PROFITABILITY ANALYSES OF QUÉBEC DAIRY CATTLE USING HEALTH AND MANAGEMENT DATA VIA VISUALIZATION TOOLS.

By

HECTOR A. DELGADO

Department of Animal Science
McGill University, Montreal, Canada

November 2015

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree

of

DOCTOR OF PHILOSOPHY

ABSTRACT

Data routinely collected from Dairy Herd Improvement (Québec DHI) were combined with provincial veterinary-health data with the objectives of 1) creating an integrated dataset with lifetime cumulative variables, 2) developing an analysis of different factors affecting lifetime profitability in dairy cattle using an empirical approach and 3) creating a tool to analyze profitability at the herd and individual levels using an information visualization methodology. For the lifetime profitability analysis, all animals were required to have complete data and, to maximize the validity of the analysis animals were selected from herds that routinely recorded health events. Profitability formulae from different sources reported in the literature were tested with the empirical data to study their potential applicability as decision tools for herd managers. It was found that when used in combination, Cumulative Lifetime Profitability (LTP) and Cumulative Lifetime Profitability Adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC) could provide decision makers with a more complete understanding of the profitability of an animal by analyzing its individual performance and its marginal contribution to the herd.

Using the selected profitability measures, a comparative analysis of differences in profit associated with common housing and milking systems in Québec showed that in terms of milking systems there were significant differences in profitability due to the milk production revenues, the cost of age at first calving and the costs of health. Profitability results and variables that showed significant differences among the housing and milking systems, such as cumulative health costs, were transformed into visualization curves benchmarks (means and top 90 and bottom 10 percentiles distribution ranges), which demonstrated that profitability and

cumulative costs at the herd level could be better explained and analyzed using specific benchmarks as opposed to more general ones.

Finally, a prototype of an information system tool was developed to visualize profitability performance and to support decision-makers in the analysis and comparison of profitability results at the dairy herd and individual cow levels. This prototype was divided into three hierarchical categories to facilitate multidimensional analysis at the category-groups (comparisons between systems, breeds or regions), herd and individual animal levels. Based on this exploratory analysis and the development of ideas about understanding and presenting profitability with visual information methods, it is expected that in the short to medium term these concepts could be adapted and included into the existing profitability report prepared by DHI for their clients.

RÉSUMÉ

Les données recueillies de routine pour l'amélioration des troupeau laitières (Québec DHI) ont été combinées avec les données provinciales de santé animale avec comme objectifs 1) la création d'une base de données y contenant avec des variables cumulatives à vie, 2) l'élaboration d'une analyse des différents facteurs affectant la rentabilité à vie chez les bovins laitiers en utilisant une approche empirique et 3) la création d'un outil pour analyser la rentabilité aux niveau du troupeau et individuel avec l'utilisation de la méthodologie de visualisation d'informations. Pour l'analyse de rentabilité à vie, tous les animaux doivent avoir leur information complète et afin de maximiser la validité de l'analyse, les animaux ont été choisis parmi les troupeaux qui ont enregistré des évènements de santé sur une base régulière. Les formules de rentabilité provenant de différentes sources dans la littérature ont été testées avec les données empiriques pour étudier leur applicabilité potentielle comme outil de décision pour les gestionnaires de troupeaux. Il a été constaté qu'avec la utilisation combinée de la rentabilité cumulée pendant la durée de vie (LTP) et de la rentabilité cumulé pendant la durée de vie ajustée pour le coût d'opportunité (LTPOC), les gestionnaires pouvaient visualiser de façon plus large la performance de l'animal en analysant les performances individuelles et leur contribution marginale au leur troupeau.

Avec les formules de rentabilité sélectionnées, une analyse comparative des différences de la rentabilité associée aux systèmes de traite au Québec a montré qu'il y a des différences de le valeur de la production du lait cumulative et des coûts cumulatifs dans facteurs tels que l'âge au premier vêlage et la santé qui ont un effet sur la rentabilité. Les variables avec des différences significatives dans les résultats tels que LTP et le coût cumulatif de la santé ont été transformées en courbes de visualisation classées par système de référence (moyennes et 90e et 10e percentiles

de distribution) montrant que les situations individuelles au niveau du troupeau pourraient être mieux comprises et analysées à l'aide des courbes des références plus précis par rapport à les comparaisons généraux.

Finalement un outil de visualisation des informations a été conçu pour visualiser les performances de la rentabilité et de soutenir les décideurs dans l'analyse et la comparaison des résultats de la rentabilité de troupeau laitier et de chaque vache. Le prototype a été divisé en trois catégories hiérarchiques pour faciliter l'analyse multidimensionnelle: 1- Analyse de catégorie; 2- Analyse du troupeau; et 3- Analyse individuelle des animaux. Les courbes de résultats cumulatives pendant la vie ont été combinées aux résultats moyens du troupeau et la catégorie sélectionnée pour faciliter les comparaisons et l'analyse.

De cette analyse et le développement exploratoire des idées sur la façon de comprendre la rentabilité de une manière visuelle, il est prévu que certains de ces concepts seront inclus à court et moyen terme dans le rapport de rentabilité présenté par le DHI à leurs clients.

ACKNOWLEDGMENTS

My gratitude to the Fonds de Recherche Québécois en Nature et Technologies (FRQNT), to Novalait, to the Ministère de l'Agriculture, des Pêcheries et de l' Alimentation du Québec (MAPAQ) and to Agriculture and Agri-Food Canada for funding support, to DHI Valacta and to the Dossier Santé Animal (DSA) for providing the data and also to the Hugh Blair Scholarship for their financial support.

I would like to express my gratitude to Professor Kevin Wade, my thesis supervisor for accepting me as his student, for his guidance and his support. Professor Wade's good advice was crucial, especially in moments of confusion (very often).

My very special thanks to Dr. Roger Cue for accepting me as part of this wonderful project. Without his mentorship and constant supervision I could not have completed this study. Professor Cue is one of the most generous persons I have ever met and he is always happy to share his vast knowledge and wisdom with anyone who is interested. Learning from him and from Professor Wade has been truly an honour.

I would like to recognize the help of my advisory committee, Dr. Jocelyn Dubuc for pushing me out of my comfort zone, Dr. Asheber Sewalem for his enthusiasm and his input and also my special thanks to Dr. Daniel Lefebvre and Dr. Rene Lacroix for their comments and ideas. Finally I would like to mention Denis Haine my peer at University de Montreal for his help explaining me the datasets from DSA.

CONTRIBUTION TO KNOWLEDGE

CHAPTER II

The original contribution of this chapter is a profitability analysis based on information obtained from an integrated dataset created with data collected from herds of Québec for more than ten years, integrating health and production records from Provincial Health Files and DHI. Different profitability formulae selected from the literature were tested with information selected from the relational database in order to evaluate their applicability as decision-making tools. This chapter also presents an analysis of different cost variables that have a significant effect on profitability at the individual cow level.

CHAPTER III

In this chapter significant differences in lifetime cumulative profit among herds grouped by housing and milking systems in the province were identified. These significant differences among the studied groups in profitability were explained in part by variations in cumulative health, insemination services and feed costs. Cumulative means and distributions of profitability and cumulative costs by day of life were calculated by housing and milking systems to develop visualization curves and to explore their use as benchmarks for evaluating herd results.

CHAPTER IV

Chapter IV describes how the data collected during routine visits and included in a transactional database could be transformed into meta-data to develop an analytical database used for profitability analysis with an information visualization tool prototype. This prototype introduced different profitability measures that are used mostly in bio-economic and genetic analyses as potential tools for decision-making on a regular management basis. No reports about the use LTPOC used as a regular decision-making tool through information visualization techniques in dairy herds were found. The prototype includes costs of different health events recorded in the database and permits different analysis functions such as summarized health costs and also drill-down analysis of detailed costs of some of the diseases recorded such as Clinical Mastitis and Reproductive Problems at the individual and herd level.

CONTRIBUTION OF AUTHORS

In this thesis, three co-authored manuscripts are presented.

Authors of manuscripts 1, 2 and 3 (Chapters II, III and IV)

Hector A. Delgado, Roger I. Cue, René Lacroix, Daniel Lefebvre, Asheber Sewalem, Émile Bouchard, Jocelyn Dubuc, Denis Haine, Kevin M. Wade

Hector A. Delgado processed the data and created the integrated dataset and the lifetime cumulative variables, designed the analyses, created the visualization of profitability tool prototype and wrote the manuscripts. Denis Haine selected data and created datasets from the database of the provincial health file (DSA). Rene Lacroix created the basic raw datasets with information selected from the DHI Valacta database. Daniel Lefebvre, Asheber Sewalem, Émile Bouchard and Jocelyn Dubuc were involved in the development of this project by providing the data from DSA and DHI Valacta as well as by reviewing the manuscripts. Roger I. Cue and Kevin M. Wade conceptualized the experimental ideas and critically reviewed the manuscript. Chapter II has been reviewed by the co-authors and chapter III and IV have been distributed to the other authors before being submitted to the respective journals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFC	Age at First Calving
AMS	Automatic Milking System
CI	Calving Interval
CM	Clinical Mastitis
CMS	Conventional Milking Systems
cumDIM	Lifetime Cumulative number of Days in Milk Production
cumDD	Lifetime Cumulative number of Days Dry
DHI	Dairy Herd Improvement
DSS	Decision Support Systems
FIPI	Farm Input Prices Index
FPPI	Farm Product Price Index
F&L	Feet and legs problems
INFOVIS	Information Visualization Tool
IT	Information Technologies
LSM	Least Square Mean
LTP	Cumulative Lifetime Profitability
LTPOC	Cumulative Lifetime Profitability adjusted for the Regressed Opportunity Cost of the Postponed Replacement
MIS	Management Information Systems
ML	Milk-line milking system
MP	Milking parlour milking system
NPV	Net present value
OC	Opportunity cost
ROFC	Margin of milk value over feed cost
RP	Reproductive Problems
SCC	Somatic Cell Count

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

1.1 Introduction

Every day, managers and dairy producers face increasing decision-making challenges as a consequence of the last decades' changes, such as the intensification of production, that have affected the dairy industry around the world (Pietersma *et al.*, 1998). Also, considering the multiple challenges such as animal welfare and environmental legislation, international trade agreements and tariffs, difficult access to capital and land, etc., farm managers and their advisors are required to increase their level of management competence to succeed in the decision-making process (Levallois, 2008).

As a consequence these changes are reflected in the intensification of production. Based on published records by the Canadian Dairy Information Centre, Holstein cows in Canada produced 10,102 kg/yr on average in 2014, up from 7,717 kg/yr in 1991, or approximately an increase of 1.4% per year. Canada is not an isolated case. In general milk yield per cow has more than doubled during the previous forty years (1970-2010) (Oltenacu and Broom, 2010).

