., 2003; Leroy et al., 2004). (e.g. pigs: Schofield, 1990; Whittemore and Schofield, 2000; White et al., 2004; broilers: Chedad et al., 2003; De Wet et al., 2003).

Animal sounds can be monitored and their frequencies evaluated to determine their health state (Van Hirtum and Berckmans, 2004). The benefit of these monitoring systems is that they can capture a lot of data without causing any stress to the animals (Scott and Moran, 1993; Hamilton et al., 2004).

Sensors, such as pedometers for tracking oestrus behavior in dairy cows, can also be mounted directly on the animal (Brehme et al., 2004). For many years, automatic weighing devices for broilers, laying hens, and turkeys have been used to measure the average weight of a flock of birds (e.g. Turner et al., 1984; Lokhorst, 1996; Vranken et al., 2004). Mitchell et al. (2004), Laureyn (2004), Lowe et al. (2007), for example, have created telemetric sensors for measuring heart rate, body temperature, and activity, albeit primarily for research. Sensors for measuring milk conductivity and yield in dairy cows are already available, and they can be used to improve productivity and detect low welfare in individuals early (de Mol and Ouweltjes, 2001; Kohler and Kaufmann, 2003). The examples above are not exhaustive, but they show the current and future possibilities for feeding back animal signals as part of precision livestock production (PLF).

Livestock evaluations can be done on an individual or group basis. The automatic broiler weighing method, for example, developed by Turner et al. (1984) and used in the Flockman system (Filmer, 2001), is based on individual data. In practice, a self-selected group of broilers uses the perch, which biases the data and necessitates manual correction. This can be a common issue when monitoring big herds or flocks, and the consequences must be examined statistically, with individual measures serving as the foundation for group-level control. We believe that in the future, sensors and sensing systems for monitoring livestock will be widely available, putting the animal at the center of PLF. However, if PLF is to be used in the field, the availability of low-cost, dependable, and robust sensors remains the most pressing issue. More research and development is required, utilizing technologies from other applications where high demand has driven production costs down, such as web cams. To understand sensor data, agricultural engineers will still need to create application-specific algorithms.

3.2.2 Machine Learning

Animal species are bred and goods for human consumption, such as meat and milk, are obtained through conventional livestock husbandry. Food animal products account for more than a third of the protein consumed in human diets worldwide (Suryawanshi et al., 2017). Precision Livestock Farming (PLF) is a new idea that combines modern information and communication technology (ICT) with a holistic approach to improve production efficiency while also improving animal and human wellbeing. PLF is a key player in Industry 4.0, commonly known as the fourth industrial revolution. PLF employs information and communication technology (ICT) to lower investment costs and boost both productivity and animal health. (Banhazi et al., 2012).

Farmers' experience has always been the primary source of decision-making on livestock farms. However, as stated by (Hostiou et al., 2017), Precision Livestock Farming (PLF) fundamentally alters farmers' working processes by providing new information, often in large quantities, on the health status of animals, their welfare, and their food requirements in order to preserve and improve farms' technical, economic, and environmental performance (Panell, 1999). Quantitative data can also be obtained in real time. PLF and control systems utilise real-time data for data mining and machine learning techniques. (Banhazi and colleagues, 2012).

To ensure that the best available knowledge can be easily implemented on farms, information-based and electronically managed livestock production systems are required. It is now possible to process data collected every day in livestock production connected to animal control (Vranken and Berckmans, 2017). ICT is used in a variety of industries to exploit data and forecast economic benefits; animal behavior data is used by machine learning models to predict animal behavior that is linked to more efficient animal output in cattle (Espinosa et al., 2016). ML is frequently used to produce such predictions. Because managing animals individually, collecting personalized information individually brings advantages to the production. Knowledge of animal behavior is vital to assess the demands of the animals (Banhazi and Black, 2009).

The state-of-the-art in PLF in terms of artificial intelligence, and in particular, current ML techniques employed in PLF, is mostly focused on grazing animals, specifically for the cattle business.

Work on ML for grazing and for animal health, according to Van der Burg et al. (2019), are two primary subjects that represent research difficulties in the field of PLF. The sheer volume of data collected, as well as the variety of sources, makes human comprehension and control of the animal farming system extremely difficult. That is why Decision Support Systems (DSS) must collect, synthesize, and pre-analyze all relevant data in order to make it understandable to the Decision Maker (DM) and assist him or her in making decisions. As a result, approaches and tools from industrial engineering decision support must be transferred and adapted to agricultural organizations. (Panell, 1999; Ruiz-Garcia et al., 2009; Banhazi et al., 2012; Terrasson et al., 2017). In comparison to other sectors, the potential courses of action in the sheep industry are restricted, according to Villeneuve et al. (2019). Sensors that are tailored to the needs of sheep are needed to better control breeding (health issues, reproduction/struggle, lambing, etc.) because sheep have distinct production patterns than large ruminants. There has been an increase in average flock size in the world for several years, reducing the time that farmers can spend on individual observation of their animals during the sheep production cycle. This condition necessitates immediate improvement in performance control, allowing farmers to better manage their flock. Individual ewe monitoring, phenotype estimation of each animal, solutions to improve gimmer sorting and culling management, identification of animals requiring special care (health problems, lambing assistance, etc), lamb growth monitoring, and milk production monitoring for each ewe are among the major challenges identified by Villeneuve et al. (2019). These challenges have common difficulties, such as a high volume of capitalized data, a variety of data sources, and system complexity, all of which need the use of DSS.

Machine learning and computer vision techniques are used in recent animal monitoring technology. Norton et al. (2019) reviewed the most common technological approaches to animal monitoring and demonstrated how picture and sound analysis might be utilized to create digital representations of animals. Second, Milan et al. (2018) offered a discussion on how machine learning algorithms may be used to track internal and surface temperatures, breathing rate, sweat rate, walking pattern, behavior, physical dimensions, weight, and body condition score in dairy cows. Third, Astill et al. (2020) highlighted the areas in which new smart-sensor technologies would have an impact on poultry operations, as well as how sensor technology is related to big-data analytics and the Internet of Things (IoT), and how these technologies can improve poultry productivity. Finally, Dominiak and Kristensen (2017) developed strategies for classifying and prioritizing herd alarms. Future research should focus on alternate detection methods that use the prior probability or danger of a condition occurring, they said.

Recent technological advances mean that large data sets can be collected on the movement (Hussey et al., 2015; Kays et al., 2015; Tomkiewicz et al., 2010), fine-scale motion (Brown et al., 2013), social interactions (Krause et al., 2013), vocalizations (Blumstein et al., 2011) and physiological responses (Kramer and Kinter, 2003) of individual animals. Unknown nonlinear dependencies and interactions across multiple variables make it unclear what type of functional relationship one should use to describe such data mathematically. Animal behaviour researchers are thus in a position where automatically collecting detailed data sets is becoming commonplace, but extracting knowledge from them is a daunting task, mainly due to the lack of accessible analytical tools (Valletta et al., 2017). Christin et al., (2019) gave a general summary of the main steps involved in creating a supervised deep learning model (Figure 3.5).

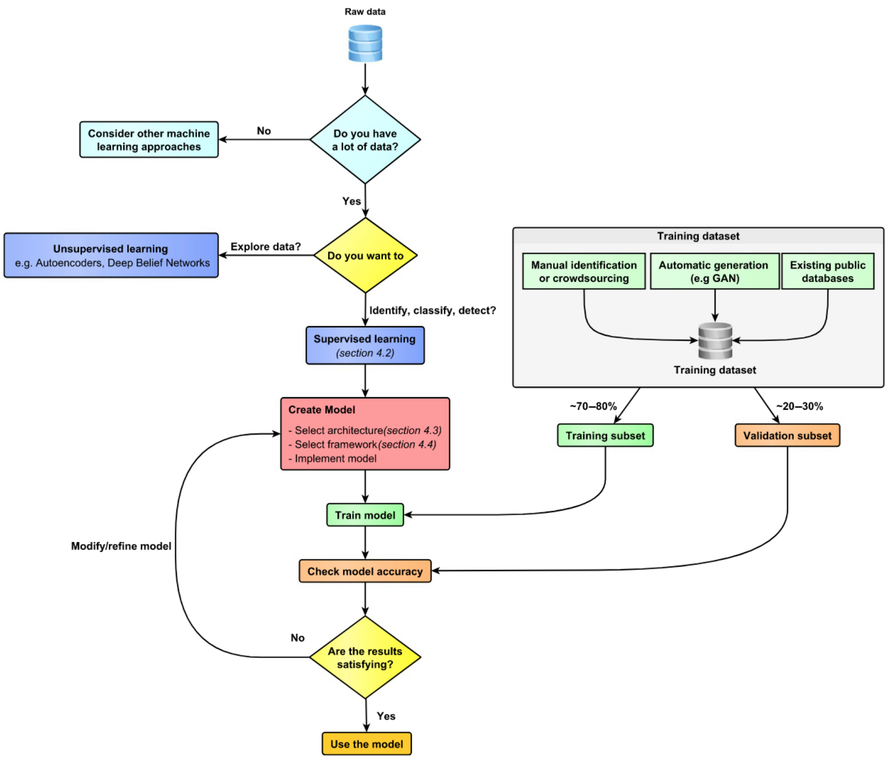

Figure 3.7 Flowchart of the steps required to create a deep learning network (Adopted from Christin et al., (2019)

There has recently been a surge in interest in detecting abnormal behavior in household animals (Pickett et al. 1981). Analyzing the animals and their behavior takes a long time and is a costly method for researchers to use. Deep learning in deep convolution neural networks may abstract multiple levels of raw data. (Wicht 2017). Thenmozhi et al. (2020) identify some of the physical characteristics and the behavioral characteristics of sheep. The physical attributes that we detect are whether the sheep is skinny (with less fur/baby sheep) or beefy in physicality, whether it shows aggressive and non-aggressive behavior, and whether the sheep is foraging. These attributes mainly help in identifying the behavioral characteristics of a sheep. Algorithms are used in order to identify the animal in the frame as well as the characteristics that are mainly depicted in that particular image. Computer vision-based image identification has started to be used in animal detection and classification. There are three steps described for this purpose; i) Image processing is carried out by initially rescaling the shorter side of the image with respect to a defined length and, after that, applying the image to the same length. Pixel intensities are normalized into the range of (Stuhlsatz et al. 2012). ii) Detection and Classification of Animals: The TensorFlow object detection API is used to construct, train, and deploy object detection models. In order to train the model, it is necessary to provide some training data by collecting images of various sheep. Once images are collected, they need to be annotated to describe the object in the image, as shown in Fig. 3.5. iii) Describing Animal Features: The test dataset images were separated 30% from the complete dataset received as input and converted into a minimum set of features (Fig. 3.6). The chosen features may contain significant information from the input dataset. Deep neural networks identify features from images and determine multiple levels of representation, with higher-level features displaying more abstract characteristics of the dataset. This work by Thenmozhi et al., (2020) aimed to identify the unusual behavior that is detected at an early stage, avoiding the death ratio, spread among other animals, and monetary loss.

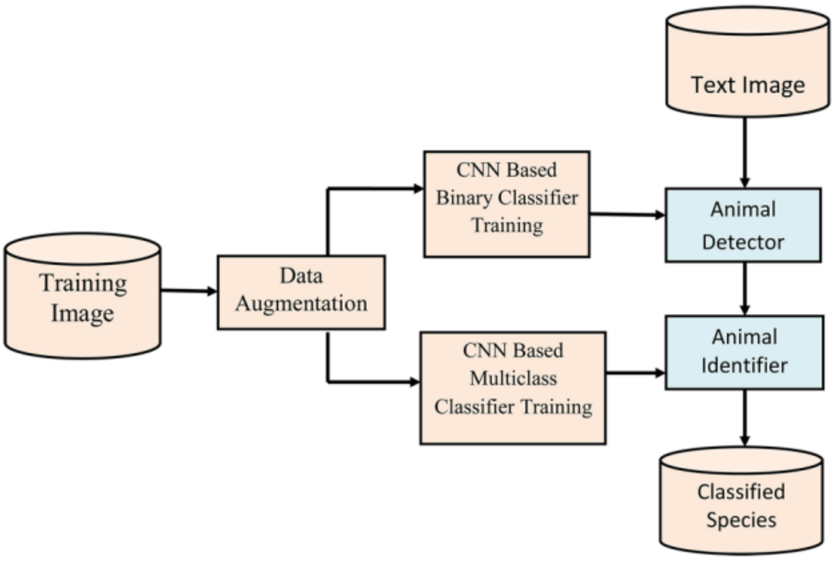

Figure 3.8 Detection and classification (Adopted from Thenmozhi et al., 2020)

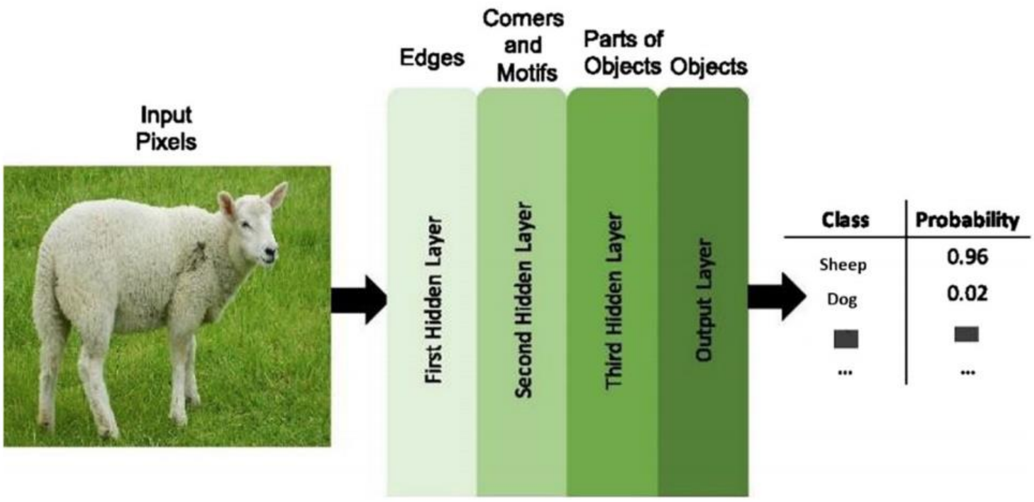

Figure 3.9 Object detection and identification (Adopted from Thenmozhi et al., 2020)

It can be seen from the above study that the field of machine learning offers many flexible algorithms that are suitable for analysis of large, complex data sets. Conventional statistical methods, such as regression or ANOVA, require the assumption of a specific parametric function (e.g., linear, quadratic, etc.), and large quantities of data must be discarded if one or more explanatory variables are missing. Machine learning algorithms, on the other hand, can accommodate intricate dependencies among explanatory variables and can function effectively in the presence of missing values for some variables. Therefore, the application of such algorithms for analysis of herd or flock management and performance data or computerized decision making on commercial farms seems very promising (Pietersma et al., 1998).

3.2.3 Precision Livestock Farming (PLF) Software

Information adoption among the farming community is widely acknowledged as one of the critical factors for efficient and effective agricultural decision-making (Cash, 2001, Galloway and Mochrie 2005, Rao 2006). Tiwari et al. (2010) argued that the livestock sector should come up with need-based, location-specific, and local language content in the form of computer software and other electronic content in regard to livestock disease control, herd/flock management, livestock production, and marketing of livestock and their products.

Tracing, storing, and recording information on each individual animal in herds or flocks that are growing all the time is no longer manageable by many farmers. Sensing technologies were developed to provide animal-centric information to serve as the farmer's' eyes and ears ’, driven by advanced technologies and powerful computers that provide massive data storage, modeling and computing capabilities (Maltz, 2020). Sophisticated intelligent software is a fundamental part of PLF, since this is a unique management system which uses systems to combine data from different sources of hardware for monitoring. The data generated is analyzed using software with an algorithm that compares current to historical activity.

ICT based information delivery to the livestock sector can significantly improve the quality of decision-making in the livestock farming system. With intensification of livestock production systems and increased market demand for animal-based products, the importance of information is growing in many developing countries (Morton and Matthewman 1996). In this process of structural change and potential growth in high-value products (Gulati et al., 2007), ICT based livestock advisory services for knowledge dissemination to the farming communities for better and informed decision-making at the farm level have become essential.

The PLF system continuously records individual animals and measured data is processed with sophisticated software, and the data is downloaded wirelessly to a computer each time the animal enters the receiving area of a base station. Alerts showing the animal's status are displayed on a local computer or in the cloud. Each leash learns normal behavioral patterns and the owner warns only when intervention is necessary and allows the farmer to plan corrective action. Significant differences in the variance of the measured raw data allow the derivation of various behaviors such as rumination and feeding (Elischer et al., 2013, Schirmann et al., 2009). In some cases, the entire decision-making process can be done automatically, by setting the thresholds in advance in the management software.

The ICT has already proven its worth for animal health care systems and for disseminating information to livestock owners in an effective manner. Various other such information systems software and expert systems could be developed based on the needs of different clients and locales. Furthermore, these may be made language specific for the clientele to cater in a more effective and precise manner.

Livestock systems are complex and therefore difficult to simulate and optimize. As they are based on biologic phenomena, stochastic processes are very important and this has to be taken into account when optimizing certain variables (Mayer et al., 1998). Besides the complexity of the system and the wide variability of the results that a given scenario can present, the optimization of these systems has to meet multi-objective purposes that can be economic, social, and environmental (Ripoll-Bosch et al., 2012). Villalba et al. (2015) emphasized that when modelling livestock management systems, they have to cope with: the complexity of the system and the representation of individual variability, the optimization of variables of different natures and dimensions, and the evaluation of the trade-offs that can occur when we change the objectives of our optimization. To solve this problem, an integrated decision support tool for sheep farming systems that combines simulation and optimization procedures is essential.

3.3 STEP III: VALIDATION IN CASE STUDY FARMS

This is the stage where we conduct validation tests on case study farms. Our aim is to develop the most appropriate integration and decision support approach for semantic and syntactic interoperability of precision flock management systems on the farm. At this stage, in accordance with the design science methodology, we produce Artifact 3, and below is the process we follow in Artifact 3. A summary of each step can be found in the process.

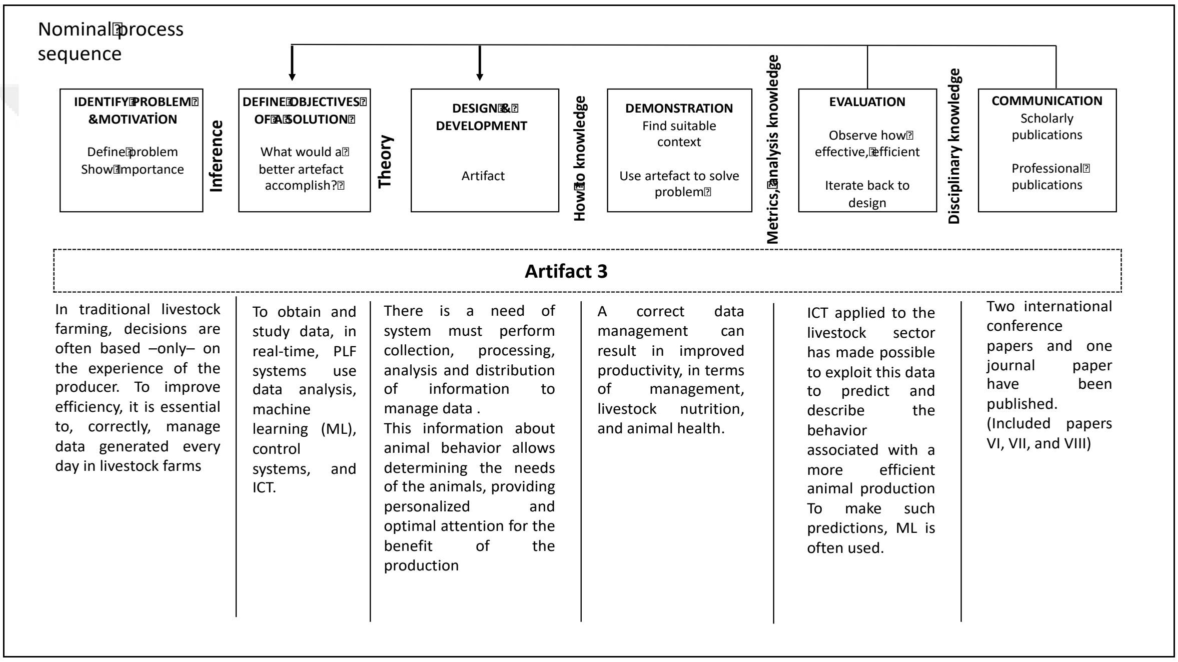

Figure 3.10 DSRM Process for the Artifact 3

3.3.1 Case study farm report

Innovation for Sustainable Sheep and Goat Production in Europe (iSAGE) is making the European sheep and goat sectors more sustainable, competitive and resilient. These improvements come from strong collaboration between industry and research institutions.

In this collaboration, industry is providing research institutions with the challenges and opportunities in the sheep and goat sector in Europe. Together, industry and research partners are thoroughly assessing the sustainability of the sector and developing strategies to respond to the identified challenges and opportunities.

iSAGE assessed the sustainability of the sheep and goat sector in Europe to future challenges such as climate change, food security, resource use efficiency and rural deprivation in marginal regions. Following the sustainability assessment, iSAGE developed strategies to meet or prevent these challenges. Such strategies include all levels of the industry, including farmers, local populations, consumers, processors, and retailers.

Industry and research working together aims to ensure that relevant issues are addressed and the project outcomes are applicable in practice.

The project started on 1 March 2016 and continued for 48 months. Precision flock management tools for intensively managed meat sheep were studied under the EU Project iSAGE Project and given as a research article format below.

Precision Flock Management Tools for Intensively Managed Meat Sheep

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Abstract

A Mobile Sheep Manager Software (M-SMS) was developed for a commercial lamb production model using a cloud architecture that collects and utilizes farm data and responds to the farm management with respect to insights into the operational and financial aspects of the farm. The metadata used in the software is composed of ewe reproductive performance, overall productivity, lamb growth rate, survival rate of newborns, and the health status of the flock. The system detects alerts occurring on the farm and suggests troubleshooting. M-SMS was combined with Cloud Services compounded with Predictive Analytics Services to help fine-tune flock management and

improve operational excellence. The Mobile Sheep Manager Software is aimed at sheep farmers who need an easy to use "point and click" solution to keep legislative records, attain operational guidance and build flock performance data. The product supports purchase, culling or breeding decisions based on targets for flock performance.

Keywords: software, sheep, precision flock management, predictive services

Introduction

Animal husbandry is one of the oldest agricultural practices in the world, but has benefited little from monitoring and processing techniques currently being adopted by other industries. Contrary to mechanized industrial developments in livestock husbandry, research and development of appropriate technology for use in monitoring animals has fallen behind other technological improvements.

Mixing within the animal system refers to conditions where different types of animals are kept together. However, over the last three decades, small-scale mixed livestock enterprises have changed into large, single-species units. Intensive and modern farming of single livestock makes the farmer totally responsible for all livestock under his control. In such a system, animals are now produced intensively, and maintained under near ideal conditions for growth and production within current technological limits (Frost et al., 1997).

Meat consumption is projected to rise nearly 73 percent by 2050 (FAO, 2011), and meat-producing animals are required to be raised in a way that is more efficient for production and has less impact on the environment. Moreover, the public is more concerned than ever about animal welfare, including both its monitoring and management (Butterworth, 2018). Precision livestock farming (PLF) can be defined as the management of livestock production using the principles and technology of process engineering (Wathes et al., 2008). Europe has been the birthplace of PLF research, and it continues strongly with over three decades of research and innovation through at least four major EU-funded (EU-PLF, BioBusiness, AllSmartPigs, BrightAnimal) and many other national projects (Mottram, 2016; Wathes et al., 2008). In livestock production, there are already a few examples of commercialization of PLF techniques, but all of them focused on dairy cattle, poultry, and pigs (Guarino et al., 2008) and a limited number of studies have been done in sheep breeding.

The purpose of this study is to report the Mobile Sheep Manager Software (M-SMS) tool developed for intensive sheep breeding for meat production to improve the efficiency of production while increasing animal and human welfare, via applying advanced information and management systems (IMS) and Cloud and Predictive Machine Learning services.

Material and methods

Experimental data

Metadata used in this study is composed of the following; ewe reproductive performance, overall productivity, lamb growing rate, survival rate of newborns, feed cost, health status of flock and financial implications. We tested Mobile Sheep Manager Software (M-SMS) tool in intensively managed sheep flock (300 heads) at Er-Gen Biotechnologies Ltd R&D farm placed in Istanbul, Turkey for two consecutive years. Er-Gen has been raising sheep for meat production and breeding stock of maternal ewes since 2008 with using traditional recording and managing system. Flock was managed with M-SMS integrated data collection station. In order to determine the effectiveness of this tools, productive and management results of this farm was compared with the results of this particular farm before its implementation.

Data collection of individual and flock production information

Sheep in different categories, such as breeding ewes, ewe-ram lambs, rams, weaned lambs, and suckling lambs were RFID tagged and tracked at their own production stages for creating inventories.

Setting targets to increase the number of lambs marketed per ewe

Er-Gen practices a terminal crossbreeding program which requires maternal ewes with acceptable maternal characteristics.

The Ewe flock was scored with the reproductive performance i) age at first lambing 1,5 ii) lambing interval 9 iii) litter size at weaning > %180 iv) total productivity (total kg of lambs at weaning) > 30kg. Being able to analyze lambing percentage, the number of open ewes and weaning reports helped to focus on ways to improve ewe productivity. The Terminal crossbred lambs were scored for i) birth weight ii) weaning weight iii) average daily gain weight (ADW) and iv) feed conversion rate. Rams were subjected to individual tests for their reproductive performance: i) scrotum circumference ii) body weight iii) libido test.

Data Collection Station

The Data Collection Station is a 3-meter-long 3-way sorting drafting gateway that is equipped with sensors to collect weight data, and RFID tags to identify the animal as well as the operation performed on the animal inside the unit. The unit is equipped with a 3-way drafting, ultrasound scanning unit, weighing platform, and RFID reader to get individual recordings of animals for different purposes of productivity measurements. A single station for multiple purposes was used to precisely collect animal data.

Figure 3.11. Data collection station

Cloud Computing

Cloud Computing is a natural fit to enable precision flock management on a farm, in a way that utilizes sensors attached to auto drafting units, and electronic tags attached to the animals to facilitate data collection. All these devices are IoT devices connected to a cloud system, and they push data when a critical event occurs on the farm. It is the cloud infrastructure that collects, measures, analyses, and suggests improvements.

M-SMS creates reports to analyze ewe performance, identifying both the top and the bottom producing ewes in the flock. The Time-tune culling decision for ewes was automatically generated by M-SMS and notified the breeder through his smartphone. By doing so, unproductive ewes are culled on time to avoid their negative impacts on profit margins, and selecting replacement ewe lambs from the right ewes improves overall flock productivity. The system autonomously improves decisions made on culling through machine learning algorithms that are trained on a weekly basis.

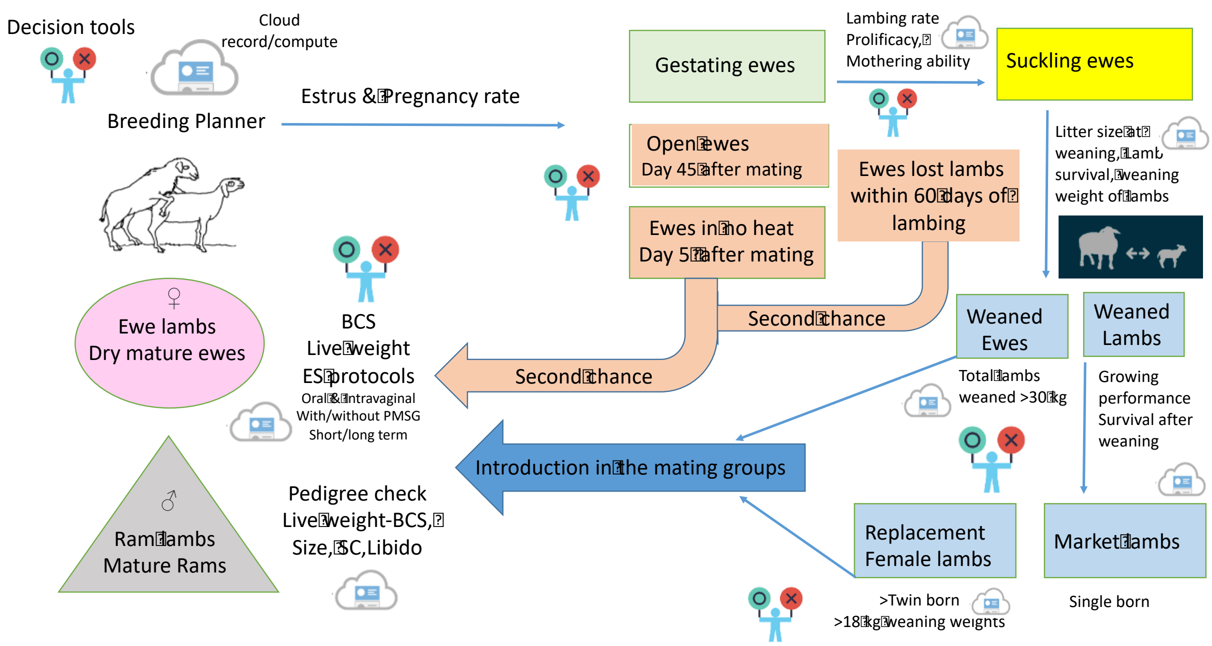


Figure 3.12. General framework of the flock module: succession of events reflecting changes in physiological stages.

Statistical analysis

The data was analyzed using descriptive statistics. The Two-tailed proportions comparison z-test was used for testing, with a 95% confidence level, whether two proportions were equal as the null hypothesis.

Results

Precision Flock Management (PFM) is a realistic method of managing sheep (sub) flocks in order to maximize revenues. The need for every sheep to be fitted with Electronic Identification (EID) tags not only provides a chance for sheep farmers to implement precision technologies, but it may also spark a debate among farmers about the traceability of their farm's performance. Furthermore, employing RFID tags makes data collecting easier, requires less labor, and dramatically eliminates data recording errors, allowing for quick data retrieval for differential sub-group management. In this study, by collecting individual measurements on animals, the top and bottom performers in the flock were easily identified and grouped to maximize production and minimize costs. This approach enabled effective selection among the ewes by keeping the high performers longer and removing the low performers earlier from the system.

In our current study, feed cost was found to be one of the strategically important improvements. A 23% decrease was recorded for total feedstuffs used per ewe. PSM helped to reduce feed costs by only feeding animals that require supplementation according to the animal's condition and history, rather than feeding the whole flock.

The Mobile Sheep Manager Software and other integrated tools for precision flock management increased the efficiency of intensively managed sheep farms for lamb production. Table 1 shows the average trait information of the same flock in which PFM was used before and after. A typical flock will have the top 25% of the animals as well as the bottom 25% for each of these traits. But it should be noted that there is also more variation between individual animals within the same flock of top and bottom performers. In fact, these improvements are mostly achieved by taking advantage of the variation within a flock. As it can be interpreted from the definition of "precision", quite important improvements can be achieved when critical growth periods are precisely controlled. The first evidence of that is a 34% increase in pregnancy rate in maiden ewes. This remarkable increase is thought to be due to the steady growth of ewe lambs which was assured by M-SMS. At this point, M-SMS provides data monitoring by weighting animals and adjusting feeding ratios to maintain a gain of at least 200 gr./day before and through breeding as suggested by Thomas (2002). Another improvement is a 19% increase in accelerated lambing performance of a prolific flock by fine tuning weaning practice and adapting to a more successful method of controlling reproduction. Joining was another contributing factor to reducing barren ewe ratio and increasing conception rates in the accelerated lambing program. PSM improved mating performance by assisting with mating selection of rams. Often, prolific ram breeds which do not show a marked decline in testis size, semen volume and libido during the non-breeding season are used in out of season matings.