However the intensification in production is not necessarily reflected in an increase in profitability, leading to the constant question that managers pose: "Is my farm making money?" To stay in business the farm must generate enough profit to exceed the opportunity cost or, at least, to exceed the loss of potential gain from other alternatives when one alternative is chosen (McKean, 2005). For a successful profitability analysis, it is not enough to consider the return per cow, per hectare or per litre of milk but it is necessary to consider the return from the entire farm business (Mainland, 1994).

Assessment and improvement of farm profitability are very important management tasks (Dale, 1998). While the process of decision-making is sometimes based on factors other than profitability, it is important to bear in mind that the decision-making process should always be financially justified (Grohn and Rajala-Schultz, 2000). The different management tasks include decision-making at different levels (e.g. herd and cow). In dairy herds, where the cow is the functional unit within the herd, most of the economic decisions are made around cow profit; a value that will depend on biological situations such as a new pregnancy or health problems such as clinical mastitis or feet and leg problems. In contrast herd profitability will be affected, for instance, by animal replacement policies or breeding decisions (Cabrera, 2012b).

Improving producers' management, therefore, is increasingly important for maintaining farm income, and management information systems can play an important role in this context (Jalvingh, 1992). To have a more accurate idea of how health, production and reproductive issues affect dairy farm profit in Québec, a joint effort between different sectors in the province was established to extract selected data from the production and health databases managed by Valacta (Québec DHI) and the Provincial Animal Health Records (DSA) respectively. This aims at analyzing profit, and developing prototype tools to help advisors and producers visualize input variables, understand their effect and optimize profitability results.

1.2 Review of Literature

1.2.1 Dairy Herd Management

Herd managers know that a dairy herd requires understanding the effects of controllable factors, such as feed ration (quantity and quality) and disease control measures (health programs), and also uncontrollable factors such as the effect of weather on animals and on crops, as well as political and market conditions. The combination of these factors constitutes a complex biological and economic system (Enevoldsen *et al.*, 1995) and will have a direct effect on the expected return (positive or negative). This return depends directly on milk revenue which constitutes 90% of the total dairy farm revenue (VandeHaar, 2006). According to VandeHaar (2006), milk revenue is a function of three capacities. The first one is capacity of the mammary glands to produce milk; second is the capacity to convert feed into milk; and third is the capacity of the farmer to manage and breed the animals. Forty-five percent of the production profit results of the herd will depend on management factors (Schroeder, 1996). Therefore it is important to develop adequate tools to help herd managers to understand their results and allow them to make decisions, supported by relevant information.

Management is the combination of different resources (logistic and physical) and as expressed by Ford and Shonkwiler (1994), "it has long being recognized that differences in managerial ability will result in differences in financial success of farms with similar resource bases under the same production conditions". Farm management can be considered to be an adaptive planning process by which the farmer has to evaluate continuously the suitability of various alternatives to make changes, ranging from minor changes in management procedures with only short-term effects to major changes in herd size with long term effects (Enevoldsen *et al.*, 1995).

When a dairy farm is analyzed from an economic perspective, the tendency is often to focus solely on profit, ignoring other essential elements of the financial framework for any successful business (Lehenbauer and Oltjen, 1998). It is important to analyze the dairy farm as a system composed of interdependent subsystems and the good harmony of this "whole" will generate the expected financial and economic results (Levallois, 2008).

Farm managers are challenged by multiple factors that affect herd profitability. Milk production and feed costs are the most important components in the profit equation (Beck, 2008) and any farm trying to survive and succeed has to keep comprehensive records of them. With the introduction of automated equipment on dairy herds, large quantities of data are being routinely collected. These data, properly interpreted, could be used to support dairy producers in making decisions on the farm. Analysis of these data can be undertaken at both the herd level and at the individual cow level, in the form of economic decision-making tools (Roche *et al.*, 2009). However, a big challenge is posed, considering that the quantity of information a user can examine and handle at a given instant is limited. Therefore, there is a risk of not taking advantage of these large amounts of data if computer applications do not adequately take into account an effective presentation and interaction with the data (Chittaro, 2001).

1.2.2 Profit – Profitability Definitions

From the economists' point of view, profit is considered a social phenomenon associated with problems of distribution of the proceeds of society's productive activities among the factors responsible for that production (Littleton, 1928). For businessmen, profit is a measure of accomplishment: the positive result from a business activity after subtracting all expenses. When comparing different sizes and types of farms different profitability measures are used, such as operator labor and management earnings, rate of return on equity or net worth, and rate of return on investment (Dale, 1998).

The concept of profit for dairy cattle has evolved over time. Balaine, (1981) was the first to introduce the concept of defining profit as the linear function of income minus expenses per herd life (time length of the animal in the herd). These linear profit functions have the advantage of simplicity at the expense of being approximate. However, VanRaden (1997) challenged the linear concept by arguing that lifetime profit includes revenues and costs that only occur once in the lifetime (e.g., heifer cost at the moment of first calving or cow salvage value).

To compare the real input of profitability of one animal in the herd, Van Arendonk (1991) outlined that the profitability of a producing cow has to be compared to the opportunity cost of a postponed replacement because there is a profit sacrificed on the replacement cow by keeping the current one producing. In other words profitability measurements are incomplete if opportunity cost (OC) is not considered.

A very simple but effective indicator of cow profitability is return over feed cost (ROFC). Canadian dairy producers use this indicator for herd profitability (Bohmanova *et al.*, 2009). Although ROFC is used as a profitability index because it includes the most important revenue (milk value) and variable cost (feed), it is important to note that other components that have an effect on profitability such as animal-specific health and reproductive costs are not included.

The major question is which profit measure is most appropriate for ranking cows for profit. Is it lifetime profit or profit per unit of lifetime (that is profit per day, or per year, of productive life)? Should cows be ranked for efficiency or for profit (Ribeiro *et al.*, 2008)? Kulak *et al*. (1997) addressed this issue with the concept of discounted lifetime profit (DLP = discounted lifetime revenue – discounted lifetime cost), where account is taken of the fact that revenues and costs do not occur all at the same time during the lifetime of the animal. It is clear that the level of technical and economic efficiency is a key determinant of costs, and every farm is a particular case, and the conclusions drawn at a given time are dependent on the relative costs at that time (Levallois *et al.*, 1997). Transforming this concept into the dairy farm, Mulder and Jansen (2001) defined a profitable cow "as an animal that can sustain a high production for many years with acceptable reproduction and without serious health problems". Therefore, in order for an animal (or a herd) to be profitable, it has to be efficient. At the cow level, individual profit depends on management decisions such as voluntary waiting period for breeding, lactation length and culling, meaning that an unclear understanding of the impact of these variables on profitability can lead to sub-optimal management decisions (Goddard, 1998).

1.2.3 Normative vs. Empiric modeling

Models represent systems, and modeling is also referred to as 'systems analysis'. To analyze the dairy farm profitability system, Benson (2008) described four types of information: "individual case studies, summary data from multiple farms, research on farm systems and components, and simulations". The economic values of the different models can be calculated with two different methodologies: normative approaches (also referred to as bio-economic modeling), and positive or empiric approaches, which involve analysis of field data (Groen, 1989, James and Ellis, 1979 in Dekkers *et al.*, 1998). One of the most important uses of modeling has been to derive economic values for animal traits based on available economic and technical data, however this task requires expertise because it is not a simple procedure (Dekkers *et al.*, 1998).

The normative approach to modeling profit in dairy herds has been used by several researchers such as Van Arendonk (1985), Groen *et al.* (1989), and Vargas *et al.* (2002) pursuing different research objectives. One of the disadvantages of the normative approach is that in order to obtain reliable results it is necessary to have adequate and sufficient knowledge of the production system and its components (Groen et al., 1997). Another limitation of the normative approach is that it limits the introduction of external parameters to interact with the model through recursive solutions (Kalantary *et al*., 2010). However bio-economic models or the normative approach allow evaluation of the impact of changes in input parameters on outputs from complex biological production systems (Dekkers *et al.*, 1998).

The Positive or Empiric approach can be used to calculate economic values for production traits and herd-life. However, this approach is less appropriate for the calculation of traits that are indirectly related to herd life such as the mammary system or feet and legs (Mulder and Jansen, 2001). The Positive approach employs field data to estimate the contribution of individual traits on overall profitability (Dekkers, 1995). This approach is straightforward, but requires large amounts of field data. A limitation of the empiric approach is that it is not possible to extrapolate economic values for a hypothetical situation, as is possible with the normative approach by changing parameters of the model (St-Onge, 2000). For Kristensen *et al.* (2008) collecting empirical data for long series of time at the herd level is challenging because of potential internal changes in the herd and possibly because of an insufficient number of herds both of which could result in inaccurate comparisons of financial performance in herds with different levels of factors. However empirical methods also have been implemented in the past to identify changes in economic results associated with a high or low prevalence of health events or health control strategies in selected samples of dairy herds (Seegers *et al.*, 2003).

Although there are difficulties in collecting empirical data for a sufficient number of years and there could be some doubt about their reliability for analysis (Kristensen *et al.*, 2008), there are techniques that can be used to overcome these issues, such as indexed prices to account for the effect of time on money and statistical mixed models to account for the random effect of different variables and to identify differences in variance within and between groups.

1.2.4 Variables and traits that have an effect on profitability

Factors that affect revenue, such as genetics, stage of lactation, level of milk production, age of cow, environment, disease (for example, mastitis), and nutrition are directly linked to milk composition. All of these factors clearly are influenced by the care and attention provided by the manager, herdsperson, veterinarian, inseminator, feed consultant, etc. (Plaizier *et al.*, 1997). There are limitations inherent in the animals themselves (e.g., genetic makeup, appetite, and individual reaction to metabolic stress) and others caused by the dairy farm management (e.g., feed management, quality of forage, milking machinery) (Fleischer *et al.*, 2001). These combined factors all play a role in optimizing profitability.

Much research has been developed in order to measure the impact of all the cost components on profit in the dairy industry. Different authors have described different classifications of costs and the way they impact profit (Balaine *et al.*, 1981, Van Arendonk, 1991, Kulak *et al.*, 1997, Jagannatha *et al.*, 1998). Cost optimization is a process of time and knowledge where producers are compelled to assess the impact of every decision concerning the different components of the cost structure and their effects on profitability. However, several difficulties arise for cost analysis, one of which is the difficulty of collecting the information at a herd level because not all producers are interested in providing their information. For analysis, this problem is overcome in various ways including, for example, using working assumptions and the estimation of non-available costs. However, the ideal scenario for analyses would be to use real data.