One of the most important benefits of precisely monitoring the flock was the achievement (27% more lambs) of lamb survival by ensuring dam health during pregnancy and after lambing. It is well known that sheep colostrum contains high levels of antibodies that can improve the health of lambs, particularly if the dams have been vaccinated. In addition to that, lamb survival was increased with improved ewe nutrition both in early pregnancy (during placental development) and in the last 50 days of pregnancy, which is a period of rapid foetal growth.

Table 1. Variation within a flock in reproductive traits, productivity of ewes and survival of lambs.

Traits	Production level of flock	
	Before PFM	After PFM
Pregnancy rates in ewe lambs (%)	70^a	94^b
Pregnancy rates in accelerated (8 months intervals at first mating) lambing system (%)	67^a	80^b
Barren ewes ratio two consecutive mating (%)	10^a	3^b

Lamb mortality (%)	13[a]	5[b]
Total productivity of ewes (total weight of lambs weaned per ewe/year)	30[a]	44[b]

Different letter indicates a t-test significant difference ($p<0.05$).

Discussion

Precision Livestock Farming (PLF) causes a dramatic change in farmers' working processes (Hostiou et al., 2017) by providing more complex and large data on animal performance, welfare, and food requirements to preserve and improve farms' technical, economic, and environmental performance (Panell, 1999). Information such as repeated liveweights and reproductive performance data might be acquired with minimal human interaction and errors with these automated devices. The effective use of such a management system is heavily dependent on how the information is used. Collecting data is pointless unless how to use it for a comprehensive approach is known. The aim is profitable and sustainable sheep management. The amount of data processed by farmers has increased dramatically.

Villeneuve et al. (2019) stressed the importance of developing a decision-making system that incorporates not just real-time data but also expert knowledge. They stressed that Decision Support Systems (DSS) must collect, synthesize, and pre-analyze all accessible data because human operators' comprehension and control of the system is difficult.

Turkey has the biggest sheep population (33,7 million) in the EU 28 and has approximately thirty-five percent of the European Union's total sheep population (Source: Eurostat (online data codes: apro_mt_lscatl, apro_mt_lspig, apro_mt_lssheep and apro_mt_lsgoat, 2017). Nevertheless, evidence suggests that sheep farmers in Turkey experience lower productivity and profit margins than other livestock sectors. Sheep farmers do not know exactly where they gain or lose income from their flocks and that this is associated with the limited use of data to monitor their sources. Efficient use of feed energy has an important link between both animal welfare and environmental impact. It emphasized the fact that we need more animal products with less feed, less manure and emissions. PFM emerged from the need to inform farmers more regularly and in more detail about the health, welfare and productivity of their animals and to help them make quick and evidence-based decisions about the animals' needs (Norton and Berckmans, 2018).

There is no doubt that Precision Flock Management is potentially one of the most powerful technologies to revolutionize the intensive sheep farming industry. The significant result of this study is that, if properly implemented, M-SMS could definitely improve farm profitability, increase animal welfare, and reduce labor and feed costs. PFM developed and tested in the case study farm within the EU Project (iSAGE), quickly attracted the interest of other intensive sheep farmers, which shows the successful commercialization potential of this technology. As stated by researchers (Thysen, 2000 and Lewis, 1998) for the other livestock industries and agribusiness, we found that efficient information management is very much part of profitable intensive sheep production. Farmers and/or investors choosing intensive sheep farming showed great interest and found quite convincing using M-SMS applications which support the operational aspects of sheep farming in an intensive management system.

The challenge to sheep breeding M-SMS development is to organize the flow of data and the proper interpretation of data. When sheep are raised under an intensive system, organizing the data collection and interpretation of the data is less complex compared to semi-intensive and extensive systems in which environmental and external factors are much more complex.

Conclusions

It is concluded that the adoption of M-SMS for precision sheep breeding has the potential to improve production efficiency and reduce costs. To ensure the potential of M-SMS developed for intensive sheep breeding, we need to verify it in the same flock for a lifetime cycle, also in different genotypes used for maternal line and in different market needs for commercial lambs in terms of slaughter weights and ages.

4. RESEARCH ARTICLES PRODUCED AT THE CASE STUDY FARMS

In this chapter, all papers published in the course of preparing this thesis are presented.

4.1 Paper I

E. Emsen, M. Kutluca Korkmaz, B. Odevci, H. Demirezer, "Evaluation of exotic Terminal and Prolific Sheep breeds for their appropriate use in terminal crossbreeding systems in specific production and marketing situation in Turkey" Steps to Sustainable Livestock International Conference 2016, Bristol, UK, 12-15 January 2016. Abstracts 2016 93.

4.1.1 Summary

Improving the efficiency of commercial lamb production is a paramount step towards achieving sustainable livestock. Broad diversity among breeds of sheep is a precious industry resource. The beneficial genetic effects of each breed can best be realized in terminal crossbreeding systems that utilize sire breeds to complement the characteristics of maternal crossbred ewes, thus greatly improving the efficiency of commercial lamb production.

In this study, three terminal sires, Suffolk, Charollais and a composite breed (half Charollais, quarter Romanov, quarter Turkish native breed: CRT) and F1 Romanov ewes were used. Terminal sires (n=5 from each breed) were mated to F1 Romanov ewes (n=50 for each sire). The crossbred offspring of these three breeds were compared for reproductive traits and total productivity. Ewes were synchronized with intravaginal CIDR (Pf izer) (12 d) and received 400 I.U. eCG by intramuscular injection at the time of CIDR removal. Rams were introduced 24 h after CIDR removal and mating continued for up to 5 days. All ewes were scanned transabdominally by using a real-time ultrasound (Draminski, Poland) at day 45 post mating. Lambs were born in an enclosed building and reared by their mother until the weaning age of 75d. All lambs were switched to a total-mixed growing diet at about ten weeks of age. Lambs were

weighed at weaning and at 16 weeks of age. The productivity of ewes (litter size) was measured at birth and weaning. Also, litter weight at 16 weeks of age was used as an indicator of income per ewe.

The conception rate obtained in this study did not differ for the ewes mated with different breeds of ram (Suffolk: 85%; Charollais: 87% and CRT: 88%). Charollais rams (192%) were superior (P > 0.05) to Suffolk (179%) and CRT (161%) rams based on litter size at birth. Lamb survival until weaning was significantly different among lambs sired by different terminal sires and CRT sired lambs had the highest survival rates (91%) than those recorded for Suffolk (82%) and Charollais (82%). Total productivity was measured at 34.9 kg, 43.3 kg and 25.9kg for Suffolk, Charollais and CRT sired ewes. It was concluded that the Charollais breed was the best sire in terms of total productivity, which is accepted as a reliable indicator of income per ewe.

4.1.2 Contribution

- This paper used different sheep genetics for their potential to be used in specific market lamb targets.
- This paper combined breeding techniques with genetic and epigenetic methods to achieve the best model of production.
- The aim of this paper is to compare different genetic sources that excel in different and opposite production characteristics, such as reproduction and meat production.
- The proposed assisted reproductive technologies (estrus synchronization and pregnancy detection) are being tested for their contribution to precision flock management.
- This paper attempts to show the best indicator of income per sheep.

4.2 Paper II

E. Emsen, M. Kutluca Korkmaz, B. Odevci, H. Demirezer, "Development of a New Synthetic Prolific Dam Line (ANAROM) via ART in Turkey" INTERNATIONAL CONGRESS ON ANIMAL REPRODUCTION, Tours, Fransa, 26 - 30 Haziran 2016.

4.2.1 Summary

The development of the Anarom synthetic breed of sheep (50% Romanov and 50% Turkish native breeds) was initiated in 2004 at the Ataturk University, College of Agriculture, and Department of Animal Science in Turkey. The Anarom breed was developed to redress some of the deficiencies of the Romanov as a sire of crossbred ewes.

Eight native breeds were involved: Morkaraman, Awassi, Akkaraman, Kivircik, Chios, Daglic, Tuj, Kangal, contributing 50% of the Damline genetic composition. The line (F1) was obtained from eight native breeds and Romanov was closed for inter-se mating and selected for age of lambing, lambing frequency, litter size at birth and weaning.

Assisted reproductive technologies (ART) such as estrus synchronization, laparoscopic artificial insemination, and embryo transfer were integrated into development procedures. The reproductive and milk traits of Anarom ewes and the body weights and survival of their lambs of the new breed, collected over a period of 3 years, were investigated. We presented a review of several studies conducted by the research team. The results of the study showed that age at puberty, fertility, lambing frequency, litter size at birth and litter weight at 60 days for Anarom ewes were superior to their native breed counterparts.

Anarom’s %50 dam line genetic composition, in terms of their genotypic and phenotypic characteristics, spans a wide geography of Eastern Europe, the Middle East and Caucasians. It is concluded that the new breed demonstrates promise and potential genetic merit for increasing meat production in East Europe, the Middle East and Caucasians. Additionally, assisted reproductive technologies have augmented developing synthetic breeds.

4.2.2 Contribution

- This paper emphasized that each country or region should develop their own dam line for sustainable production.
- This paper underlined that the genetic composition of a new breed requires a strategic agenda planned by domain experts.
- The aim of this paper is to provide suggestions if ART's are needed to speed up genetic progress.
- This paper aimed to give a road map for selecting production characteristics for accelerated production.
- This paper highlighted that improvements in system components should cover wider geography to widely spread the outcomes of a development.

4.3 Paper III

E. Emsen, M. Kutluca Korkmaz, B.B. Odevci, "Principal Component Analysis of Factors Effecting Reproductive Performance of Prolific Sheep" Book of Abstracts of the 69th Annual Meeting of the European Federation of Animal Science. Dubrovnik, Croatia, 27-31 August 2018.

4.3.1 Summary

The Romanov breed has been selected for crossbreeding with Turkish native breeds as a source of increasing reproductive efficiency through crossbreeding due to its other advantages, such as high adaptability, suitability for being managed successfully in different systems, and higher survivability rates of its crossbred lambs, which are lacking in other prolific breeds. Reproductive efficiency in a prime lamb producing ewe flock is a key driver of profitability (Cottle, 2010).

In this study, principal components analysis was applied to a set of reproductive traits of prolific sheep in order to reduce the number of traits and understand their relationship for breeding purposes.

Multivariate techniques, other than path coefficients and multiple regression, have been used only to a very limited extent in the field of animal science. Principal component analysis is a multivariate technique for reducing p-correlated measurement variables to a smaller set of statistically independent linear combinations of the original measurements. This technique attempts to find linear compounds of the original variables which can account for the dependency structure existing among the original measurements (Pinto et al., 2006).

A total of 100 Romanov crossbreed ewes (2-4 age) were used to record pregnancy rate, birth type, sex, litter size at birth and weaning age, and total productivity. The Correlation coefficient and Principal Component Analysis (PCA) were used to determine relationships in reproductive performance. The highest correlation coefficient was computed between litter size at birth and total productivity (r=0,72) and this value was continued up to litter size at birth with r=0,51. The power of explaining the variance of these factors was found at %67,488. The indicators for explaining the total variance were birth type, total productivity, birth weight and weaning age. In the result of PCA, 3 components out of 9 were explained.

4.3.2 Contribution

- This paper addresses the importance of successful management of productive (prolific) flocks in different systems.
- This paper determines the key drivers of profitability in prime lamb production.
- The aim of this paper is to run principal component analysis to reduce the number of factors effecting productivity.
- This paper indicates classic statistical analysis is very limited in the field of animal production and more complex analysis is required.
- This paper attempts to find linear compounds of the original variables which can account for the dependency structure existing among the original measurements.

4.4 Paper IV

B.B. Odevci, M. Aydın, "Generic Monitoring of Livestock Data Management" 4th International Management Information Systems Conference, İstanbul, Turkey, 2017.

4.4.1 Summary

Precision livestock farming is seen as a way forward in a world in which there is growing concern about food and its impact on human health and animal welfare, and in which food producers are facing reduced profit margins.

Precision livestock farming is defined as covering the life cycle management of animals and exploiting multiple identification and associated sensory and location technologies to optimize feeding and control to achieve objective yield factors, improved animal health, and optimized usage of resources with respect to such factors.

This paper reviews the development of precision livestock farming (PLF) in sheep. PLF relies upon automatic monitoring of livestock data and related physical processes. The decision on which data set should be monitored depends on the production targets of livestock farming operations. In addition to that, we examine the viability of technology and data management in the case of intensive sheep breeding for meat production, which fits into minimizing the environmental footprint of lamb production, ensuring high levels of welfare and health for animals, and increasing productivity.

We propose relevant data types, data models, along with the underlying technology. Since PLF treats livestock production as a set of interlinked processes, which act together in a complex network, data sensors having a high impact and deterministic role on production should be carefully investigated. Most of the research has focused on data related to animal growth, the output of fiber, some endemic diseases, aspects of animal behavior, and the physical environment of a livestock building, such as its thermal micro-environment and emissions of gaseous pollutants such as ammonia. It was concluded that PLF is an early technology with great promise, but one that requires considerable research and development before uptake, especially for small ruminants.

4.4.2 Contribution

- This paper addresses the future challenges concerning animal breeding and consumer protection.
- This paper reviewed the research conducted on the development of precision livestock farming.
- The aim of this paper is to examine the viability of technology and data management in meat production for intensively managed farms.
- This paper attempts to show that how to decide on which data set should be monitored depends on the production targets of livestock farming operations.
- This paper proposed relevant data types, data models, along with the underlying technology.

4.5 Paper V

B.B. Odevci and E. Emsen. Disruptive Innovation in sheep breeding for ensuring complete traceability of lambs. INNOVATIONS TO IMPROVE SUSTAINABILITY IN THE SHEEP AND GOAT SECTOR. An iSAGE training course and an iSAGE workshop. Thessaloniki, 13th-15th January 2020.

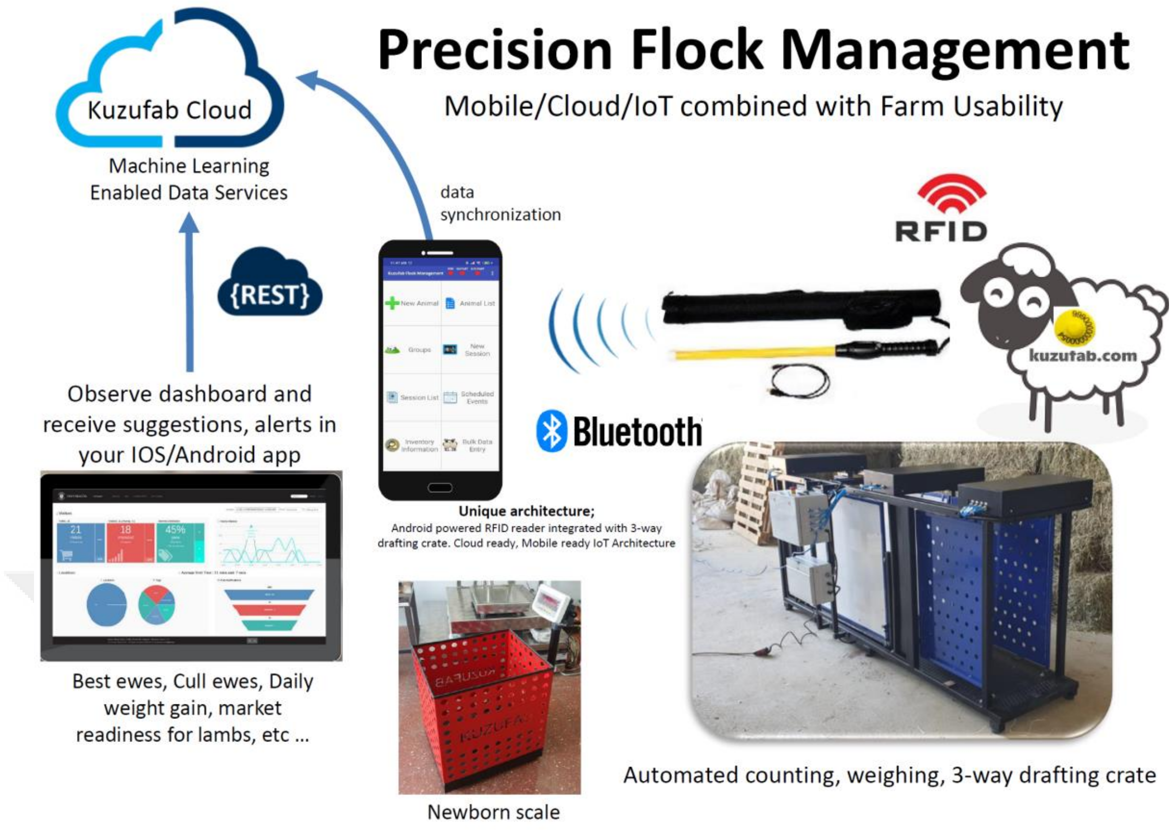
4.5.1 Summary

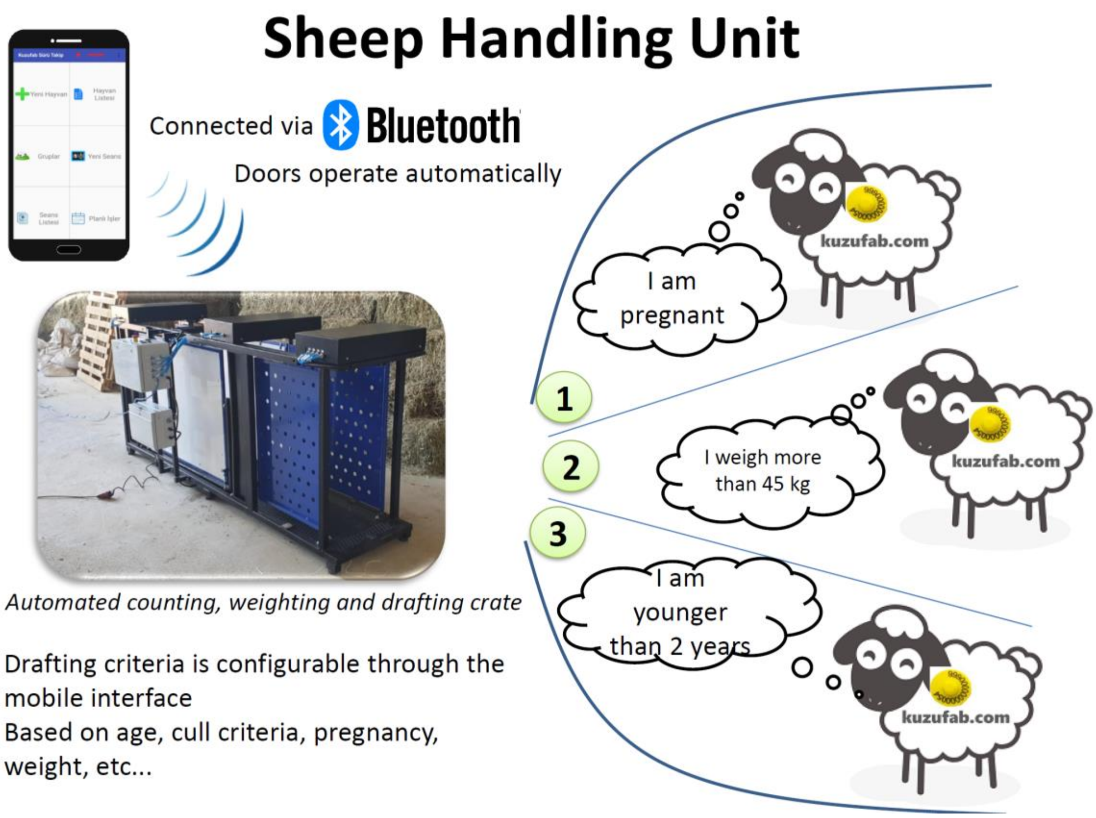
Problem statement of sheep breeding;

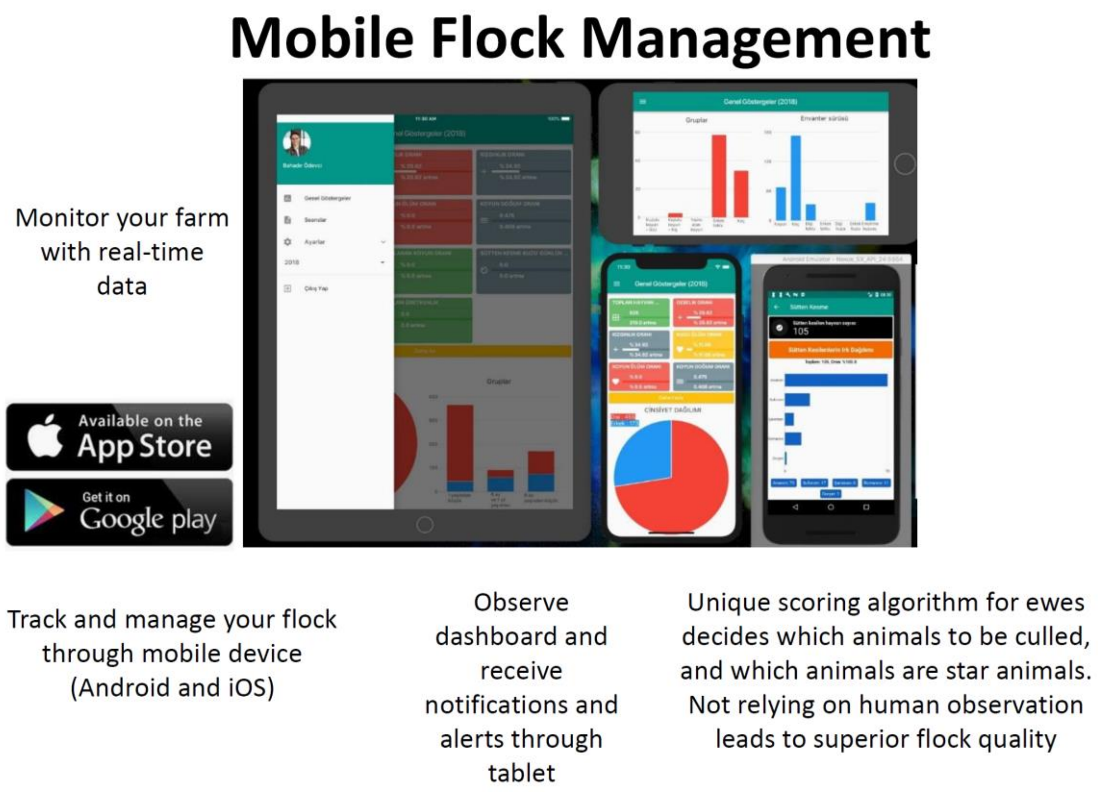
- Meat consumption is projected to rise by nearly 76 percent by 2050 (FAO, 2011).
- The environmental impact of livestock breeding is a problem.
- Animal welfare is a growing concern.
- We should improve productivity per head.

- Facts; i) Sheep breeding benefits little from monitoring and processing techniques compared to other livestock. ii) Traditional breeding refers to small-scale mixed livestock enterprises raised on pasture and decisions on animals are taken by human experience and open to predators and parasites.
- Solutions; Technologic breeding refers to large scale of single species livestock, intensive and systematic management based on data-driven control, and targeted sustainable and profitable production.
- Focus; Areas to excel in sustainable-profitable lamb production are i) reproduction performance of flock, ii) lamb survival rates, iii) growth rate of lambs, iii) feed cost analysis, and iv) health status of flock.
- Key Performance Indicators (KPI); Flock should be divided into age and sex groups to measure group instrictic performance. i) female group in reproductive stage: age at first lambing < 18 months, lambing intervals < 9 months, litter size at weaning > 180%, total productivity of ewe > 30 kg, ii) male group in reproductive stage: Libido test positive, scrotum circumference > 32 cm, body weight and condition scores are ideal, aseasonal mating ability, iii) market lambs for slaughter: birth and weaning weights, daily gain weights, feed conversion ratio, dressing percentage, meat quality.

Technology packages to monitor and track farm performance.


Precision Flock Management
Mobile/Cloud/IoT combined with Farm Usability
Kuzufab Cloud
Machine Learning Enabled Data Services
{REST}
data synchronization
RFID
kuzufab.com
Bluetooth
Observe dashboard and receive suggestions, alerts in your IOS/Android app
Unique architecture;
Android powered RFID reader integrated with 3-way drafting crate. Cloud ready, Mobile ready IoT Architecture
Best ewes, Cull ewes, Daily weight gain, market readiness for lambs, etc ...
Newborn scale
Automated counting, weighing, 3-way drafting crate


Sheep Handling Unit
Connected via Bluetooth
Doors operate automatically
I am pregnant
I weigh more than 45 kg
I am younger than 2 years
kuzufab.com
1
2
3
Automated counting, weighting and drafting crate
Drafting criteria is configurable through the mobile interface
Based on age, cull criteria, pregnancy, weight, etc...



PLF achievements with technologically equipped farms

- Neonatal lamb mortality decreased from %13 to %5
- The pregnancy rate in ewe lambs increased from %70 to %94.
- 20% reproductive efficiency (estrus, conception, litter size, pregnancy) increase in the mature ewes on an accelerated 8-monthly lambing schedule.
- The total meat production productivity of ewes was recorded at an average of 44 kg, which is 14 kg more than in previous years.
- Barren ewes’ ratio was significantly reduced from 10% to 3%.
- A 23% decrease was recorded for total feed used per ewe.

4.5.2 Contribution

- This paper addresses that it has been thought that the future of farms will have to be well equipped to collect on a daily basis and automatically record performance traits, health, and behaviour.

- This paper emphasized that PLF management technologies allow for real-time monitoring of animal welfare, health, environmental effects, and productivity. The most up-to-date PLF systems can assist farmers in collecting and managing extensive data to guarantee that livestock production is safe, environmentally sustainable, and compliant with the highest health and welfare requirements.
- The aim of this paper is to show the real definition of PLF, which is to manage the smallest production unit (the individual animal if possible) in order to deal with production performance on an individual basis rather than a herd basis. This approach is expected to improve animal health, wellbeing and the profitability of the farm operation.
- This paper attempts to prove that animal and animal products tracking technologies to achieve climate neutrality in the agri-food sector (the "Farm-to-Fork Strategy") is one of the most critical strategies in future agri-food business.

4.6 Paper VI

B.B. Odevci, E. Emsen and M. Kutluca Korkmaz. Machine learning algorithms for lamb survival and weaning weights. EAAP Annual Meeting, Crotia, Dubrovnik, 531. 2018.

4.6.1 Summary

Lamb survival is a complex trait influenced by many different factors associated with management, climate, the behaviour of the ewe and lamb, and other environmental effects. Lamb survival and the weaning weights of lambs are important issues in high altitudes and cold climates.

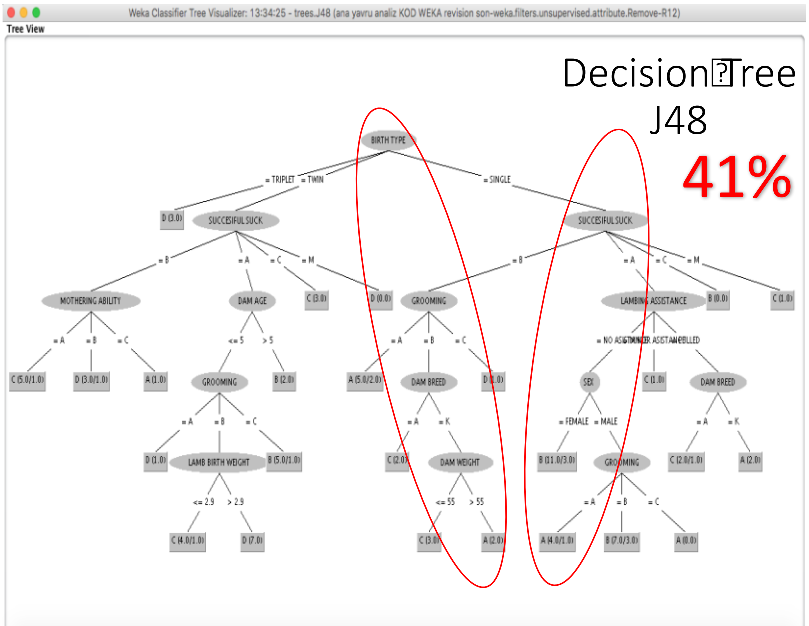
In this study, machine learning (ML) algorithms were applied to the behavioural (dam-lamb) and productive traits effecting lamb survival and weaning weights of crossbreed lambs produced in the high altitude and cold climate regions of Turkey.

The data set included 69 Romanov F1 lambs from 55 fat-tailed indigenous ewes (Awassi=23 and Morkaraman=37; 2-5 ages) managed in a semi-intensive system at the Ataturk University Experiment Station, Erzurum, Turkey. Lambs are born in February-March (winter) under shed lambing conditions. Sources of data on dam and lamb behavioural factors were used as stated by Emsen et al. and Dwyer. Lambs are weaned at 60 days of age.

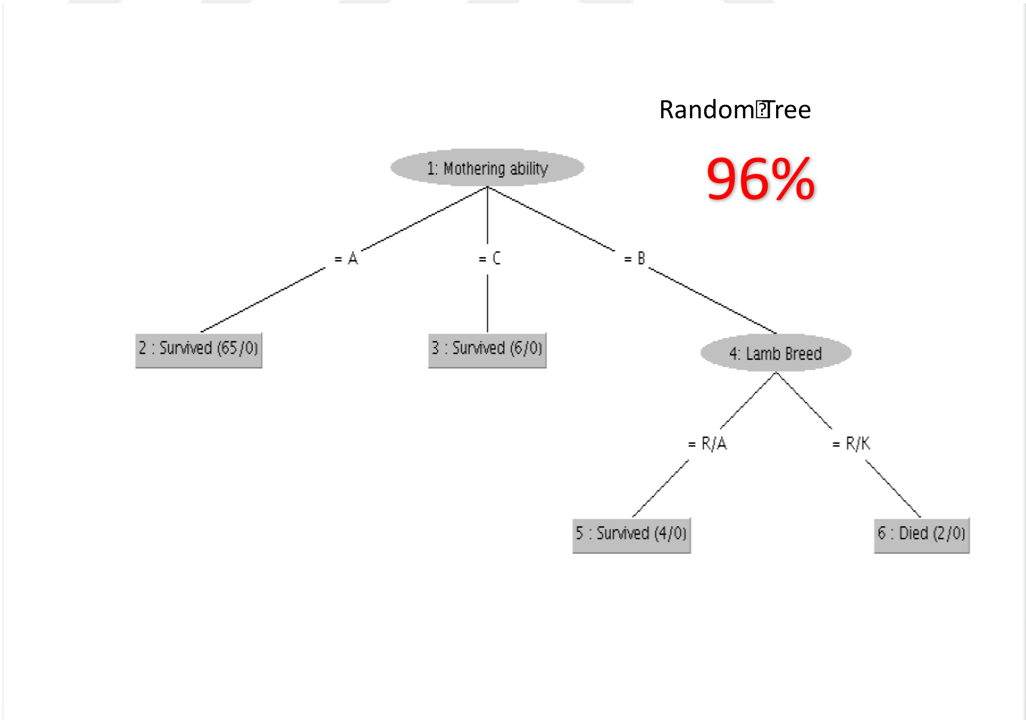
Factors included were dam body weight at lambing, age of dam, litter size at birth, lamb birth weight, lamb sex, lambing assistance, maternal and lamb behaviour, and weaning weights of lambs. In lamb survival and weaning weights, we used classification algorithms which were implemented using The Waikato Environment for Knowledge Analysis (WEKA).