1.2.4.1 Heifer Cost

The cost to raise a heifer to first calving or 24 months represents between 15 and 20 % of all the costs on the dairy farm. Some insist on speeding up the development of the heifers as a way to lower the cost, (up to 20 months), however this fast growth may result in a reduction of the future milk production (VandeHaar, 2006).

The Dairy Production Centre of Expertise Québec-Atlantic (Valacta), publishes annual reports with various average statistics and, since 1985, the average age at first calving has only declined from 30 months to 28 months, and not at all over the past 10 years, this in spite of the work of nutritionists, geneticists, dairy specialists and others (Cue *et al.*, 2012). Pietersma *et al.* (2006) noted that Québec heifers were large enough and heavy enough to be bred at 14 months of age.

The impact of the age at first calving on herd profitability was demonstrated by Lang (2011), who relates average age at first calving with turnover rate to estimate the number of animals needed for replacement. For example if the average age at firsts calving is 24 months and the herd turnover rate is 30% it will require 35% less heifers for an adequate replacement compared to a herd of the same size but with a turnover rate of 40% and an average age of first calving of 28 months.

1.2.4.2 Longevity – Herd Life and Culling

Livestock animals have to both stay alive and reproduce regularly to be of economic interest for the breeder. For this reason, dairy cows are more often removed from the herd when their contribution to profit is under herd average rather than as a result of reaching old age (Essl, 1998). When herd-life increases, fewer heifers need to be raised and replacement costs are decreased (Jagannatha *et al.,* 1998, Heikkilä *et al.*, 2012). Jagannatha *et al.* (1998) also suggests that a longer herd life should reduce health costs and losses caused by avoidable culling.

Longevity can be seen as a composite of production traits and can be seen as the ultimate breeding goal (Mulder and Jansen, 2001, Vargas *et al.*, 2002),This trait is defined as the probability for a cow to stay in the herd in a specific lactation without being involuntarily culled for health reasons, e.g. clinical mastitis, feet and legs problems (Vargas *et al.*, 2002) and having an important positive effect in the overall profitability (Sewalem *et al.*, 2006). The process of making decisions on culling determines the longevity of animals within the herd.

When removing an animal from a herd (culling), the removed animal is replaced with another cow, usually a first-lactation heifer (Hadley *et al.*, 2006). Voluntary culling occurs when a farmer makes a conscious decision to cull a healthy, fertile cow, for instance, on the basis of low milk production. In contrast, involuntary culling occurs when a farmer is forced to cull a potentially profitable cow because of infertility, illness, injury, or death (Berry *et al.*, 2005). Valacta records for Québec (2014), for instance, indicate that 16,341 cows were culled from dairy herds in 2013 due to mastitis. This represented 27.57% of all cows involuntarily culled.

The decision process for culling an animal should involve an objective assessment in which the farmer should consider different traits including health, production and fertility, among others. Reducing the rate of involuntary culling allows a higher voluntary replacement rate, which can increase profits for a dairy farm (Sewalem *et al.*, 2008). The selection and monitoring of adequate reproductive programs are crucial for the stayability of the cows because animals with late pregnancies have a significantly higher risk of culling than early pregnant cows (Cabrera, 2014).

According to Nordlund and Cook (2004) the critical removal time occurs within the first sixty days after calving because between one fifth and one quarter of all herd removals occur within this period. This is explained by a health failure in the transition time, when the economic loss is higher compared to culling an animal later in the lactation cycle. The economic losses caused by early culling include lower price for the carcass (lower weight and quality), the expected future income obtained from the milk of the culled animal and also those losses related with idle production factors (Van Arendonk *et al*., 1984). Another economic loss caused by early culling is the difficulty in recovering the expenses caused by keeping the animal through the early stage of the lactation period (Jagannatha *et al.*, 1998, Camps *et al.*, 2009, Cue *et al.*, 2012).

Although survival and culling decisions are crucial to profitability results, often these decisions are not necessarily made due to an objective assessment but depend on the intuition of the decision maker (dairy producers) (Lehenbauer and Oltjen, 1998). However, with the use of dynamic programming, herd-managers are getting new tools to help them in the process of making economic culling decisions, such as the retention pay-off prediction model developed by Shahinfar *et al*. (2014).

1.2.4.3 Health and Reproduction

An analysis of the three main types of financial losses caused by diseases at a farm level is presented by Schepers and Dijkhuizen (1991). The first one is less efficient production and higher veterinary costs before disposal (decreased milk yield, altered milk composition, decreased milk quality, discarded milk, decreased feed intake, drug costs, veterinary fees, labor costs). The second is reduced slaughter value and idle production factors at disposal, and the third is loss of future income when replacing animals before reaching optimal economic age for culling.

Reproductive performance, along with the health condition of the herd, are among the major factors influencing the profitability of a dairy herd. Different studies have shown the impact of health and reproductive issues on profitability (Enting *et al.*, 1997, Kelton *et al.*, 1998, McLaren *et al.*, 2006, Guard, 2008, Heikkilä *et al.*, 2012). The estimation of the effects of diseases, commonly affecting dairy herds is as important as estimating the effect of different production and fertility traits on profitability. If the cost of the health problem, and the components of that cost, are known, it is easier to judge whether an allocation of resources can be expected to reduce that cost and return a net profit (Guard, 2008).

These decisions have an effect on both current and expected future returns and need to be based on information originating inside the farm, but also require reliable reference benchmarks for an effective assessment. Therefore it is important to use tools that combine on-farm data with external data (St-Onge, 2004) in order to provide usable information.

1.2.4.3.1 Clinical Mastitis

Almost all dairy managers know their herd somatic cell count (SCC), but most struggle to characterize their herd's risk of clinical mastitis compared with the industry. Without clearly established benchmarks and targets, many dairy herds sustain elevated disease levels because the rate is ‘‘normal’’ for their herd (Nordlund and Cook, 2004); therefore efforts to prevent mastitis will not generate the expected impact, and health costs will likely not be reduced.

The economic impact of mastitis results from two origins: the control costs (i.e., use of additional resources) and the losses (i.e., reduced revenues). According to Camps *et al.*(2008), the estimated cost of mastitis in Canada per farm/herd/year in Canada is $27,891 while the estimated cost of a clinical mastitis case in Canada is on average $983 (including production losses)

(Camps *et al.*, 2008). Losses are the economic consequences of production decreases and are quite often difficult to assess. These losses not only include decreases in milk production but also include costs associated with a higher risk of culling. According to Seegers *et al.* (2003) the risk for a cow of being culled following the occurrence of clinical mastitis, or elevated SCC, is increased by a factor of 1.5 to 5, mainly depending on the severity of the milk production drop and the farmer's anticipation of the future yield of the cow.

Different studies have addressed the decision of whether to cull or treat an animal that has clinical mastitis (or even elevated SCC) (Hadley *et al.*,2006; Heikkilä *et al.*, 2012; Gordon *et al.*, 2013). A study on Ayrshire cattle in Finland concluded that, regardless of the high costs of Clinical Mastitis (CM) and its increasing probability of occurrence with later parities, it may be profitable to treat CM and keep the diseased cow in the herd almost as long as the healthy ones (Heikkilä *et al.*, 2012). Hadley *et al.* (2006) presented an example of the indirect consequences of early culling due to CM: "Due to clinical mastitis, lifetime is affected and early culling is increased. Replacement heifer cost is one of the largest costs for dairy producers, therefore, culling practices should be scrutinized to control costs and achieve more profitable milk production". To help decision-makers determine optimal decisions based on the cost of specific CM pathogens, Cha *et al*. (2015) developed a decision model that concluded that the time for replacement was up to 5 months sooner for cows with CM compared with cows without CM.

Management factors could be associated with the presence of clinical mastitis. A study of the incidence rate of CM in Canada (Olde Riekerink *et al.*, 2008) found that tie-stall herds had a higher incidence rate of CM than herds in other systems. A study presented by Gordon *et al.* (2013) on clinical mastitis on dairy farms in Switzerland showed similar results where farms with tie-stall systems had a significantly higher number of cases for clinical mastitis compared to free-stall.

1.2.4.3.2 Reproduction and Fertility Issues

Reproductive problems require special attention because of their diversity and the different situations that might cause them. For herd managers, analysis of reproductive performance should be considered at both the herd and individual levels based on the selected reproductive programme for the herd and also based on the individual value of the cow that would determine the number of inseminations allowed or the quality of the semen used (Cabrera, 2014).

A low reproductive performance has an effect on the overall profitability caused by a reduction in milk yield and the number of calves born, and an increase in the cost of veterinary services. According to Leblanc (2010), housing systems, number of animals per worker and effectiveness of insemination practices, among others, are specific items under dairy producers' control that affect the reproductive function. Insemination services, reproductive treatments and culling decisions represent an area of dairy herd management affecting profitability (Grohn and Rajala-Schultz, 2000).

Fertility in dairy cattle has an important effect on herd economics. Different variables have been used to denote the fertility of a dairy cow such as calving interval, days-open, non-return rates, or number of inseminations per successful pregnancy. It is obvious that these variables are highly related and directly depend on the insemination and replacement policy of the farmer (Groen *et al.*, 1997). Dekkers (1991) reported that an improvement in fertility increases profit, not only by reducing culling cost but also by increasing incomes from milk sales and shorter calving intervals (CI).

Different studies have reported the effect of reproductive problems in dairy cattle. In Québec a study by Bonneville-Hébert *et al.* (2011) analyzed data from herds in this province and showed how animals with dystocia, retained placenta or merits complex were more prone to be a repeat breeder and being culled as a consequence. Drackley (1999) reported that cows with any health disorder around calving time produced 7.2 kg less milk per day during the first 20 days postpartum than did healthy cows. Cows with retained foetal membranes and subsequent metritis produced 8.2 kg less milk per day and those with displaced abomasum and secondary ketosis produced 8.5 kg/d less than cows with no health disorders. Grohn and Rajala-Schultz (2000) studied the impact of dystocia, retained placenta and metritis in Ayrshire cows from Finland, finding significant differences in losses in milk yield associated with the effect of these disorders across parities. Finally, Mahnani *et al.* (2015) reported reductions of 305 days in milk yield of 129 kg per cow and an increase of 16.4 days open associated with metritis cases in Iranian Holstein dairy farms.