The most successful classification algorithms applied for lamb survival and weaning weights were MultilayerPerceptron with 100 and 41% accuracy rates, respectively. Trees. Variables were categorized for lamb survival, lamb behaviour, and mothering ability. Within the classification Trees, Ramdomtree for lamb survival and J48 for weaning weights of lambs clearly outperformed all other methods with 96 and 41% accuracy rates, respectively.

Weaning Weight



Predicting Lamp Survival Rate



Our results showed that machine learning algorithms we used have better predictive power in classifying lamb survival than those for weaning weights of lambs.

4.6.2 Contribution

- This paper highlights the survival of offspring from livestock is a complex trait and factors associated with this trait are common in most food producing animals.
- In this paper, the studies were carried out in the context of applying machine learning algorithms to productive traits of lambs such as survival rate and weight at weaning. Weaning is the process of gradually introducing an infant mammal to what will be its adult diet while withdrawing the supply of its mother's milk.
- In this paper, classification algorithms applied to lamb survival showed that machine learning algorithms have better predictive power in classifying lamb survival than weaning weights.
- This paper demonstrates that lamb survival can be successfully explained by ML algorithms. The most important factor determining lamb survival was found to be mothering ability, and the breed of lamb was the second critical factor. Single born male lambs with no assistance during birth, licked longer time by their mothers, reached higher weaning weights, but the results of MLA were not stable for twin born lambs.

4.7 Paper VII

B.B. Odevci and E. Emsen. Machine learning model for maternal quality in sheep. European Conference Precision Livestock Farming on 26th – 29th August 2019. Cork, Ireland.

4.7.1 Summary

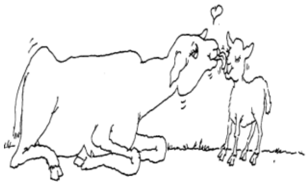
This paper aims to identify determinant traits of ewes by measuring their impact on lamb survival. For that, we devised a machine learning model that correlates ewe traits to lamb survival, and figured out which ewe traits explain the correlation and hence help us to identify the better mother.

In this study, we kept pregnant ewes under 24-h observation by two researchers starting approximately 3 days before expected parturition dates. We conducted the study using native and crossbreed lambs produced in high altitude and cold climate regions. It is critical to note that parturition takes place with minimum interruption unless there is a birth difficulty.

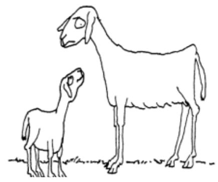
The independent variables used in the machine learning model pertain to the mother's behaviour during parturition. However, we also took into consideration factors like dam breed, dam body weight at lambing, age of dam, litter size at birth, lamb breed and sex.

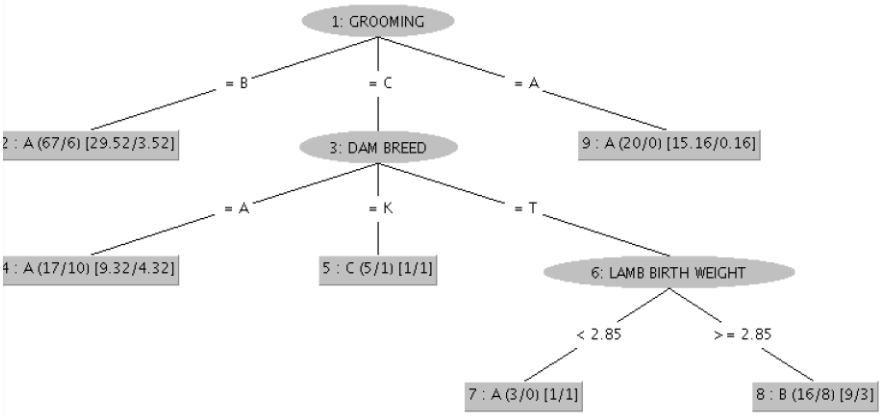
Lamb survival is a nominal output variable, hence we tried out several classification algorithms like Bayesian Methods, Artificial Neural Networks, Support Vector Machines, and Tree-based algorithms. The classification algorithms applied to lamb survival were Bayesian Methods, Artificial Neural Networks, Support Vector Machines, and Trees. The RandomForest algorithm was found to be the best performer among tree algorithms. We were able to present tree visualization for mothering ability with an 80% accuracy rate and 0.43 Kappa Statistics.

The result of the study shows that grooming behaviour is the first determinant of mothering ability. If the grooming duration is longer than 15 minutes, then it is a good mother.



Mothering ability





Labels on Outgoing edges from Grooming refers to;
A: >30 minutes grooming
B: 15-30 minutes grooming
C: <15 minutes grooming

4.7.2 Contribution

- This study set out to focus on mothers' behaviour during and after parturition.
- This paper discussed the traits that identify the best mother.
- This paper argues that the behavior of the mother represents the best mothering ability. Maternal behaviour in the first few hours after delivery consists of focused licking and grooming of the young, accompanied by frequent low-pitched bleats, and acceptance of the neonate at the udder. Licking or grooming serves to dry the offspring, and is important in the formation of an exclusive olfactory memory in the mother for her own neonates. This is established within an hour or so of giving birth, and the dam will then restrict her maternal care only to those offspring with which she has formed an exclusive attachment.
- This research has shown that grooming behavior is the first and most accurate behavior of a mother to be categorized as a good mother. If grooming lasts more than 15 minutes, mothering ability is superior independent of the breed of mother.

However, if grooming is less than 15 min, dam breed plays an important role in describing mothering ability.

4.8 Paper VIII

Odevci, B.B., Emsen, E., Aydin, M.N., 2021. Machine learning algorithms for lamb survival. Computers and Electronics in Agriculture 182, 105995.

4.8.1 Summary

Lamb survival is influenced by the culmination of a sequence of often interrelated events, including genetics, physiology, behaviour, and nutrition, with the environment providing an overarching complication. Machine learning algorithms offer great flexibility with regard to problems of complex interactions among variables.

The objective of this study was to use machine learning algorithms to identify factors affecting lamb survival in high altitudes and cold climates. Lambing records were obtained from three native breeds of sheep (Awassi = 50, Morkaraman = 50, Tuj = 50) managed in semi-intensive systems. The data set included 193 spring born lambs, out of which 106 lambs were sired by indigenous rams (n = 10), and 87 lambs were sired by Romanov Rams (n = 10).

Factors included were dam body weight at lambing, age of dam, litter size at birth, maternal and lamb behaviors, and lamb sex. Individual and cohort data were combined into an original dataset containing 1351 event records from 193 individual lambs and 750 event records from 150 individual ewes. The classification algorithms applied to lamb survival were Bayesian Methods, Artificial Neural Networks, Support Vector Machines, and Decision Trees. Variables were categorized for lamb survival, lamb behavior, and mothering ability. RandomForest performed very well in their classification of the mothering ability, while SMO was found to be the best at predicting lamb behavior. REPtree tree visualization showed that grooming behavior is the first determinant of mothering ability. Classification trees performed best for lamb survival.

Our results showed that Classification Trees clearly outperform others in all traits included in this study.

4.8.2 Contribution

- This paper is the combined and extended versions of Paper VI and Paper VII.
- The animal husbandry management system structure is quite complex. Various problems are large and complex, and some can not establish a precise mathematical model.
- Machine Learning (ML) and breeding share important objectives such as prediction and, unsurprisingly, several works have applied ML algorithms.
- Sheep breeding, like other livestock breeding, uses big data sets and statistical techniques that fall within the ML scope.
- In terms of the survival of newborns and factors effecting this very important parameter, ML methods can support us in creating assumptions by analyzing a large amount of data and these methods can help us in decision making.
- This paper provides an approach to machine learning algorithms into the behavioural and productive traits effecting lamb survival. With this information, appropriate animal breeding and management programs can be formulated to reduce lamb mortality rates.

5 DISCUSSION

Digitalizing animal agriculture with Precision Livestock Farming (PLF) technologies is becoming more critical for transitioning farms into smart farming systems. Thanks to PLF technologies, livestock agriculture has the potential to address pressing concerns such as animal welfare and public health by becoming more transparent and fostering increased consumer trust. Furthermore, the adoption of PLF and associated technologies is required to minimize the number of animals required to produce the same quantity of output, resulting in reduced farm waste and, as a result, increased farm environmental and economic sustainability.

The livestock industry, where intensification took place, had the largest implementation of PLF application. PLF developers primarily serve the dairy cattle industry by creating a wide range of management tools and technical services. (Abeni et al., 2019). Other ruminants, particularly tiny pasture ruminants, are less likely to profit from such arrangements. The first and most significant aspect of effectively controlling farm management complexity is the animal farming system. In comparison to a closed barn, animals kept in pasture environments are more challenging to control, especially in terms of infrastructure and communication choices. (Morgan-Davies et al., 2018). Intensive systems are favored for their higher yield, but higher maintenance costs are an inevitable fact of this system. While PLF and new technology are becoming more integrated, they are connected with intensive farms that use systems similar to those used for dairy cows. When compared to dairy animals, meat animals are handled only on particular occasions, such as weighting, sheering, and medical procedures, which simplifies PLF technology. Limited handling for meat-producing animals should be devoted to technical solutions, and these opportunities should be used to collect data, make breeding decisions, and accurately manage the flock. Farmers' acceptance and receptivity to new technologies, however, remains low, as it is in many other regions of the world.

This thesis aims to present the technologies currently developed for sheep farming and their potential to be incorporated into a medium-scale meat-specialized farming system.

While the technical aspects of incorporating PLF technologies into intensively managed flock meat production will be discussed, the importance of transforming sheep farmers into green-spirited entrepreneurs with more accepting attitudes toward innovation, technology, and systematic management will be highlighted due to their inherent influence on the adoption of any new technology.

The PLF system should be constructed on a smart architecture that helps the most people for the least amount of money. Electronic identification (EID) systems are a critical component of the PLF farm setup and the sole technology that is currently required by EU legislation. (Official Journal of the European Union, 9.1.2004). RFID technologies allow each animal to be identified independently and the data to be stored and used for various decision-making processes.

In simple terms, an automatic drafter (AD) is an automated system focused on a selective gate that can distinguish and direct the movement of animals. The majority of AD systems use the recognition of animals' EIDs as a selection criterion. However, in this thesis, AD is combined with a weighting system based on physiological occurrences such as being mated or not, pregnant or not, or culled or not based on observation or testing criteria. Animal drafting is one of the most labor-consuming tasks on the farm, particularly in intensive sheep operations. ADs and EIDs could thus be used in tandem for more than just data collection and feeding control. (Rutter, 2017) but also as a tool for the flock to reduce manual effort. (Morgan-Davies et al., 2018).

Currently, there are a number of commercial flock management software solutions available. The most essential elements are flock registry, yield tracking, breeding line, and decision-making aids for farmers comparing individual animals to flock trends and averages. Software is differentiated by key features, compatible devices, integration with other software/databases, cloud or disk-based, mobile-friendly or not, basic pricing, support packages, and so on. Below is a list of the most popular software products.

Table 5.1. Comparison of livestock farming software products regarding main features, integration capabilities and hardware device compatibility.

Product name	Main features	*Compatible devices*	Integration
AgriWebb	• Complete farm records for multiple species including cattle and sheep • Grassland management • Reminders • Reports • Weight insights for livestock	Individual animal control is aided by connectivity with electronic identification (EID) readers and weigh heads. Hardware from Tru-Test, Gallagher, Te Pari, PTS, and Shearwell	Government databases Figured accounting and financial planning software
Farmworks	• Recording of statutory information for cross-compliance • Recording of productivity attributes for genetic improvement to make replacement selection easier by tracking relevant qualities at the farm level • Information on weight gain and slaughter, including prices and grades • Feed management information • Pedigree recording for four generations • Scrapie status entry and reporting	• Bluetooth connections to most weigh scales. • Designed for both sheep and cattle EID and links to Shearwell stick readers and race readers. • Can be utilized for auto drawing with Shearwell and Te Pari crates and connects to Te Pari equipment through WiFi.	• BCMS, Arams, ScotMoves, ScotEID, EID Cymru • Signet and Breedplan
Standard Total Sheep	• Individual records for each animal in the flock, including lifetime activities, treatments, movements, feed and weight gain, thorough lambing history, complete genealogy, and costings. • Individual or group activities are recorded; • Movements, flock health, fertility, weights, and financial	• It works with Sum-Total It's Mobile Sheep App, which runs on the company's Speedata Hand-Held EID Logger or any Android phone or tablet connected to EID stick readers via Bluetooth. • From Tru-Test and Gallagher weighers, the module imports weighing	• Purchases and sales of sheep and medicines only need to be recorded once to update both the accounts ledger and the movements/stock levels/costings at the same time.

	performance are all reported analytically.	session files (cvs or excel).	
Farmax monitoring package	• Several scenarios at the farm level can be tested • Feed deficit/surplus warnings are built-in • Production forecasts • Financial recording and analysis are built-in, with profit forecasting possibilities	• No integration with any EID readers or weigh scales	• No integration
FarmIT 3000	• Record cow and sheep breeding records, movements, veterinarian and medical information, breeding traits, and weights. • Data collected can be utilized to analyze the system and be used inside the breeding program thanks to reports and tools. • Keeping track of a variety of field activities, such as planting, harvesting, and so on	• Connects to a variety of stick readers • Communicates with Tru-Test and Gallagher Weigh Scales • Imports weight and other data	• BCMS, Arams, EID Cymru, Scot EID • Signet
Sheep Manager-Company Farmplan	• Documentation of statutory legal documents • Veterinary and medical documentation • Animal performance monitoring as well as pedigree data • Documentation of breeding cycle events	• Stick readers and weighing devices are both compatible. • On a Windows Mobile device, actions are recorded.	• ARAMS
Select Sheepware-Company TGM Software	• Produces performance analysis for ewes, rams, and lambs, including ewe efficiency calculations based on tupping and lamb weights, and links to several weigh-head systems	• PC-based software that can be downloaded from their website • Agrident EID readers and Workabout Pro EID readers can be integrated.	• Government databases • No integration with financial software packages
AWRLink-Company TGM Software	• Allows for management recording • Does not analyze flock	• Agrident readers users can get free software. • Only accessible for	• No integration

	performance data • Medicine records are preserved for assurance	Agrident readers models • Transfer data from reader to PC	

For example, products like Sheep Tracker, SumIt, Flock Filer, and Farmplan (links accessible in the web reference section) combine data from numerous sources to present a broad picture of flock dynamics as well as track individual animals and their genetic history. Farmers, on the other hand, show little enthusiasm, even after learning about the potential benefits of implementing such software. Adoption hesitancy is typically tied to the stockperson's perceived function, as well as the belief that software can not replace the manual labor required on the farm. (Kaler and Ruston, 2019).

Table 5.2. Comparison of livestock farming software products regarding system architecture and pricing.

Product name	Cloud or disk-based	Mobile friendly	Basic price	Support package
AgriWebb	Fully cloud-based	Yes – When the gadget finds a mobile signal, the mobile app automatically syncs.	£21/month	Unlimited live phone, chat, and email assistance are included in all plans. Personal setup and training calls are included in the "Precision" plan.
Farmworks	Disk based	FarmWorks Mobile is an Android app that works in tandem with FarmWorks on a computer. It connects to a Shearwell stick reader, allowing one to record births, deaths, movements, treatments, comments, groups, and tag replacements.	The FarmWorks software for setting up sheep on a PC costs £375. FarmWorks with Stock Recorder costs £1,580 for sheep and cattle. The cost of FarmWorks	Purchase price includes one year of free technical support and upgrades. Annual support after first year is £115 for FarmWorks Complete or £95 for FarmWorks Cattle or FarmWorks Sheep

			Mobile is £30 per year.	
Standard Total Sheep	PC-based	The Total Mobile Sheep App is compatible with all Android 5.0 and higher smartphones and tablets.	The total cost of the Standard Sheep Module is £595. A £100 Electronic Weigher Interface Module is available as an option. For a 12-month license on one device, the mobile app costs £95.	The purchase price includes three months of starter support. Annual support and updates start at £85 per year (Bronze level)
Farmax monitoring package	Windows software, data stored in the cloud	No	Sheep assessing performance £50/month subscription for full monitoring package	Unlimited training and assistance are included in the price.
FarmIT 3000	PC-based, including a free FarmIT Online Account for data exchange and third-party access.	Apps are available for Windows and Android, and an iPhone app is in the works. The Android app integrates with the core software as well as Google Maps.	The program installation costs £399. The costs listed above are for a lifetime license and are based on business rather than holding number, allowing several farms to be operated.	An annual maintenance charge of £80 covers updates, phone and email support, and higher-level assistance with data analysis.
Sheep Manager	Disk-based	The Animal Logger application from Farmplan can be used on a Windows Mobile device.	The setup fee is £395. A basic version is £195. The cost of the animal logger application is £74 per year.	The upfront fee includes 12 months of email/phone support. The cost of renewing support for a sheep manager is £171 per year.

Select Sheepware	It is not cloud-based, but it backs up to the cloud so that data may be shared.	Yes, the Select Sheepware mobile app allows data to be transferred from the reader to the office PC via email or cloud without the need for a cable connection.	With a minor annual charge, the software costs £250 for up to 100 breeding ewes. Alternatively, a subscription for up to 100 ewes costs £14 per month (users choosing to subscribe do not incur additional charges)	Support is provided for a period of 12 months at no cost. Unless subscribed, support for up to 100 ewes starts at £50 per year, and this covers the support.
AWRLink	There is no cloud backup and the system is not cloud-based.	No, all data is in the form of a spreadsheet. Only csv files are accepted.	There are no hidden fees or extra charges.	No

Source: (Parrot, 2021, https://www.fwi.co.uk/livestock/sheep/a-buyers-guide-to-sheep-management-software)

Precision Livestock Farming applications and potential factors influencing livestock production were summarized by Di Virgilio et al., (2018) and shown in Figure 5.1. Examples of regularly used tools in intensive livestock production systems, the variables that may be obtained with those tools, and how they can be used to achieve various production goals (A); and factors influencing intensive and extensive livestock production systems (B). In (A), the tools are listed with capital letters (from A to K) and are enclosed in a grey circle inside a grey box. Variables are presented in numerical order (from 1 to 8) and are encircled by a green circle. The capital letter matching to the instrument that could be used to retrieve each variable is indicated. The orange box contains all the applications for each variable and tool. The variables and tools that could be employed for each application are also represented by a number and a capital letter.

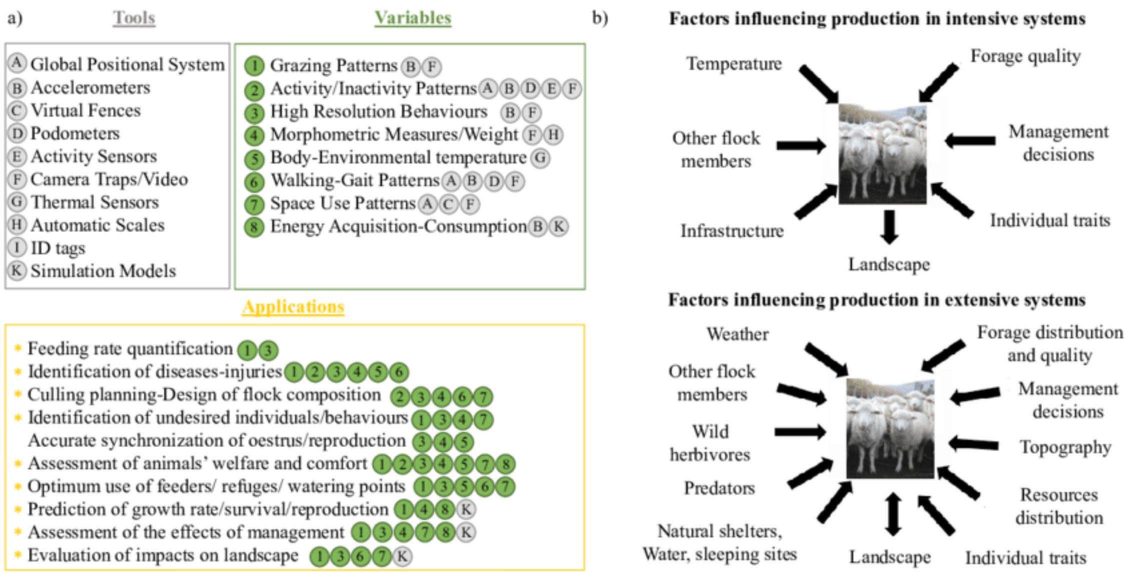


Figure 5.1. Applications of Precision Livestock Farming and probable factors affecting livestock productivity (Photo by: María Andrea Relva. Full-size DOI: 10.7717/peerj.4867/fig-1)

In this thesis, the focus was given to developing a model for addressing factors influencing the efficiency of meat production on intensively managed farms. The data model was simpler than those applied to extensive systems due to the lower complexity and number of factors. The model was based on scientific literature search and research at case study farm levels to strengthen the model. The first step was to describe and evaluate the flock performance for their appropriate use in the most efficient meat production system in the specific production and marketing situation in the region. Refer to Paper I (Emsen et al., 2016). In this step, achieving the best model of production was formulized by testing breeding techniques following the best indicator of income per sheep. The second step was to emphasize the importance of the genetic composition of a breed for its qualifications in sustainable production and it requires a strategic agenda planned by domain experts, as stated in Paper II (Emsen et al., 2016). Key drivers of profitability in meat production need to be determined with an appropriate complex analysis. In this thesis, the third step was taken to run principal components analysis to reduce the number of factors effecting productivity. Refer to Paper III (Emsen et al., 2018).

A graphical depiction of key PLF stakeholders is shown in Fig 5.2. (Ramirez et al., 2019). The main players can be identified as academia, producers, industries, government agencies, commodity groups, and consumers. The development of PLF originated from the integration of industry, academia, and producers. Government agencies, commodity groups, and consumers provide funding and strategic direction for development. industry can be defined as companies developing and marketing commercial technologies/equipment implemented by producers. Producers are those farms that deal with animal management, feeding, care, ownership, and marketing. Finally, academia is a public/private institution focused on research, teaching, and extension. Imaginably, the goals of these entities (industry, academia, and producers) are different. However, they are mutually dependent on each other's existence. Clear goals and intellectual exchange among entities are needed to span the transdisciplinary nature of the PLF.

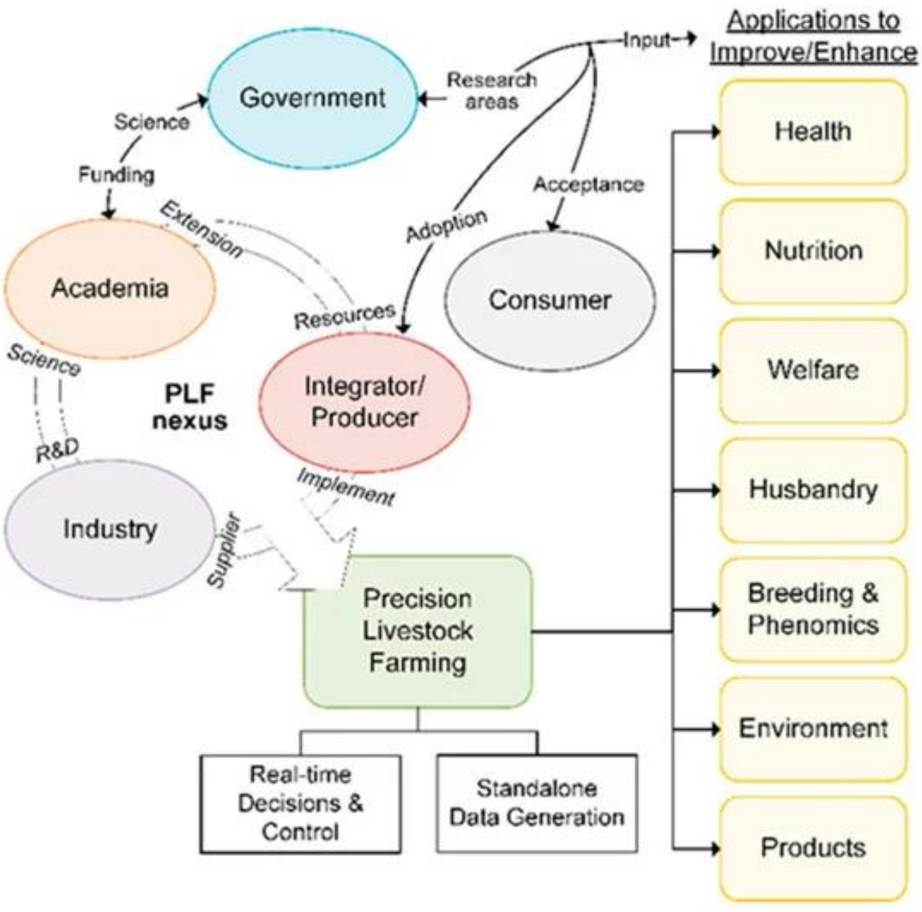


Figure 5.2. Key precision livestock farming (PLF) stakeholders and their interactions to drive and create applications for improving animal production systems. Government

agencies shape the direction of PLF and have increasing invested in PLF areas. Social acceptance of PLF practices by consumers will also play a key role in research and development, as well as adoption. (Adapted from Ramirez et al., 2019).

This study focused on addressing the future challenges concerning animal breeding and consumer protection. The papers produced in the scope of this thesis proposed data types, data models, and technology by exchanging experience and experience among entities such as academia, producers, and consumers. Refer to paper IV (Odevci and Aydn, 2017), paper V (Odevci and Emsen, 2020), paper VI (Odevci et al., 2018), paper VII (Odevci and Emsen, 2019), paper VIII (Odevci

The systems listed above were considered according to their suitability for the management and business models common in meat sheep farming. However, adoption of new technologies does not take place immediately in medium-scale extensive farming. It could be the opposite direction for intensive farming. As sheep farmers usually belong to more conservative technology consumers, characterized by an average age of 60 and a very transparent community, the dynamics do not favor financial risk-taking involved with new technologies. PLF technologies should target green-spirited entrepreneurs who are attracted to a life on the farm. Financial barriers linked to production volumes and resource management of extensive farming are a barrier to innovation, but it could be an advantage for intensive farming. It is obvious that future prospects increase the importance of technology and promote its wider adoption. Trends such as global lamb meat economics, global warming, awareness of animal welfare, antibiotic resistance and European agricultural policies could influence farming practices and stimulate wider adoption of PLF systems in the near future. The PLF system used in the thesis passed the research phase and was tried in field conditions for commercial production.

6. CONCLUSION

Decreasing farmers' workload and increasing the economic viability of farm operations are very important for sustainable production. This way, it will be possible for a farm to produce on a large scale and enable the farm to benefit from economies of scale. This is the way a farm can become more profitable. Since the end of the ongoing pandemic of coronavirus disease, the majority of our economic and social activities have been impacted. This impact is very critical for animal breeding. The COVID-19 pandemic impacted field activities as expected farm visits have been interrupted. Today, there is a need for data collection in farms to be automatic, and farms should be equipped with monitoring tools and animal breeders should be remotely assisted at the time, not only when they need help, but also alert them when things are going in the wrong direction on their farm. By this approach, farmers will be able to better understand the genetical characteristics and the needs of their breeds. This will help farmers to overcome the coming hurdles of climate change, food security and biodiversity.

Precision Livestock Farming (using IoT and AI) has been developed in Japan and Western countries to facilitate smart livestock management. Further research focuses on how to adapt and validate PLF. The traits measurements in the animal breeding sector should be done in a transparent and objective way, and it opens a wide window for PLF technologies. Farms will be equipped with technology that will enable them to collect and record data on performance traits, on health, and on the behavior of livestock on a daily basis. This will not require any visit from a veterinarian or operator or expert to the farm.. Since the beginning of the COVID-19 pandemic, we have observed a need for monitoring equipment for animal breeding units. Jean Monnet said it perfectly: "Humans accept change only out of necessity and they only see necessity in crisis." Hence, we will see evolution in our current practices very quickly and dramatically.

PLF management tools provide real-time monitoring of animal welfare, health, environmental impact and production. PLF systems help farmers to collect and manage detailed information about their flock to ensure livestock production is sustainable and in compliance with health and welfare standards. Current PLF tools and technologies are mainly applied to the production of pigs, poultry and dairy cows. Small ruminants and other meat-producing livestock have been less subjected to PLF Technologies. This thesis aims to describe the benefits of PLM and propose a model to implement PLF for livestock like small ruminants or any other livestock.

Industry 4.0 is a collective approach to digitalization, interconnectedness, and new technologies, and is known as the fourth industrial revolution. Industry 4.0 will change manufacturing supply chains with new products, services, and business models through the use of IoT. Digital networks obviously provide a high level of resilience and responsiveness, and also provide more efficient and transparent service delivery. Industry 4.0 is gaining worldwide popularity among policymakers, businesses and academia. Scientists argue that the 4th industrial revolution extends beyond ICT integration in industrial manufacturing and includes organizational and cultural transformations.

This thesis focuses on demonstrating a technological and organizational model for future livestock farming, adapting the latest technological improvements in production systems to combat restrictions, challenges, etc. This approach aims to make meat-producing livestock farms become more agile and adapt to changing environments. Hence, livestock farming will need to reframe their business models and invest in how they can digitize their management systems and products. They will also need to reassess their capabilities, technologies, and interoperability strategies in order to transition to Industry 4.0.

This thesis proposes to develop a new approach for meat production livestock farms to adapt to PLF by using recent developments such as Cloud Computing, Internet of Things, Big Data, and Machine Learning, which allow for the integration of different lines of development into smart, connected systems.

The model proposed in this thesis will let livestock farming develop into a data-driven, intelligent, agile, and autonomous connected system of systems. Data of each food producing animal should be integrated into the food chain, and it should be available to the end consumer. Specifically, the Eurogroup for Animals supports the adoption of a "Method-of-Production + label," which is a label that would combine method-of-production marking with simple information on animal welfare, based on a core set of animal welfare indicators. The expected impacts of the projects concern the development of a "Method-of-Production +" label should be mandatory to ensure full transparency to consumers. The scope of an animal welfare-related label should further cover the entire supply chain: breeding, fattening, transport, and slaughter. Thus, meat producing animal farms will have a bright and promising future where they can be a part of digital platforms for the supply chain.

Applying the term "Industry 4.0" to "Agriculture" leads to new evolved terms such as "Agriculture 4.0" or "Agri-Food 4.0". Industry 4.0 is about integrating and providing interoperability across the latest developments in digital technologies.

Digital platforms allow enterprises to be integrated with supply chains. This enables enterprises to transmit real-time information in terms of behavior and performance. Farms that are equipped with PLF tools tend to use the method and technology to provide required information to the supply chain. Supply chain stakeholders' requirements are dynamic; hence, farms require to adopt technology and methods to remain linked to the supply chain and organized.

One of the critical advantages of adapting PLF technology is that it can easily be adapted to traceability of products. Animal and animal products tracking technologies to achieve climate neutrality in the agri-food sector (the "Farm-to-Fork Strategy") is one of the most critical strategies for the future of the agri-food business. The European Commission refers to labeling as a central instrument to provide consumers with high-quality information regarding the sustainability level of food production, the nutritional value of food items, as well as consumer information related to animal welfare.