1.2.4.3.3 Feet and Legs Problems

Similar to clinical mastitis, feet and legs problems also generate economic losses, not only caused by the treatment (direct cost) but also by the consequences in production and overall condition of the animal. Shearer and Van Amstel (2011) found that sole ulcers and digital diseases were the conditions with the highest economic impact followed by digital dermatitis. The economic losses caused by feet and legs problems resulted from a decrease in reproductive performance, an increase in the involuntary rate of culling, and the cost caused by the extra management attention required by lame animals.

The milk losses caused by the effect of digital diseases were analyzed by Enting *et al.* (1997) who found that animals that were culled for lameness had considerably and significantly lower milk, fat and protein productions (1.3, 14.1 and 16.4% respectively). This study found three more sources that contributed substantially to the total economic losses: prolonged calving intervals, costs of veterinary treatments and costs of labor and treatments by the farmer.

Other studies have analyzed the association between the housing floor systems and the presence of digital diseases. Sogstad *et al.* (2005) in his study of the prevalence of claw lesions in Norwegian dairy cattle showed that there were significant differences between tie-stall and free-stall systems. The prevalence of claw lesions was 1.5 times higher in free-stall systems compared to tie-stalls.

1.2.5 Data Analysis

Different alternatives are found in the literature describing the different traits and models to explain the effect that direct and indirect factors such as those mentioned previously have on profitability (Stott and Elston, 1991, Enting *et al.*, 1997, Stott *et al.*, 2005). Regression models have been commonly used, for example, by Kulak *et al*. (1997) to test the impact of age at first calving, reproduction traits and number of mastitis and reproduction treatments per lactation on profitability, by Enting *et al* (1997) to estimate the effects of lameness and and other diseases such as gynaecological or metabolic disorders on milk, fat and protein production and by Mulder and Jansen (2001) to calculate the Estimated Breeding Value (EBV) of traits used in the Lifetime Profitability Index (LPI).

To predict lactations yields, random regressions have been used in different analyses (VanRaden, 1997, Roche *et al.*, 2009). Random regressions are useful when working with prediction curves because they allow the fitting of lactation curves to individual lactations. This is because the curve parameters are treated as random variables, and reasonable estimates may be obtained with even a few data points (VanRaden, 1997). Another advantage presented by Cue *et al.* (2012) is their adaptability to changes in the model over time and their ability to allow each animal to have its own "curve". Random regression models also allow for the presence of missing data, and covariates that may vary with time, and allow the presence of repeated measures as well as the inclusion of covariates, measured at individual or group levels (Hedeker *et al.*, 1991).

To account for the selection and repeated measures of different variables such as weight, number of services, days open, and calving interval, the mixed models procedure of SAS can be used for the analyses (Gandini *et al.*, 2007, Cue *et al.*, 2012). The mixed models procedure allows for the adjustment of differences caused by production characteristics that might have an effect on test-day yields such as geographical region, breed, herd management, lactation number, age at calving, month of calving, and number of days in lactation. Some of these effects could be considered as random effects and should be included in the model to estimate economic breeding values in an attempt to remove any management differences (St-Onge, 2000). Also, the use of random variables is appropriate to calculate the variance between and within the groups when working with nested models. Mixed models also allow for differences in the correlations among test-day milk yield caused by the effect of time, because consecutive test days usually have higher correlation compared to more distant test days (Schaeffer and Jamrozik, 1996).

1.2.6 Management Information Systems

Information systems and computers, by providing routine information to decision-makers, can help them to observe and analyze what is occurring on the dairy farm and also give them an overall view identifying strengths and weaknesses to correct. While these tools are now in common use, advances in computing techniques, and the constant development of new software, are providing promising management advances in this area.

Management Information Systems (MIS) cover the broad category of computer systems that realize the collection, maintenance and use of information for organizational purposes (Jalvingh, 1992) and are specialized in providing support in the process of decision-making (Verstegen *et al.*, 1995).

In daily practice, advice given on management measures is often intuitively based. As a consequence producers sometimes receive contradictory advice from different sources, leading to a low adoption rate of any measures. Literature on the efficacy of management measures mostly gives general values, which are not applicable in a farm specific situation (Huijps, 2009). However computerized information systems can help herd managers understand and analyze the information in the process of decision making (Pietersma *et al.*, 1998). Combining off-farm with on-farm information creates the so-called info-fog. The info-fog could be used as useful tool in the in the complex process of on-farm decision-making (St-Onge, 2004). The complexity of this process is explained due to the multiple interrelationships among animals, management levels and economic factors, according to St-Onge (2004).

In contrast with MIS, as presented by Stott and Elston, (1991), a "Decision support systems (DSS) may provide the solution of meeting the need of the average farmer for decision making support by reducing the demands on management time and skills while providing flexible and rigorous analyses of complex decision problems".

Key to the success of a DSS is the routine availability of high-quality data and an effective system to understand and analyze the information in order to make decisions. Such approaches can be undertaken at both a herd level and an individual cow level in the form of economic decision-making tools (Roche *et al.*, 2009). According to Cabrera (2012a) a DSS: 1- be highly user-friendly; 2- farm- and user-specific; 3- be grounded on the best scientific information available; 4- remain relevant over time; and 5- provide fast, concrete and simple answers to producers' complex questions.

Different examples of DSS and MIS designed to help dairy producers to make better decisions and using different levels of technology and information are reported in the literature (Parrot *et al*. 2003, Plaziers *et al*. 1997, Pietersma *et al*. 2001, Giordano *et al*. 2011, Freer *et al.* 1997).

These DSS and MIS range from a simple multi-agent heifer management system (MAHMS) to integrate heifer data from different sources (Parrot *et al*., 2003), a DSS to determine the optimum moment for culling (Plaziers *et al*., 1997), a case-acquisition and decision support system to support the analysis of group-average lactation curves (Pietersma *et al*., 2001), a DSS to assess the nutritional quality for sheep or cattle of grazing pastures (Freer *et al.* (1997) to a model that quickly calculates the outcomes of different reproduction strategies Giordano *et al*., 2011).

There are different examples of DSS and MIS focused on helping herd-managers regarding various aspects that have an effect on profitability. An information visualization software named "Herd-Line" was created to help producers visualize the overall and specific values of the herd as well as individual phenotypic and genotypic performances (St-Onge, 2004). Cabrera *et al.* (2009), (Cabrera, 2012b) working with linear programming and Markov-chain analysis models developed a decision support system to help producers to estimate net present values of their animals in order to make decisions regarding culling-replacement. Finally, Giordano (2012), also using Markov-chain analysis created a simulation model to compare the economic and reproductive outcomes of breeding programs combining timed artificial insemination and different levels of artificial insemination after estrus detection.

1.2.6.1 Information Visualization Methods

As stated by Fekete *et al.*, (2008) "If vision perceives some pattern, there might be a pattern in the data that reveals a structure". This is an important premise of the Information Visualization methods (Infovis), which are useful in developing insights from collected data. Information Visualization methods work with inductive methodology because they are based on human perception as a filter and, although Infovis allow for the visualization of a great volume of information to be rapidly interpreted and analyzed, the presentation has to be the adequate (Stolte *et al.*, 2002, Ware, 2013). Research in information visualization methods explores, not only the space of successful designs and techniques, but also moves into the application of accumulated knowledge in a principled manner (Heer *et al.*, 2005).

Frohlich (1997) proposed the development of visual and interactive tools as one of the solutions to help with the processing of relevant information since profitable decision-making depends on interpreting all of the inputs accurately. But important as good quality data and top-notch technology are, a visual analysis involves posing questions, formulating hypotheses and discovering results (Eick, 2000). One of the main attractions of Infovis is the ability to solve real-world problems. Infovis can be used as an effective tool to perceive, understand and control the data, and obtain a competitive advantage in the process of making decisions for business (Wright, 1997). Interactive visualization systems may be beneficial to the dairy industry, where multiple reports and information sources tend to exist in an unorganized manner and where profitable decision-making depends on interpreting all of the inputs accurately (St-Onge, 2004).

St-Onge (2004) describes the interactive visualization techniques as "an aim at creating graphical interfaces that increase a user's interaction with visually represented information". This is explained because these techniques are intended to enhance users' perceptions and facilitate users' actions. Building user interfaces that intelligently present information is a difficult task. Application designers are forced to anticipate every presentation situation that might arise in an application and decide which graphical techniques are most effective in each situation (Mackinlay, 1986). Although current visualization technologies are of much better quality and provide increased functionality, there is still not enough market segmentation and specific application development to avoid the "one size fits all" model (Toker *et al.*, 2013).

In order to transform the collected raw data into a graph that can be automated and understood, there are different steps to transform and convert them into information. Chi (2000) identified four distinct stages in the construction of the visualization process: Value, or the raw data, Analytical abstraction, or information, Visualization abstraction, or information that is visualized on the screen using a visualization technique, and finally View, which is the end-product or where the user interprets and analyzes the presented information.

The process of data visualization can be summarized according to Ware, (2013) in four different stages: 1-The collection and storage of data itself; 2- the pre-processing designed to transform the data into something we can understand; 3- the display hardware and the graphics algorithms that produce an image on the screen; and finally 4- the human perceptual and cognitive system (the perceiver). These different stages are combined in a number of different feedback loops.

Another important aspect that has to be considered during the stages of visualization development was expressed by Lam *et al.* (2012) who discuss the importance of understanding the potential user's work environment and work flow in order to achieve the proposed goals and effectiveness and finally to improve any current design by identifying usability problems.

1.3 Rationale and Objectives

1.3.1 Rationale

Profit in a dairy enterprise is a function of milk production, herd life, feed consumption and costs such as those pertaining to health, reproduction and housing (Visscher, 1995). It could be inferred that profitability does not depend only on efforts for a single factor, but also requires that producers have a better knowledge of all factors affecting revenues and lifetime costs (fixed and variable), and the impacts and consequences of their management decisions on profitability. Profitability and its components have been studied and interpreted for years as a way to calculate the performance and competitiveness of any productive sector.

This lack of understanding of the different factors affecting profit requires an effort to integrate and prioritize which factors are the ones affecting profit and in which order they should be prioritized, considering limitations for the farmer such as cash flow. For instance, replacement heifer costs are one of the largest costs for dairy producers, implying that culling practices should be scrutinized to control costs and achieve profitable milk production (Hadley *et al.*, 2006).

The fundamental principle is to recognize that a dairy cow is a business asset that is owned and operated for profit. A significant challenge is to evaluate objectively the projected cash flows related to the production traits of dairy cattle and to the lactation cycle. Information from these cash flows provides a means of evaluating the potential for profit (Lehenbauer and Oltjen, 1998).