In the past ten years, labeling initiatives informing consumers about farm animal welfare in food production have emerged in the EU Member States. Today, there are a dozen labeling schemes pertaining to farm animal welfare in at least six Member States. The diversity of these voluntary initiatives from the private, public, and nonprofit sectors fits the expectations of European consumers, who demand information on farm animal welfare, as 47% of EU citizens "do not believe there is currently a sufficient choice of animal welfare-friendly food products in shops and supermarkets."

Last but not least, the benefit of PLF systems is that they meet the requirements of the Future Internet (FI) technologies of the meat supply chain domain. The FI is a general term that labels the emergence of a new era in the evolution of the Internet. It combines several trends in internet development into an integrated approach. These trends include:

The on-going industrialization of IT in the form of cloud computing and open service delivery platforms;
Wireless networking technologies and the deployment of fibre are paving the way for new (real-time) applications.
With the breakthrough of the Internet of Things, comes the vision of ubiquitously connecting intelligent devices and sensors.

Fresh food products' shelf life span is not high, which demand for temperature-conditioned transportation and cold chain storage and very short time for delivery lead times. Particularly after the Covid-19 pandemic, there is more than ever demand for food safety, quality and legislation for environmental concerns, which demands traceability of the products' production information across transit of the products. This requires a complex network structure where SMEs trade with multinationals in the input and retail sectors. This demands orchestration in logistics so that aggregated demand can be satisfied with fragmented supply.

Farm to fork logistics operation is not a trivial problem. It requires flexible chain tracking and tracing systems supported by decision support systems. There are critical features that this system should encompass, namely real-time visualization, logistics intelligence, and logistics connectivity. The Farm to fork logistic system should functionally be able to provide intelligent analysis and reporting of exchanged data.

Current information systems for agri-food logistics have limitations, and the FI offers a solution to overcome this, because it aims at the provision of an integrated architecture.

REFERENCES

Abeni F., Petrera, F., Galli, A. (2019). A survey of Italian dairy farmers' propensity for precision livestock farming tools. Animals 9, 202. https://doi.org/10.3390/ani9050202.

Acebron, L. B., and & Dopico,, D. C. (2000). The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. Food Quality and Preference, 11, 229-238.

Adams, L., and Courtney, J. (2004). Achieving relevance in IS research via the DAGS framework. In R.H. Sprague Jr. (ed.), Proceedings of the Thirty-Seventh Annual Hawaii International Confer-ence on System Sciences. Los Alamitos, CA: IEEE Computer Society Press. , 2004

Adhiguru, P., Birthal, P.S., and Ganesh-Kumar, B., (2009). Strengthening Pluralistic Agricultural Information Delivery Systems in India. Agricultural Economics Research Review 22 (1), 71-79.

Archer, L.B. (1984). Systematic method for designers. In N. Cross (ed.), Developments in Design Methodology. London: John Wiley, 1984, pp. 57–82.

Astill, J., Dara, R.A., Fraser, E.D.G., Roberts, B., and Sharif, S., (2020). Smart poultry management: Smart sensors, big data, and the internet of things. Comput. Electron. Agric. 170.

Atkins, K.D., and ; Richards, J. (Sheep CRC, 2007). Making gains from precision production in sheep . Sheep CRC Report 1-_18.

Banhazi, T. M., and & Black, J. L. (2009). Precision livestock farming: A suite of electronic systems to ensure the application of best practice management on livestock farms. Australian Journal of Multi-disciplinaryDisciplinary Engineering, 7(1), 1-e14.

Banhazi, T.M., Lehr, H., Black, J.L., Crabtree, H., Schofield, P., Tscharke, M., Berckmans, D., (2012). Precision Livestock Farming: An international review of scientific and commercial aspects. Int. J. Agric. Biol. Eng. 5 (3), 1–9.

Berckmans, D. (2014). Precision livestock farming technologies for welfare management in intensive livestock systems. Revue scientifique et technique (Office International des Epizooties), 33(1),189-196.

Berckmans, D. (2017) General introduction to precision livestock farming, Animal Frontiers, Volume 7, Issue 1, January 2017, Pages 6–11.,

Bettencourt, E. M. V., and , Tilman, M., (2013) Henriques, P. D.S., Narciso, V., Carvalho, M.L.S. (2013) The Economic and Sociocultural Role of Livestock in the Wellbeing of Rural Communities of TimorLeste. CEFAGE-UE Working Paper 2013/01.

Black, J. L., and & Banhazi, T. M. (2013). Economic and social advantages from precision livestock farming in the pig industry. In Paper presented at the Paper presented at the PLF13, Leuven, Belgium.

Blumstein, D.T., Mennill, D.J., Clemins, P., Girod, L., Yao, K., Patricelli, G., Deppe, J.L., Krakauer, A.H., Clark, C., Cortopassi, K.A., Hanser, S.F., McCowan, B., Ali, A.M. and Kirschel, A.N.G. (2011). Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. Journal of Applied Ecology, 48: 758-767.

Boleman, S. J., Boleman, S. L., Miller, R. K., Taylor, J. F., Cross, H. R., & Wheeler, T. L., Koohmaraie, M., Shackelford, S. D., Miller, M. F., West, R. L., Johnson, D. D., and& Savell, J. W. (1997). Consumer evaluation of beef of known categories of tenderness. Journal of Animal Science, 75, 1521-1524.

Bowling, R. A., Smith, G. C, Carpenter , Z. L., Dutson, T. R., and& Oliver, W. M. (1977). Comparison of forage-finished and grain-finished beef carcasses. Journal of Animal Science, 45, 209-215.

Bowling, R.A., Riggs, J.K., Smith, G.C., Carpenter, Z.L., Reddish, R.L., and& Butler, O.D. (1978). Production, carcass and palatability characteristics, of steers produced by different management systems. Journal of Animal Science, 46, 333-340.

Brown, D. D., Kays, R., Wikelski, M., Wilson, R., and& Klimley, A. P. (2013). Observing the unwatchable through acceleration logging of animal behavior. Animal Biotelemetry, 2013, 1e16.

Brown, D.J., Savage, D.B., Hinch, G.N., and Semple, S.J. (2012). Mob-based walk-over weights: similar to the average of individual static weights? Animal Production Science 52(7), 613–618.

Cardello, A. V. (1995). Food quality: relativity, context and consumer expectations. Food Quality and Preference, 6, 163-170.

Christin, S., Hervet, É., and& Lecomte, N. (2019). Applications for deep learning in ecology. figshare, https ://figsh are.com/s/9810c 18226 8244c5d4b2.

Coetzee, J. and Malan, F. (2007). Afronding van lammers in voerkraal. [WWW document]. URL http://www.landbou.com/kundiges/dierevoeding/afronding-van-lammers-voerkraal. 01 April 2008.

Cole, R.,; Purao, S.,; Rossi, M.,; and Sein, M.K. (2005). Being proactive: Where action research meets design research. In D. Avison, D. Galletta, and J.I. DeGross (eds.), Twenty-Sixth Inter-national Conference on Information Systems. Atlanta: Association for Information Systems, 2005, pp. 325–336.

Delgado, C. (2005) Rising demand for meat and milk in developing countries: implications for grasslands-based livestock production. In Grassland: a global resource (ed. D. A. McGilloway), pp. 29–39. The Netherlands: Wageningen Academic Publishers.

Di Virgilio A, Morales JM, Lambertucci SA, Shepard ELC, Wilson RP. (2018). Multi dimensional Precision Livestock Farming: a potential toolbox for sustainable rangeland management. *PeerJ* 6:e4867 https://doi.org/10.7717/peerj.4867.

Dickson-Hoyle, S., and& Reenberg, A. (2009). The shrinking globe: Globalisation of food system and the changing geographies of livestock production. Danish Journal of Geography, 109, 105- 112.

Dominiak, K.N., and Kristensen, A.R., (2017). Prioritizing alarms from sensor-based detection models in livestock production - A review on model performance and alarm reducing methods. Comput. Electron. Agric. 133, 46–67.

Eekels, J., and Roozenburg, N.F.M. (1991). A methodological comparison of the structures of scientific research and engineering design: Their similarities and differences. Design Studies,12, 4 (1991), 197–203.

Emsen, E., Kutluca Korkmaz M., Odevci, B., and Demirezer, H. (2016). Evaluation of exotic Terminal and Prolific Sheep breeds for their appropriate use in terminal crossbreeding systems in specific production and marketing situation in Turkey. Global Farm Platform: Steps to Sustainable Livestock Conference. 2016 12th-15th January, 2016, University of Bristol, UK.

Emsen, E., Kutluca Korkmaz M., Odevci, B., and Demirezer, H. (2016). , Development of a New Synthetic Prolific Dam Line (ANAROM) via ART in Turkey. 18th International Congress on Animal Reproduction, TH INTERNATIONAL CONGRESS ON ANIMAL REPRODUCTION, Tours, France. 2016

Emsen, E., Kutluca Korkmaz, M., Kutluca Korkmaz and Ocevci, B.B. (2018). Odevci Principal component analysis of factors effecting reproductive performance of prolific sheep. EAAP Annual Meeting, Crotia,Dubrovnik. 431. , 2018.

Espinosa, H.R., Duque, A.B., and Arroyave, J.E.N., (2016). Application of geographic information systems (gis) for the implementation of precision farming. Livestock Res. Rural Develop. 28 (8).

European Food Safety Authority (EFSA) (2012). – Technical meeting on animal welfare: workshop on the use of animalbased measures for dairy cows, pigs and broilers, 4–5 July, Parma (Italy). EFSA, Parma.

FAO. (2001). Pastoralism in the new millennium. FAO Animal Production and Health paper 150. http://www.fao.org/docrep/005/Y2647E/y2647e00.htm

FAO. (2002). Some Issues associated with livestock industries of the Asia-pacific region. Regional Office for Asia and the Pacific Publication 2002/06. Bangkok, FAO RAP & Animal Production & Health Commission for Asia and the Pacific.

FAO. (2006). Livestock's Long Shadow: Environmental Issues and Options. [WWW document]. URL http://www.fao.org/ag/magazine/0612sp1.htm. 02 April 2010.

FAO. 2017. The future of food and agriculture – Trends and challenges. Rome. http://www.fao.org/3/a-i6583e.pdf

Font i Furnols, M., Realini, C. E., Guerrero, L., Oliver, M. A., Sañudo, C., Campo, M. M., Nute, G. R., Cañeque, V., Álvarez, I., San Julián, R., Luzardo, S., Brito, G., and& Montossi, F. (2009). Acceptability of lamb fed on pasture, concentrate or combinations of both systems by European consumers. Meat Science, 81, 196–202.

Font i Furnols, M., San Julián, R., Guerrero, L., Sañudo, C., Campo, M. M., Olleta, J. L., Oliver, M. A., Cañeque, V., Álvarez, I., Díaz, M. T., Branscheid, W., Wicke, M., Nute, G. R., and& Montossi, F. (2006). Acceptability of lamb meat from different producing systems and aging time to German, Spanish and British consumers. Meat Science, 72, 545–554.

Food and Agriculture Organization of the United Nations (FAO) (2012). OECD-FAO agricultural outlook 2012–2021.

French, P., O'Riordan, E. G., Monahan, F. J., Caffrey, P. J, Mooney, M. T., Troy, D. J. and& Moloney, A. P. (2001). The eating quality of meat of steers fed grass and/or concentrates. Meat Science, 57, 379-386.

French, P., O'Riordan, E. G., Monahan, F. J., Caffrey, P. J., Vidal, M., Mooney, M. T., Troy, D. J. and& Moloney, A. P. (2000). Meat quality of steers finished on autumn grass, grass silage or concentrate-based diets. Meat Science, 56, 173-180.

Frost, A. R., Schofield, C. P., Beaulah, S. A., Mottram, T. T., Lines, J. A., Wathes, C. M . (1997). A review of livestock monitoring and the need for integrated systems. Computers and Electronics in Agriculture 17: 139-159.

Fulcher, A.J., and Hills, P. (1996). Towards a strategic framework for design research. Journal of Engineering Design,7, 1 (1996), 183–193.

Garnier, J. P., Klont, R., and& Platow, G. (2003). The potential impact of current animal research on the meat industry and consumer attitudes towards meat. Meat Science, 63, 79–88.

Gerber, P. (2005). Enviromental issues associated with livestock production intensification in rapidly growing economies: Problem statement and identification of policy needs in Asia. Rome, FAO Livestock Environment and development initiative.

Groot Koerkamp, P. W. G., Bos, A. P., and& van Henten, E. (2007). Precision livestock farming: Creating order beyond control. In S. W. R. Cox (Ed.), Precision livestock farming '07 (pp. 17e26). Wageningen, The Netherlands: Wageningen Academic Publishers.

Grunert, K. G. (2006). Future trends and consumer lifestyles with regard to meat consumption. Meat Science, 74(1), 149–160.

Hamilton, D.N., Ellis, M., Bertol, T.M., and Miller, K.D., (2004). Effects of handling intensity and live weight on blood acid-base status in finishing pigs. J. Anim. Sci. 82, 2405–2409

Harrison, A.R., Smith, M. E., Allen, D. M., Hunt, M. C., Kastner, C. L. and& Kropf, D. H. (1978). Nutritional regime effects on quality and yield characteristics of beef. Journal of Animal Science, 47, 383-388.

Hedrick, H.B., Paterson, J. A., Matches, A. G., Thomas, J. D., Morrow, R. E., Stringer, W. C., and Lipsey, R. J. (1983). Carcass and palatability characteristics of beef produced on pasture, corn silage and corn grain. Journal of Animal Science, 57, 791-801.

Hevner, A.R.,; March, S.T.,; and Park, J. (2004). Design research in information systems research. MIS Quarterly,28, 1 (2004), 75–105.

Hostiou, N., Fagon, J., Chauvat, S., Turlot, A., Kling-Eveillard, F., Boivin, X., and Allain, C., (2017). Impact of precision livestock farming on work and humananimal interactions on dairy farms. A review. Biotechnol. Agron. Soc. Environ. 21, 268–275.

Hussey, N., Kessel, S., Aarestrup, K., Cooke, S., Cowley, P., Fisk, A., Harcourt, R., Holland, K., Iverson, S., Kocik, J., Mills, J., Whoriskey, F. (2015). ECOLOGY. Aquatic animal telemetry: A panoramic window into the underwater world. Science. 348. 1221. 10.1126/science.1255642.

Issanchou, S. (1996). Consumer expectations and perceptions of meat and meat quality. Meat Science, 43, S5-S19.

Kaler, J., Ruston, A. (2019). Technology adoption on farms: using Normalisation Process. Theory to understand sheep farmers' attitudes and behaviours in relation to using precision technology in flock management. Preventive Veterinary Medicine 170, 104715. https://doi.org/10.1016/j.prevetmed.2019.104715.

Kays, R., Crofoot, M. C., Jetz, W., and& Wikelski, M. (2015). Terrestrial animal tracking as an eye on life and planet. Science, 348(6240). http://dx.doi.org/10.1126/science.aaa2478. aaa2478eaaa2478.

Kilgour R., Waterhouse T., Dwyer C., and Ivanov I. (2008) Farming Systems for Sheep Production and Their Effect on Welfare. In: The Welfare of Sheep. Animal Welfare, vol 6. Springer, Dordrecht

Koenders, E., Rooijakkers, L., Van Hertem, T., Vranken, E., Berckmans, D., and& Berckmans, D. (2015). Towards the development of a practical visualisation tool for farmers and other stakeholders. In Paper presented at the 7th European Conference on Precision Livestock Farming, Milano, Italy.

Krause, J., Krause, S., Arlinghaus, R., Psorakis, I., Roberts, S., and& Rutz, C. (2013). Reality mining of animal social systems. Trends in Ecology & Evolution, 28(9), 541e551. http://dx.doi.org/10.1016/j.tree.2013.06.002.

Lehr, H. (2014). Recent advances in precision livestock farming. International Animal Health Journal, 1(2), 44-49.

Maltz, E. (2010). Novel Technologies: sensors, data and precision dairy farming. Proceedings of the First North American Conference on Precision Dairy Management, The Second North American Conference on Robot Milking, Toronto, Canada, March 2–5. pp. 164–178.