The introduction of information systems (IS) to farm management has contributed to helping to increase the volume of recorded data about the farm. However this has also led to difficulties generated by the interpretation of these systems (Levallois, 2008). The provision of appropriate information is important to making good decisions. To supply appropriate (in terms of quantity, quality, and form) and timely information, data need to be collected, analyzed and presented to decision makers (Huijps, 2009).

Different dairy sector stakeholders in Québec collect relevant information. Valacta collects and keeps records of information relevant to the production and nutrition of the herd while the Provincial Health Files (DSA) keep records of health events. Data currently available from veterinarians and from milk recording include herd reports of health events however none of them provides the integration of cow profitability and health events (Cue, 2011). The opportunity to use relevant information sources gives a unique chance to develop a framework of diagnosis and analysis of the different factors affecting profitability and to develop potential scenarios to improve results exploring the use of different techniques of visualization.

1.3.2 General Objectives

The main purpose of this study is to understand management factors affecting and influencing lifetime cow and herd profitability, based on an empirical approach and also to create a methodological framework using information visualization methods to monitor profitability as a means of achieving continuous improvement at the dairy farm.

1.3.3 Specific Objectives

- To calculate using field data the associated costs of various health and management events and their impact on profitability.

- To explore the use of different profitability measures and selected management indicators in the process of decision-making, using information collected on a regular basis on the farms.

- To create visualization curves allowing comparisons of lifetime profitability and cumulative costs by management groups and to determine if these curves could be used as potential benchmarks for decision makers.

- To integrate the information into a dynamic information visualization prototype interface presenting lifetime profitability results at different hierarchical levels allowing end-users to visualize and to compare the selected profitability results.

1.4 REFERENCES

Balaine, D. S., R. E. Pearson, and R. H. Miller. 1981. Profit Functions in Dairy Cattle and Effect of Measures of Effeciency and Prices. J. Dairy Sci. 64:87-95.

Beck, T. 2008. How Does Cost Efficiency Affect Farm Profitability?. Accessed June 5, 2012. http://www.das.psu.edu/research-extension/dairy/capitalregion/news/df-200712-01

Benson, G. A. 2008. Pasture-Based and Confinement Dairy Farming in the United States: An Assessment. Journal of International Farm Management 4:14-29.

Berry, D. P., B. L. Harris, A. M. Winkelman, and W. Montgomerie. 2005. Phenotypic associations between traits other than production and longevity in New Zealand dairy cattle. J. Dairy Sci. 88:2962-2974.

Bohmanova, J., F. Miglior, J. Jamrozik, B. J. Van Doormaal, K. J. Hand, and D. Lazenby. 2009. Genetic analysis of return over feed in Canadian Holsteins. Animal 4:173.

Bonneville-Hébert, A., E. Bouchard, D. Du Tremblay, and R. Lefebvre. 2011. Effect of reproductive disorders and parity on repeat breeder status and culling of dairy cows in Quebec. Canadian Journal of Veterinary Research 75:147.

Cabrera V.E. 2014. Economics of fertility in high-yielding dairy cows on confined TM systems Animal, 8 (Suppl. 1) (2014), pp. 211–221.

Cabrera, V. E. 2012a. DairyMGT: A Suite of Decision Support Systems in Dairy Farm Management. INTECH Open Access Publisher.

Cabrera, V. E. 2012b. A simple formulation and solution to the replacement problem: A practical tool to assess the economic cow value, the value of a new pregnancy, and the cost of a pregnancy loss. J. Dairy Sci. 95:4683-4698.

Cabrera, V. E., R. D. Shaver, and M. A. Wattiaux. 2009. Optimizing Income over Feed Supplement Costs. Page 116 in Proc. Four-State Dairy Nutrition and Management Conference.

Camps, M., K. Huijps, H. Barkema, and H. Hogeveen. 2009. Costs of mastitis in Canada. PhD Thesis. Open Access Version via Utrech University Repository.

Cha, E., Kristensen, A. R., Hertl, J. A., Schukken, Y. H., Tauer, L. W., Welcome, F. L., & Gröhn, Y. T. 2014. Optimal insemination and replacement decisions to minimize the cost of pathogen-specific clinical mastitis in dairy cows. J. Dairy Sci. 97:2101-2117.

Chi, E. H. 2000. A taxonomy of visualization techniques using the data state reference model. Pages 69-75 in Proc. Information Visualization, 2000. InfoVis 2000. IEEE Symposium.

Chittaro, L. 2001. Information visualization and its application to medicine. Artif. Intell. Med. 22:81-88.

Cue, R. 2011. Profitability in Quebec dairy cattle, research proposal. McGill University.

Cue, R., D. Pietersma, D. Lefebvre, R. Lacroix, K. Wade, D. Pellerin, A. de Passillé, and J. Rushen. 2012. Growth modeling of dairy heifers in Québec based on random regression. Can. J. An. Sci. 92:33-47.

Dale, J. M. 1998. Assessing and Improving Farm Profitability University of Maryland Cooperative Extension Fact Sheet 539.

Dechow, C. D., E. A. Smith, and R. C. Goodling. 2011. The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds. Anim. Welf. 20:145-158.

Dekkers. J.C.M. 1991 Estimation of economic values for dairy cattle breeding goals: bias due to sub-optimal management policies. Livest. Prod Sci. 29:131.

Dekkers. J.C.M. 1995. Genetic improvement of dairy cattle for profitability. In: Animal science research and development. Moving toward a new century: 307-327. Centre for Food and Animal Research, Agriculture and Agri-Food Canada, Ottawa, Canada.

Dekkers, J. C. M., J. H. Ten Hag, and A. Weersink. 1998. Economic aspects of persistency of lactation in dairy cattle. Livest. Prod. Sci. 53:237-252.

Drackley, J. K. 1999. Biology of dairy cows during the transition period: the final frontier? J. Dairy Sci. 82:2259.

Eick, S. G. 2000. Visualizing multi-dimensional data. ACM SIGGRAPH computer graphics 34:61-67.

Enevoldsen, C., J. T. Sørensen, I. Thysen, C. Guard, and Y. T. Gröhn. 1995. A diagnostic and prognostic tool for epidemiologic and economic analyses of dairy herd health management. J. Dairy Sci. 78:947-961.

Enting, H., D. Kooij, A. A. Dijkhuizen, R. B. M. Huirne, and E. N. Noordhuizen-Stassen. 1997. Economic losses due to clinical lameness in dairy cattle. Livest. Prod. Sci. 49:259-267.

Essl, A. 1998. Longevity in dairy cattle breeding: a review. Livest. Prod. Sci. 57:79-89.

Fekete, J.-D., J. J. Van Wijk, J. T. Stasko, and C. North. 2008. The value of information visualization. Pages 1-18 in Information visualization. Springer.

Fleischer, P., M. Metzner, M. Beyerbach, M. Hoedemaker, and W. Klee. 2001. The relationship between milk yield and the incidence of some diseases in dairy cows. J. Dairy Sci. 84(9):2025-2035.

Ford, S. A. and J. S. Shonkwiler. 1994. The effect of managerial ability on farm financial success. Agr. and Resour. Econ. Rev. 23:150-157.

Freer, M., A. D. Moore, and J. R. Donnelly. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises—II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agric. Syst. 54:77-126.

Frohlich, D. 1997. Direct manipulation and other lessons. Handbook of Human-Computer Interaction:463-488.

Gandini, G., C. Maltecca, F. Pizzi, A. Bagnato, and R. Rizzi. 2007. Comparing local and commercial breeds on functional traits and profitability: the case of Reggiana dairy cattle. J. Dairy Sci. 90:2004-2011.

Gantner, V., S. Jovanovac, N. Raguz, D. SOLIC, and K. Kuterovac. 2010. Nonlinear vs. linear regression models in lactation curve prediction. Bulgarian Journal of Agricultural Science 16:794-800.

Giordano, J. O., Kalantari, A. S., Fricke, P. M., Wiltbank, M. C., & Cabrera, V. E. 2012. A daily herd Markov-chain model to study the reproductive and economic impact of reproductive programs combining timed artificial insemination and estrus detection. J. Dairy Sci. 95:5442-5460

Giordano, J. O., P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94:6216-6232.

Gordon, P. F., B. H. P. Van den Borne, M. Reist, S. Kohler, and M. G. Doherr. 2013. Questionnaire-based study to assess the association between management practices and mastitis within tie-stall and free-stall dairy housing systems in Switzerland. BMC veterinary research 9:200.

Groen, A. 1989. Cattle breeding goals and production circumstances. PhD Thesis. Wageningen Agricultural University, Wageningen, Netherlands.

Groen, A. F., T. Steine, J. J. Colleau, J. Pedersen, J. Pribyl, and N. Reinsch. 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49:1-21.

Grohn, Y. T. and P. J. Rajala-Schultz. 2000. Epidemiology of reproductive performance in dairy cows. Anim. Reprod. Sci. 60-61.

Guard, C. 2008. The costs of common diseases of dairy cattle (Proceedings). In Proceedings of the Central Veterinary Conference West, San Diego, Ca. Accessed Oct. 08 2013. http://veterinarycalendar.dvm360.com/avhc/Veterinary+Food+Animal/The-costs-of-common-diseases-of-dairy-cattle-Proce/ArticleStandard/Article/detail/586496

Hadley, G. L., C. A. Wolf, and S. B. Harsh. 2006. Dairy Cattle Culling Patterns, Explanations, and Implications. J. Dairy Sci. 89(6):2286-2296.

Hedeker, D. R., R. D. Gibbons, and J. M. Davis. 1991. Random regression models for multicenter clinical trials data. Psychopharmacology Bulletin.

Heer, J., S. K. Card, and J. A. Landay. 2005. Prefuse: a toolkit for interactive information visualization. Pages 421-430 in Proceedings of the SIGCHI conference on Human factors in computing systems. ACM.

Heikkilä, A. M., J. I. Nousiainen, and S. Pyörälä. 2012. Costs of clinical mastitis with special reference to premature culling. J. Dairy Sci. 95:139-150.

Huijps, K. 2009. Economic decisions in mastitis management. Dissertation Faculty of Veterinary Medicine. Utrecht University, the Netherlands.

Jagannatha, S., J. F. Keown, and L. D. Van Vleck. 1998. Estimation of relative economic value for herd life of dairy cattle from profile equations. J. Dairy Sci. 81:1702-1708.

Jalvingh, A. W. 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. Livest. Prod. Sci. 31:351-365.

Kalantari A.S., H. Mehrabani-Yeganeh, M. Moradi, A. H. Sanders and A. De Vries. 2010. Determining the optimum replacement policy for Holstein dairy herds in Iran. J. Dairy Sci. 93: 2262-2270.