March, S., and Smith, G. (1995). Design and natural science research on information technology. Decision Support Systems,15, 4 (1995), 251–266.

Martin, J. M. and& Rodgers, R. W. (2004). Forage-produced beef: Challenges and potential. The Professional Animal Scientist, 20, 205-210.

Meena, H. R., and Singh, Y. P. (2013). Importance of information and communication technology tools among livestock farmers: A review. Scientific Journal of Pure and Applied Sciences 2: 57-65.

Milan, Hugo F.M., Perano, Kristen M., Gebremedhin, and Kifle G., (2018). Survey and future prospects in precision dairy farming. In: 10th International Livestock Environment Symposium. American Society of Agricultural and Biological Engineers, p. 1.

Ministry of Agriculture, Fisheries and Food. (1991). National Food Survey 1990. London: H.M. Stationery Office.

Ministry of Agriculture, Fisheries and Food. (1998). National Food Survey 1997. London: H.M. Stationery Office.

Montossi, F., Font-i-Furnols, M., Campo, M., San Julian, R., Brito, G., and Sanudo, C. (2013). Sustainable sheep production and consumer preference trends: Compatibilities, contradictions, and unresolved dilemmas. Meat Sci. 95:772–789.

Morgan-Davies, C., Lambe, N., Wishart, H., Waterhouse, T., Kenyon, F., McBean, D., McCracken, D. (2018). Impacts of using a precision livestock system targeted approach in mountain sheep flocks. Livestock Science 208, 67–76

Naas, I. A., Carvalho, V. C., Moura, D. J., and& Mollo, M. (2006). Precision livestock production. In A. Munack (Ed.), Vol. VI. CIGR Handbook of Agricultural Engineering (pp. 313e325). St. Joseph, MI, USA: American Society of Agricultural Engineers (ASAE).

Napolitano, F., Braghieri, A., Caroprese, M., Marino, R., Girolami, A. and& Sevi, A. (2007). Effect of information about animal welfare, expressed in terms of rearing conditions, on lamb acceptability. Meat Science, 77, 431-436.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S. & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science, 130, 57-69.

Nierenberg, D. (2005). Happier meals: Rethinking the global meat industry. Washington, D. C., World Watch Institute.

Norton, T., Chen, C., Larsen, M.L.V., Berckmans, D., (2019). Review: Precision livestock farming: building 'digital representations' _to bring the animals closer to the farmer. Animal 13 (12), 3009–3017.

Nunamaker, J.F.; Chen, M.,; and Purdin, T.D.M. (1990). Systems development in information sys-tems research. Journal of Management Information Systems,7, 3 (Winter 1990–91), 89–106.

Odevci B.B. and Emsen, . E (2020)msen. Disruptive Innovation in sheep breeding for ensuring complete traceability of lambs. Innovations to Improve Sustainability in the Sheep and Goat Sector. INNOVATIONS TO IMPROVE SUSTAINABILITY IN THE

SHEEP AND GOAT SECTOR. An iSAGE training course and an iSAGE workshop. Thessaloniki, 13th-15th January 2020.

Odevci B.B. and E. Emsen, E. (2019).. Machine learning model for maternal quality in sheep. European Conference Precision Livestock Farming on 26th – 29th August 2019. Cork, Ireland.

Odevci B.B. and E. Emsen, E. (2019). Mobile precision flock management tool for intensively managed meat sheep. 26th – 29th August 2019. Cork, Ireland.

Odevci B.B., Emsen,. E.msen and M. Kutluca Korkmaz M. (2018). Machine learning algorithms for lamb survival and weaning weights. EAAP Annual Meeting, Crotia, Dubrovnik, 531. 2018.

Odevci B.B., M. Aydın, (2017). Generic Monitoring of Livestock Data Management, 4th International Management Information Systems Conference, Generic Monitoring of Livestock Data Management,Istanbul. 2017

Odevci, B.B., Emsen, E., and Aydin, M.N. (2021). Machine learning algorithms for lamb survival, Computers and Electronics in Agriculture, Volume 182, 2021, 105995, ISSN 0168-1699, https://doi.org/10.1016/j.compag.2021.105995.

Panell, D.J. (1999). Social and economic challenges in the development of complex farming systems. Agroforestry Systems, 45, 393–409.

Pannell, D.J. and S. Schilizzi, S. (1999), "Sustainable agriculture: A question of ecology, equity, economic efficiency or expedience"? Journal of Sustainable Agriculture, 13 (4): 57–66.

Hayley Parrot, H. (2021) A buyer's guide to sheep management software. Available from: https://www.fwi.co.uk/livestock/sheep/a-buyers-guide-to-sheep-management-software.

Parsons, R., K. Ruhf, G. W Stevenson, J. Baker, M. Bell, E. Epley, J. Gilbert, C. Hinton and J. Keller. (2010). Research Report and Recommendations from the FarmLASTS Project. USDA CSREES. April 2010. https://www.uvm.edu/farmlasts/FarmLASTSResearchReport.pdf

Pedersen, S. (2005). Climatization of animal houses: A biographical review of three decades of research. Tjele, Denmark: Danish Institute of Agricultural Sciences.

Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S., (2007). A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems 24, 45–77.. doi:10.2753/mis0742-1222240302.

Preston, M., and Mehandjiev, MN. A. (2004). A framework for classifying intelligent design theories. In Proceedings of the 2004 ACM workshop on Interdisciplinary software engineering research (WISER '04). Association for Computing Machinery, New York, NY, USA, 49–54. DOI:https://doi.org/10.1145/1029997.1030008

Ramirez, B., Xin, H., Halbur, P., Beermann, D., Hansen, S., Linhares, D., Peschel, J., Rademacher, C., Reecy, J., Ross, J., Shepherd, T., Koltes, J. (2019). At the Intersection of Industry, Academia, and Government: How Do We Facilitate Productive Precision Livestock Farming in Practice?. Animals. 9. 635. 10.3390/ani9090635.

Reich, Y. (1994). The study of design methodology. Journal of Mechanical Design,117, 2, (1994), 211–214.

Richards, J.S., Atkins, K.D., Thompson, T., and Murray, W.K. (2006). Data from walkover weighing – where are we at? In 'Proceedings from the Australian Society of Animal Production 26th Biennial Conference'. (Eds NR Adams, KP Croker, DR Lindsay) Short Communication 32. (University of Western Australia: Perth)

Rosegrant, M.W., Fernandez, M., Sinha, A., Alder, J., Ahammad, H., de Fraiture, Charlotte, Eickhour, B., Fonseca, J., Huang, J., Koyama, O., Omezzine, A. M., Pingali, P., Ramirez, R., Ringler, C., Robinson, S., Thornton, P., van Vuuren, D., Yana-Shapiro, H. (2009). Looking into the future for agriculture and AKST. IN: McIntyre, B. D.; Herren, H. R.; Wakhungu, J.; Watson, R. T. (Eds.). International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD): Agriculture at a Crossroads, global report. Washington, DC, USA: Island Press. pp.307-376.

Rossi, M., and Sein, M.K. (2003). Design research workshop: A proactive research approach. Paper presented at the Twenty-Sixth Information Systems Research Seminar in Scandinavia, Informa-tion Systems Research in Scandinavia Association, Haikko, Finland, August 9–12., 2003.

Rowe, J. B. (2010). The Australian sheep industry — Undergoing transformation. Animal Production Science, 50, 991–997.

Rowe, J.B. , and Atkins, K. (2006). Precision sheep production – pipedream or reality? In 'Australian Society of Animal Production 26th Biennial Conference 2006'. Short Communication number 33. (Australian Society of Animal Production).

Ruiz-Garcia, L., Lunadei, L., Barreiro, P., and Robla, J.I. (2009). A review of wireless sensor technologies and applications in agriculture and food industry: State of the art and current trends. Sensors, 9, 4720–4750.

Rural Industries Research & Development Corporation. (2016)., C/- Charles Sturt University, Locked Bag 588, Wagga Wagga NSW 2678, August 2016.

Rutter, S.M. (2017). Advanced livestock management solutions. In: Ferguson, D.M., Lee, C., Fisher, A. (Eds.), Advances in sheep welfare. Elsevier, Woodhead Publishing, Cambridge, UK, pp. 245–261.

Santos-Silva, J., Mendes, I. A., and & Bessa, R. J. B. (2002). The effect of genotype, feeding system and slaughter weight on the quality of light lambs: Growth, carcass composition and meat quality. Livestock Production Science, 76, 17-25.

Sapp, P.H., Williams, S. E., and& McCann, M. A. (1999). Sensory attributes and retail display characteristics of pasture- and/or grain-fed beef aged 7, 14 or 21 days. Journal of Food Quality, 22, 257-274.

Saunders, C., Guenther, M., and& Driver, T. (2010). Sustainability trends in key overseas markets: market drivers and implications to increase value for New Zealand exports. Research report N° 319. New Zealand Lincoln University

Schroeder, J.W., Cramer, D. A., Bowling, R. A., and& Cook, C. W. (1980). Palatability, shelf-life and chemical differences between forage and grain-finished beef. Journal of Animal Science, 50, 852-859.

Schulze, C., Spilke, J., and Lehner, W. (2007) Data modeling for Precision Dairy Farming within the competitive field of operational and analytical tasks. Comput Electron Agric 59: 39-55.

Scott, G.B., and Moran, P., (1993). Fear levels in laying hens carried by hand and by mechanical conveyors. Appl. Anim. Behav. Sci. 36, 337–345.

Singh, S.P., Ghosh, S., Lakhani, G.P., Jain, A., and Roy, B. (2014) Precision Dairy Farming: The Next Dairy Marvel. Journal of Veterinary Science and Technology, 5: 164

Śledzik, Karol. (2013). Schumpeter's View on Innovation and Entrepreneurship. SSRN Electronic Journal. 10.2139/ssrn.2257783.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and& de Haan, C. (2006). Livestock's long shadow: environmental issues and options. Rome, Italy: FAO.

Suryawanshi, K., Redpath, S., Bhatnagar, Y., Ramakrishnan, U., Chaturvedi, V., Smout, S., Mishra, C., (2017). Impact of wild prey availability on livestock predation by snow leopards. Roy. Soc. Open Sci. 4 (6).

Takeda, H.,; Veerkamp, P.,; Tomiyama, T.,; and Yoshikawam, H. (1990). Modeling design processes. AI Magazine, 11, 4 (Winter 1990), 37–48.

Terrasson, G., Villeneuve, E., Pilniere, V., and Llaria, A. (2017). Precision livestock farming: A multidisciplinary paradigm. In Proc. Symposium for Empowering and Smart Interfaces in Engineering, Smart Interfaces 2017, Venice, Italy.

Thornton, P.K., (2010). Livestock production: recent trends, future prospects. Philosophical Transactions of The Royal Society B Biological Sciences.. doi:10.1098/rstb.2010.0134

Thornton, P.K., Jones, P.G., Owiyo, T.M., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N., Orindi, V., Otiende, B., Ochieng, A., Bhadwal, S., Anantram, K., Nair, S., Kumar, V., Kulkar, U. (2006). Mapping climate vulnerability and poverty in Africa. 200p. Nairobi (Kenya): ILRI.Thornton, P. K. et al. 2006 Mapping climate vulnerability and poverty in Africa. Nairobi, Kenya: ILRI. See http://www. dfid.gov.uk/research/mapping-climate.pdf

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and& Polasky, S. (2002). Agricultural sustainability and intensive production practices. Nature, 418, 671–677.

Tisdell, C. A. (1998). Asia's (Especially China's) Livestock Industries: Changes and enviromental consequences. Working papers on Economics, Ecology and the Environment, Department of Economics, University of QLD.

Tomkiewicz, S. M., Fuller, M. R., Kie, J. G., and& Bates, K. K. (2010). Global positioning system and associated technologies in animal behaviour and ecological research. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1550), 2163e2176. http://dx.doi.org/10.1098/rstb.2010.0090.

Trivedi, C., (2012). Book Review: Jost Hamschmidt and Michael Pirson (eds.), Case Studies in Social Entrepreneurship and Sustainability: Volume 2 - The Oikos Collection. Journal of Entrepreneurship.. doi:10.1177/0971355712449941

Troy, D. J., and& Kerry, J. P. (2010). Consumer perceptions and the role of science in the meat industry. Meat Science, 86, 214–226.

Turkish Statistical Institute, (2012). Turkish Statistical Institute http://www.tuik.gov.tr/AltKategori.do?ust_id=13 (2012)

Vaishnavi, V., and Kuechler, B. (2005). Design research in information systems. Association for Information Systems,, 2005 (available at www.isworld.org/Researchdesign/drisISworld.htm).

Valetta, J. J., Torney, C., Kings, M., Thornton, A., and& Madden, J. (2017). Applications of machine learning in animal behaviour studies. Animal Behaviour, 124, 203–220. https://doi.org/10.1016/j.anbehav.2016.12.005

Van der Burg, S., Bogaardt, M., Wolfert, S., (2019). Ethics of smart farming: Current questions and directions for responsible innovation towards the future. NJAS - Wageningen J. Life Sci. 90–91 (March 2020), 1–10.

Van Dijk, J., Sargison, N. D., Kenyon, F. and& Skuce, P. J. (2010). Climate change and infectious disease: helminthological challenges to farmed ruminants in temperate regions. Animal 4, 377 –392.

Verbeke, W., (2001). The emerging role of traceability and information in demand-oriented livestock production. Outlook on Agriculture 30 (4), 249-255.

Villeneuve É, Akle A. A, Merlo, C., Masson, D., Terrasson, G., Llaria, A. (2019). Decision support in precision sheep farming IFAC-PapersOnLine 51(34) 236

Vranken, E., and Berckmans, D., (2017). Precision livestock farming for pigs. Animal Frontiers 7 (1), 32–37.

Vuren, D.P. van, Ochola, W.O., Riha, S.,Giampietro, M., Ginzo, H., Henrichs, T., Hussain, S., Kok, K., Makhura, M., Mirza, M., Palanisama, K.P., Ranganathan, C.R., Ray, S., Ringler, C., Rola, A., Westhoek, H.J., Zurek, M., Avato, P., Best, G., Birner, R., Cassman, K.G., Fraiture, C. de, Easterling, B., Idowu, J., Pingali, P.L., Rose, S., Thornton, P.K., Wood, S. (Van Vuuren, D. P. et al. 2009). Outlook on agricultural change and its drivers. In Agriculture at a crossroads (eds B. D. McIntyre, H. R. Herren, J. Wakhungu & R. T. Watson), pp. 255–305. Washington, DC: Island Press.

Walls, J.,; Widmeyer, G.,; and El Sawy, O. (1992). Building an information system design theory for vigilant EIS. Information Systems Research,3, 1 (1992), 36–59.

Walls, J.,; Widmeyer, G.,; and El Sawy, O. (2004),. Assessing information system design theory in perspective: How useful was our 1992 initial rendition? Journal of Information Technology Theory & Application,6, 2, (2004), 43–58.

Wathes, C.,hristopher & Kristensen, H.,elle & Aerts, J.eanM.-Marie, and & Berckmans, Daniel. (2008). Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall?. Computers and Electronics in Agriculture. 64. 2-10. 10.1016/j.compag.2008.05.

Yavuz, F.ahri Yavuz, Bilgic, A., bdulbaki BilgicTerin,, M.ustafa Terin, and Guler I.rfan O. Guler (2013)., Policy implications of trends in Turkey's meat sector with respect to 2023 vision, Meat Science,Volume 95, Issue 4, 2013, Pages 798-804, ISSN 0309 1740,https://doi.org/10.1016/j.meatsci.2013.03.024.

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Fidelity Information Systems, Lead Architect at a Dynamic Pricing Project in a top tier bank in Turkey, Lead Architect, Turkey, 2010-2011

IBM Netherlands B.V. Lead Architect at a Core Banking Project in a top-tier European Bank, Netherlands, 2008-2010

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