Kelton, D. F., K. D. Lissemore, and R. E. Martin. 1998. Recommendations for recording and calculating the incidence of selected clinical diseases of dairy cattle. J. Dairy Sci. 81:2502-2509.

Kristensen, E., S. Østergaard, M. A. Krogh, and C. Enevoldsen. 2008. Technical indicators of financial performance in the dairy herd. J. Dairy Sci. 91:620-631.

Kulak, K. K., J. C. M. Dekkers, A. J. McAllister, and A. J. Lee. 1997. Lifetime profitability measures for dairy cows and their relationships to lifetime performance traits. Can. J. Anim. Sci. 77:609.

Lam, H., E. Bertini, P. Isenberg, C. Plaisant, and S. Carpendale. 2012. Empirical studies in information visualization: Seven scenarios. IEEE Transactions on Visualization and Computer Graphics, 18:1520-1536.

Lang, B. 2011. The Cost of Raising Replacement Dairy Heifers. Factsheet - Ministry of Agriculture, Food and Rural Affairs, Ontario ORDER NO. 11-055.

Leblanc, S. 2010. Assessing the association of the level of milk production with reproductive performance in dairy cattle. J. Reprod. Dev. 56:1-7.

Lehenbauer, T. W. and J. W. Oltjen. 1998. Dairy Cow Culling Strategies: Making Economical Culling Decisions. J. Dairy Sci. 81:264-271.

Levallois, R. 2008. Analyse des résultats technico-économiques d'une entreprise laitière par un système expert. Canadian Journal of Agricultural Economics/Revue canadienne d'agroéconomie 37:681.

Levallois, R., Y. Allard, P. Carle, S. Gagnon, D. Pellerin, R. Roy, and A. Thériault. 1997. L'augmentation de la production par vache est-elle rentable. Pages 129-162 in Proceedings of the Sympsium sur les Bovins Laitiers, CPAQ,.Drummondville QC.

Littleton, A. C. 1928. What is profit? The Accounting Review 3:278-288.

Mackinlay, J. 1986. Automating the design of graphical presentations of relational information. ACM Transactions on Graphics (TOG) 5:110-141.

Mahnani, A., Sadeghi-Sefidmazgi, A., & Cabrera, V. E. 2015. Consequences and economics of metritis in Iranian Holstein dairy farms. J. Dairy Sci. 98:6048-6057.

Mainland, D. D. 1994. A decision support system for dairy producers and advisors. Agricultural Systems 45:217-231.

McKean, E. 2005. The new Oxford American dictionary. Oxford University Press, New York, N.Y.

McLaren, C. J., K. D. Lissemore, T. F. Duffield, K. E. Leslie, D. F. Kelton, and B. Grexton. 2006. The relationship between herd level disease incidence and a return over feed index in Ontario dairy herds. Can. Vet. J. 47:767.

Mulder, H., & Jansen, G. 2001. Derivation of economic values using lifetime profitability of Canadian Holstein cows. Parity, 1 no. 3:1.

Nordlund, K. V. and N. B. Cook. 2004. Using herd records to monitor transition cow survival, productivity, and health. Vet. Clin. North Am. Food Anim. 20:627-650.

Olde Riekerink, R. G. M., H. W. Barkema, D. F. Kelton, and D. T. Scholl. 2008. Incidence rate of clinical mastitis on Canadian dairy farms. J. Dairy Sci. 91:1366-1377.

Oltenacu, P. A., and D. M. Broom. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim. Welf. 19:39–49.

Parrott, L., R. Lacroix, and K. M. Wade. 2003. Design considerations for the implementation of multi-agent systems in the dairy industry. Comput. Electron. Agric. 38:79-98.

Pietersma, D., R. Lacroix, D. Lefebvre, E. Block, and K. M. Wade. 2001. A Case-Acquisition and Decision-Support System for the Analysis of Group-Average Lactation Curves. J. Dairy Sci. 84:730-739.

Pietersma, D., R. Lacroix, D. Lefebvre, R. Cue, and K. M. Wade. 2006. Trends in growth and age at first calving for Holstein and Ayrshire heifers in Quebec. Can. J. Anim. Sci. 86:325-336.

Pietersma, D., R. Lacroix, and K. M. Wade. 1998. A Framework for the Development of Computerized Management and Control Systems for Use in Dairy Farming. J. Dairy Sci. 81:2962-2972.

Plaizier, J. C. B., G. J. King, J. C. M. Dekkers, and K. Lissemore. 1997. Estimation of Economic Values of Indices for Reproductive Performance in Dairy Herds Using Computer Simulation. J. Dairy Sci. 80:2775-2783.

Ribeiro, A. C., A. J. McAllister, and S. A. Queiroz. 2008. Profitability measures of dairy cows. Revista Brasileira de Zootecnia 37:1607-1616.

Roche, J. R., J. K. Kay, N. C. Friggens, M. W. Fisher, K. J. Stafford, and D. P. Berry. 2009. Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92:5769-5801.

Schaeffer, L. R. and J. Jamrozik. 1996. Multiple-Trait Prediction of Lactation Yields for Dairy Cows. J. Dairy Sci. 79:2044-2055.

Schepers J.A., Dijkhuizen A. A. 1991. The economics of mastitis and mastitis control in dairy cattle: a critical analysis of estimates published since 1970. Prev. Vet. Med. 10 213–224.

Schroeder, J. 1996. Feeding for Milk Components and Profit. NDSU Extension Service, North Dakota State University of Agriculture and Applied Science. Accessed Sept. 07 2013. https://library.ndsu.edu/repository/bitstream/handle/10365/5400/as1118.pdf?sequence=1

Seegers, H., C. Fourichon, and F. Beaudeau. 2003. Production effects related to mastitis and mastitis economics in dairy cattle herds. Vet. Res. 34:475-491.

Sewalem, A., F. Miglior, G. J. Kistemaker, P. Sullivan, and B. J. Van Doormaal. 2008. Relationship between reproduction traits and functional longevity in canadian dairy cattle. J. Dairy Sci. 91:1660-1668.

Sewalem, A., F. Miglior, G. J. Kistemaker, and B. J. Van Doormaal. 2006. Analysis of the relationship between somatic cell score and functional longevity in Canadian dairy cattle. J. Dairy Sci. 89:3609-3614.

Shahinfar, S., Kalantari, A. S., Cabrera, V., & Weigel, K. 2014. Short communication: Prediction of retention pay-off using a machine learning algorithm. J. Dairy Sci. 97:2949-2952.

Shearer, J. K. and S. R. Van Amstel. 2011. Lameness in dairy cattle. Dairy Production Medicine, (1st ed.). Ed. Carlos A. Risco and Pedro Melendez Retamal. West Sussex, UK: Wiley-Blackwell, 233-253.

Sogstad, Å., T. Fjeldaas, O. Østerås, and K. Forshell. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Prev. Veterinary Med. 70:191-209.

St-Onge, A. 2000. Economic values of traits for dairy cattle improvement estimated using field recorded data. Animal Science. MS Thesis. McGill University, Montreal, Canada.

St-Onge, A. 2004. The interpretation of dairy data using interactive visualization. Animal Science. PhD Thesis. McGill University, Montreal, Canada.

Stolte, C., D. Tang, and P. Hanrahan. 2002. Polaris: A system for query, analysis, and visualization of multidimensional relational databases. IEEE Transactions on Visualization and Computer Graphics, 8:52-65.

Stott, A. and D. Elston. 1991. Interpretation of linear profit functions in the presence of correlated predictors, with application to decision support in a dairy enterprise. Agricultural Systems 37:87-98.

Stott, A. W., M. P. Coffey, and S. Brotherstone. 2005. Including lameness and mastitis in a profit index for dairy cattle. Anim. Sci. 80:41-52.

Toker, D., C. Conati, B. Steichen, and G. Carenini. 2013. Individual user characteristics and information visualization: connecting the dots through eye tracking. Pages 295-304 in proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM.

Valacta. 2011. Évolution de laproduction laitière québécoise2010. in Le producteur de lait québécois. Vol. may 2011. Fédération des producteurs de lait du Québec (FPLQ), Longueuil, Quebec.

Valacta. 2014. Évolution de la production laitière québécoise 2013. Le producteur de lait québécois. Vol. Numéro spécial, mai 2014. Fédération des producteurs de lait du Québec (FPLQ)Longueuil,Québec.

Van Arendonk, J. A. M. 1985. A model to estimate the performance, revenues and costs of dairy cows under different production and price situations. Agricultural Systems 16:157-189.

Van Arendonk, J. A. M. 1991. Use of Profit Equations to Determine Relative Economic Value of Dairy Cattle Herd Life and Production from Field Data. J. Dairy Sci. 74:1101-1107.

VandeHaar, M. J. 2006. Alimentation, gestion et croissance des génisses laitieres de remplacement. in Proceedings 30 Symposium sur le bovin laitiere, Quebec.

VanRaden, P. 1997. Lactation yields and accuracies computed from test day yields and (co) variances by best prediction. J. Dairy Sci. 80:3015-3022.

Vargas, B., A. F. Groen, M. Herrero, and J. A. M. Van Arendonk. 2002. Economic values for production and functional traits in Holstein cattle of Costa Rica. Livest. Prod. Sci. 75(2):101-116.

Verstegen, J. A. A. M., R. B. M. Huirne, A. A. Dijkhuizen, and J. P. C. Kleijnen. 1995. Economic value of management information systems in agriculture: a review of evaluation approaches. Comput. Electron. Agric. 13:273-288.

Visscher, P. M. 1995. Genetic analyses of profit for Australian dairy cattle. Animal Science 61:9.

Ware, C. 2013. Information visualization: perception for design. Elsevier.

Wright, W. 1997. Business visualization applications. IEEE Computer Graphics and Applications, 17:66-70.

CHAPTER II

ANALYSIS OF DIFFERENT PROFITABILITY FORMULAE AS DECISION-MAKING TOOLS IN QUÉBEC DAIRY HERDS

Different Profitability Models as Decision-Making Tools by *Delgado et al.* Different profitability models used in bio-economic and empirical studies were tested using lifetime cumulative records from Québec dairy herds. A retrospective cohort study with a mixed model analysis was conducted to identify if variations in cumulative profitability results were associated with different selected variables. To understand the use of the selected profitability measures and different cost variables as decision-making tools, lifetime results cumulated by event dates were transformed into different visualization curves.

Running Title: Our Industry Today

Analysis of Different Profitability Models as Decision-Making Tools in Québec Dairy Herds

H. A. Delgado[*], R. I. Cue[*], D. Haine[#], A. Sewalem[‡§], R. Lacroix[*†], D. Lefebvre[*†], J. Dubuc[#], E. Bouchard[#], K. M. Wade[*]

[*]Department of Animal Science, McGill University, Macdonald-Stewart Building, Room MS1-084, Macdonald Campus 21111 Lakeshore Road Ste. Anne de Bellevue, QC H9X 3V9
[†]Valacta, 555 boul. des Anciens-Combattants, Sainte-Anne-de-Bellevue, QC H9X 3R4
[‡]Agriculture and Agri-Food Canada §Canadian Dairy Network, 660 Speedvale Avenue West, Suite 102 Guelph, Ontario, Canada N1K 1E5
[#]Université de Montréal, Département de sciences cliniques, 3200, rue Sicotte, CP. 5000, Saint-Hyacinthe (Québec) Canada J2S 7C6

Corresponding author: K. M. Wade

Contact address: kevin.wade@mcgill.ca

2.1 ABSTRACT

Data routinely collected by Québec Dairy Herd Improvement (**DHI**) were integrated with provincial veterinary health data with the objectives of 1) creating a combined source of information including lifetime cumulative variables (revenues and costs), 2) exploring different lifetime profitability measures and developing an analysis of variables affecting profitability results, and 3) analyzing alternatives about the use of these lifetime profitability results as decision making tools. The dataset for the analysis consisted of lifetime records for a total of 13,668 Holstein cows from 113 herds and in cohorts between 2000 and 2009.

A retrospective cohort study was conducted with the information from the selected herds. Cumulative Lifetime Profitability (**LTP**) and Lifetime Profitability adjusted for Regressed Opportunity Cost of Postponed Replacement (**LTPOC**) were tested as dependent variables. Independent variables selected for analysis were age at first calving, lifetime cumulative dry days, lifetime cumulative days in milk (**cumDIM**) and cumulative health events (clinical mastitis, reproductive problems and feet and legs problems). The statistical analysis was conducted with a Mixed Models analysis.

Significant differences in LTP were found for Age at First Calving (**AFC)**. Animals that calved for the first time at 24 months achieved the best LTP result ($3,198 ± 36). Animals required on average 422 cumDIM to reach break-even for LTP at $97 ± 108. The health events cumulated by animal lifetime in the study showed a significant negative linear effect on profitability.

The results of the cumulative lifetime profitability measures and the costs of health events and breeding services were integrated in different visualization curves. The visualization of the different curves showing LTP and LTPOC over the lifetime of an animal helps to understand and analyze information since factors affecting profitability could be underestimated by decision makers due to the length of lactations cycles. A visual sub-report on profitability could show not only the profit results, but also the factors that affected profitability.

(Key Words: Profitability, dairy cow, management, decision-making)

2.2. INTRODUCTION

Every day, managers and dairy producers face increasing decision-making challenges as a consequence of the last decades' changes that have affected the dairy industry around the world (Pietersma *et al.*, 1998). Also considering the multiple challenges such as animal welfare and environmental legislation, international trade agreements and tariffs, difficult access to capital and land, among others, farm managers and their advisors are required to increase their level of management competence to succeed in the decision-making process (Levallois, 2008).

To stay in business the farm must generate profit at least high enough to exceed the opportunity cost (**OC**) or in other words the loss of potential gain from other alternatives when one alternative is chosen (McKean, 2005): therefore, assessment and improvement of farm profitability are very important management tasks (Dale, 1998). Whereas sometimes the process of decision-making is based on factors other than profitability, it is important to bear in mind that the decision-making process should always be financially justified (Grohn and Rajala-Schultz, 2000).

Production and productivity, health costs, costs of reproduction and housing, among others, are part of the daily operational and tactical information that is recorded by producers to make decisions. At the same time these components are crucial to estimate profitability (Visscher, 1995, Perez-Cabal and Alenda, 2003) and to identify those factors responsible for farm inefficiencies having an effect on profitability (Atzori *et al.*, 2013). It is clear that profitability does not depend only on focusing on a single factor, but also demands that producers have a better knowledge of all factors affecting revenues and lifetime costs (fixed and variable) and the direct and indirect impacts and consequences of their management decisions on profitability.

The combination of genetics and management input have a direct and/or indirect effect on the volume and composition of milk, which are the most important components of revenue. The implementation and monitoring of appropriate management practices and control policies of animal care would help to optimize profit (Plaizier *et al.*, 1997, Fleischer *et al.*, 2001). According to Schroeder (1996) 55% of the variation in milk composition is due to heredity, while 45% is due to environmental factors such as feeding and management.

Among management variables with an important effect on profitability are reproductive and health programs. Different studies have shown the impact of health issues on profitability (McLaren *et al.*, 2006, Guard, 2008, Heikkilä *et al.*, 2012). These different studies present not only the direct costs inherent in breeding services and in health costs associated with prevention and treatment but also indirectly how health and reproductive problems affect milk production, breeding costs, rates of culling, and the rate of genetic progress for traits of economic importance (Plaizier *et al.*, 1997).

An example of these indirect consequences is presented by Hadley *et al.* (2006): "Due to clinical mastitis, lifetime is affected and early culling is increased. Replacement heifer costs are one of the largest costs for dairy producers, therefore, culling practices should be scrutinized to control costs and achieve more profitable milk production". For herd managers one of the most important decision making factors is that their herds are business assets that should be profitable (Lehenbauer and Oltjen, 1998).

Profitability analysis involves not only an operational task of recording data but also a more sophisticated knowledge of the system and how the individual cow contributes to the overall profit of the herd. Considering the cow as the functional unit within the herd, the relative value of a cow will depend on biological situations such as a new pregnancy or pregnancy loss and herd profitability will be affected by the replacement policies or decisions (Cabrera, 2012).

Profitability and its components have been studied and interpreted for years as a way to calculate the performance and competitiveness of any productive sector. While much research has been developed in order to measure the impact of all cost components, the dairy cattle sector still has no consistency in terms of the costs and returns that should be included in measures of profit (Kulak *et al.*, 1997). An extensive review of literature describes different classifications of costs and the way they impact profit (Van Arendonk, 1991, Kulak *et al.*, 1997, Jagannatha *et al.*, 1998) and how to use the available information to create indexes to rank dairy farms based on profitability (Atzori *et al.*, 2013).

One of the most commonly used formulae is The Return Over Feed Cost (**ROF**) or Margin Over Feed Cost (**ROFC**). This is probably the simplest profit indicator. Return over feed cost is a herd-profit index used by Canadian dairy producers to evaluate profitability of their cows and make culling decisions in their herds (Bohmanova *et al.*, 2009).

Profitability is all about finding the optimum level of expenses given the farm resources (Beck, 2008). An important component in any profit formula is cost, and the level of technical and economic efficiency is a key determinant of costs; every farm is a particular case; and the conclusions drawn at a given time are dependent on the relative costs at that time (Levallois *et al.*, 1997). To balance between efficiency and profitability in the dairy farm it could be said that a profitable cow is an animal that can sustain a high production for many years with acceptable reproduction and without serious health problems (Mulder and Jansen, 2001). Therefore in order to be profitable the cow has to be efficient.

Once an appropriate profitability measure for dairy cows has been established, the relationship of profit to various traits can be assessed. Different alternatives are found in the literature describing the different traits and models to explain the effect that direct and indirect factors have on profitability (Kulak *et al.*, 1997)

The estimation of the effects of diseases commonly affecting the dairy herds is as important as estimating the effect of different production and fertility traits on profitability. If the cost of the health problem and the components of that cost are known, it is easier to judge whether allocation of resources can be expected to reduce that cost and return a net profit (Guard 2008). Different studies in the literature have calculated the costs of diseases in dairy cattle with different methodologies (Enting *et al.*, 1997, Guard, 2008, Cha *et al.*, 2011).

The objectives of this study were: a) to integrate datasets from the Provincial Veterinary Health database with the corresponding information from Québec DHI to create combined datasets with complete information on the different events affecting profitability during the cow's lifetime and also cumulative lifetime records of selected variables that have an effect on profit by event date; b) to calculate different lifetime profitability measures, using field data from the combined datasets, and to determine if various health and reproductive events, registered in the integrated dataset, are associated with changes in profitability; c) to explore how these lifetime profitability results could be visualized and used by herd managers and advisors in the process of decision-making, using the information collected on a regular basis on the farms.

2.3 MATERIALS AND METHODS

A retrospective cohort study was conducted with the information recorded on a routine basis from the selected herds from the combined integrated datasets to identify variables which had significant effect on profitability. The dataset for the analysis consisted of lifetime records for a total of 13,668 Holstein cows from 113 herds and in cohorts between 2000 and 2009 (cohorts defined by year of Quota). Fertility traits with negative partial correlations with profitability, cumulative days in milk and cumulative health events were tested as dependent variables using a Mixed Models analysis that included the random effects of herd and year of cohort.

Identification records from a total of 1,379 herds and 344,883 lactations (one record per animal per lactation) were obtained from the Provincial Veterinary Health File (Dossier Santé Animal – DSA; St-Hyacinthe, Québec). After the process of identifying herds and animals common to both sources (DSA and Québec DHI), DSA extracted health data for only those herds where the matching rate for identified animals was over 90%. The edited DSA dataset was comprised of a total of 591,406 records (including health and reproductive events) for 163,826 animals and 1,106 herds.

To create the integrated datasets with cumulative-lifetime profit information on an individual cow and herd basis, test-day, lactation, breeding-service records and animal information were obtained from Québec DHI. For the statistical analysis only herds and animals with complete data for production, including feed costs (feed advisory is an optional service offered by Québec DHI) and milk revenues were considered. Also the herds selected needed to have reported at least one case of clinical mastitis (**CM**), one case of reproductive problems (**REPR**) and one case of feet and leg problems (**F&L**) each year between the 2000 and 2012 to avoid the inclusion of herds where health events were not reported. A total of 113 herds and a total of 13,668 Holstein animals from the Province of Québec were selected from the integrated dataset.

2.3.1 Construction of the Cumulative Lifetime Values Database

The data for milk quantity-quality, milk components, milk revenue and feed cost were extracted from the Québec DHI test-day files. The data integrated from both Québec DHI and Provincial Animal Health Files was structured as a series of discrete events (date of calving, date of breeding, test-days, etc.) as presented in Table 2.1. All the different variable costs and revenues in the life of the cow were recorded and studied as a succession of events, each having, to some extent, impacts on the following one. All profitability results were calculated using the different revenues and costs at each event date and were cumulated by event dates in a single row. Appendix 1 presents the description of the event date codes. All of the different economic returns and costs were converted into constant Canadian Dollars, to avoid differences in the value of the money over the years, following the methodology described by Statistics Canada Prices (1996). Farm Input Prices Index (**FIPI**) and Farm Product Price Index (**FPPI**) were obtained from the Statistics Canada website (Canada, 2014a, b, c). The methodology for the construction and analysis of constant prices was described by St-Onge (2000).

2.3.2 Costs Included in the Study

To calculate profit, some of the costs involved in the different formulae were estimated using appropriate costs for the province because only milk value and feed cost data were included in the provided datasets. To obtain this estimated cost information different provincial and national sources were consulted.

2.3.2.1 Health Costs. For lists of health costs analyses by Booth *et al.*(2004), Guard (2008) and Lefebvre (2009), among others, were consulted. The working assumptions for health costs for this study are presented in Table 2.2. The health problems included in this study reflect the health events selected in 2007 by the Canadian Dairy Network to be of economic interest in dairy cattle production (Van Doormaal, 2009). For this study direct costs (veterinarian cost, medication, laboratory tests and hand labor) were included. For some health events, milk is required to be discarded during the treatment days and some days afterwards because of the residual effects of the treatment. As reported in the literature (Kossaibati and Esslemont, 1997; Guard, 2008; Ruegg, 2011), the number of days when milk is discarded will depend on the nature of the health event, its severity and the nature of the treatment. For this study if any health problem required milk withdrawal during the treatment and post-treatment period, the working assumption was that the value of the milk was determined by calculating the milk value by day, plus an additional fourteen days of milk revenue. Indirect costs caused by health events such as milk losses and delays in breeding services were not included in this study because these costs are reflected in the cumulative lifetime profitability of the animal, therefore including them would duplicate the cost.

2.3.2.2 Cost of the Heifer at the Moment of First Calving. The cost of raising a heifer to the moment of first calving depends, among other factors, on variations among herd practices and on the fact that not all the animals calve for the first time at the same age. Therefore it was necessary to estimate a factor of variation that reflected real costs according to the current situation in Québec. For this research it was decided to adapt the costs presented by Beauregard (2012). An estimated cost of $3,000 at 24 months of age and $3 per extra day from that moment until the moment of first lactation was calculated in this study.

2.3.2.3 Breeding Services Costs. Based on different reviews (Giguère, 2011; Roy, 2011) the cost of a breeding-service (insemination) was estimated as $70, assuming that the services were hired and the method was artificial insemination. It was observed that for some animals in the dataset that there were no records of breeding-services registered for a recorded calving. If this was the case, the cost of one service was included to account for the service cost of the next calving.

2.3.2.4 Other costs. In Canada milk production is subject to a quota system of supply management where farmers must get permission from government and pay on average $25.000 (in the province of Québec) to produce and sell one kilo of dairy fat per day per year. Given this capital cost, a fat quota opportunity cost was included by charging interest on the market value of fat quota as a marginal cost for the product under quota (Dekkers and Gibson, 1998; Mulder and Jansen, 2001). Variable costs related to hired labor were not included because of variations in management systems. Smaller herds are more likely to use family labor and bigger ones have additional hires: farm size may, therefore, be a useful indicator to be considered in further studies. It is possible to include estimated values for hired labor by kilogram of milk but this would not reflect differences in management among herds. Fixed costs were not included in this study. Different studies have developed profit formulae without these costs, emphasizing mainly the characteristics of the animals (Jagannatha *et al.*, 1998).

2.3.3 Revenues Included in the Study

The most important revenue was milk. This value was obtained from the data supplied by Québec DHI. In addition to milk revenue other returns were also considered. An income for every newborn calf was estimated based on gender. If the animal was born dead the assigned value was $0. Cow salvage value was estimated based on the "Left-herd-reason" variable obtained from the Animal file dataset (Québec DHI) and the last body weight recorded (Québec DHI). If no body weight was recorded, an average weight, specific for each lactation and breed was estimated (St-Onge, 2000).

Prices used to estimate the newborns and salvage values were obtained from the tables published by market data updated by the Fédération des producteurs de bovins du Québec (FPBQ, 2014) and Agriculture and Agri-Food Canada (AAFC, 2014). Returns and costs were computed on a lifetime cumulative basis based on the different revenues and costs recorded at each event date. The methodology used to compute these values was adapted from Kulak *et al.* (1997). If the animals were transferred to other herds, a commercial value was estimated following the tables of AAFC and the last body weight recorded.

2.3.4 Profitability Measures

Different lifetime profitability formulae were computed for this study with two purposes; first to estimate if there were relationships among profitability and selected traits obtained from the integrated database and second, to evaluate if these formulae could be useful as decision-making tools for herd managers and advisors.

Different versions of ROFC, LTP and LTPOC (Table 2.3) were selected and organized into three main classification groups. Group 1 or ROFC shows the return of cumulative milk revenue after deducting cumulative feed cost. Group 2 or LTP presents different variations of LTP including LTP adjusted to birth-date or Net Present Value (**NPV**) and a third one including the estimated fat quota interest. Group 3, LTPOC presents different variations of this formula including adjusted values to birth-date (NVP) and also the estimated fat quota interest. For those formulae that required adjusting values to birth-date, the value was discounted at 3% a year. The interest for the Fat Quota was set at 5% per year, as was the OC for the interest on the capital invested in the fat quota. The value of one kilogram of quota was estimated at the commercial value in Québec ($25,000).

2.3.5 Statistical Analysis

For Model 1 residuals of results of the different profitability formulae were correlated using a Multivariate Analysis of General Linear Methods similar to the study presented by Kulak *et al.* (1997). This correlation analysis was used to understand the relationship among the different profitability measures. Partial correlations were also obtained adjusting for the effect of cumulative milk and cumulative fat production and the random effect of herd and year of cohort.

Model 1 Correlation Analysis Among Profitability Formulae and Profit Related Traits

$$y_{nij} = \mu + Herd_j * Year_i + e_{nij}$$

Where y_{nij} is the *nth* profit measure of the individuals with year of cohort i and in herd j, $Herd_j$ is the effect of herd j on profit measure n, $Year_i$ is the effect of the *ith* cohort-year with the interaction of the *jth* herd on profit measure n, e_{nij} is the residual effect for y_{nij}.

Correlations among selected traits (cumulative milk and cumulative fat) and profitability formulae were tested with a similar model to obtain a matrix of these correlations and then to obtain partial correlations adjusted for milk and fat production with the Correlation Procedure

(Proc Corr) methodology from SAS 9.4.

Age at first calving, Cumulative Days Dry (**cumDD**) as well as Cumulative Days in Milk (cumDIM) and health traits were tested as dependent variables using a Mixed Models analysis that included the random effect of herd-year in the designed statistical model in an attempt to remove any management differences (St-Onge, 2000). The final cumulative values of CM*,* REPR and F&L were tested as independent variables as were AFC*,* **cumDD** and cumDIM as reproduction traits. To determine if a classification model (for cumDD and cumDIM) was necessary, or whether a simpler model with linear and/or quadratic regressions would suffice, an over-parameterized model was fit with both the classification effect of cumDIM and cumDD and linear and quadratic regressions on cumDIM and cumDD. The linear and quadratic effects of these traits as well the fixed-classification effect were tested for statistical significance ($P < 0.05$). To test the statistical significance of these traits on the different Lifetime Profitability measurements, the proposed model was defined as:

Model 2 Effect of different selected traits on profitability formulae

$$y_{nijkml} = \mu + HY_i + AFC_j + cumDIM_k + CumDD_l + \sum_{m=1}^{n} (b_m * HEC_m) + e_{nijkml}$$

Where y_{nijkml} is the profitability measure (LTP and LTPOC) of the *n*th cow, first calving in the *ith* year and herd; HY_i is the random effect of the *ith* herd and year of cohort for the first calving; AFC_j is the fixed effect of the jth Age at first calving; $CumDIM_k$ is the fixed effect of the kth cumulative days in milk; $CumDD_l$ is the fixed effect of the lth cumulative days dry; b_m is the partial regression coefficient of cumulative number of health cases m; HEC_m is the fixed health effect where m1 = REPR, m2 = CM and m3 = F&L; and finally e_{nijkml} is the random error, assumed distributed identically, and independently normal.

The final cumulative records per animal were tested with the previously described model 2. A separate analysis was developed with the cumulative results obtained at the end of the first lactation to test the effect of AFC on profitability at the end of this period (lactation 1).

2.4 RESULTS AND DISCUSSION

The selected animals from these herds were given the opportunity to stay in production for at least four lactations. Because of the truncation effect caused by the impossibility of cohorts after 2009 reaching four lactations, only animals from cohorts from 2000 to 2009 were selected (a total of 10 cohorts).

2.4.1 Construction of the Cumulative Lifetime Dataset

2.4.1.1 Interpolations of Variables by Event Dates with the Integrated Data. To have a clear idea of the impact on profitability of the different health and breeding-services events, the event coded as “INT” (Table 2.1) was inserted the day before the recording of any of these events. The “INT” event shows the results of the cumulative profit variables the day before so that it is easier to understand and visualize how the LTP results are affected every time a health event or a breeding service occurs. As detailed in Table 2.1, on January 28th the selected animal was diagnosed with a case of Cystic Ovary (Event Code = “H”) therefore the interpolated values for milk value, feed cost and profitability measures were calculated for January 27th and included in the dataset with the event code “INT”. The estimated health cost for this event was $55. The daily feed cost for the 28th of January was $7 (from Table 2.1, cumulative feed cost on the 28th – cumulative feed cost on the 27th or $4,264 - $4,257 = $7). The daily milk revenue on the 28th of the same month was $31 ($17,943 - $17,912 = $31). Therefore the Cumulative Profit on the 28th

was the result of $9,704 (LTP of the 27^{th}) minus $7 (daily feed cost) minus $55 (health cost) plus $31 (daily milk revenue) equals to $9,673. Importantly the inclusion of these interpolated events does not affect the cumulative profitability results in the different analyses.

Figure 2.1 presents the curves for LTP and LTP without avoidable losses (costs caused by health events and repeated breeding services) shown in Table 2.1. As can be observed, the "INT" event allows a clearer visualization of the costs of health and breeding services on the cumulative profit which otherwise would not be visible due to their small size compared to the revenues between test day visits (approximately one month). Figure 2.1 shows the LTP and the LTP without the costs caused by health events and repeated breeding services for an animal in the third lactation. Only the different events that occurred during the third lactation are shown in this graph and because of that there is already a gap between both profitability measures. This difference can also be noticed in Table 2.1 (Event date 02/12/2009). By comparing the curves in Figure 2.1, it can be observed how the gap between both curves widened from $140 to $ 1,354 at the end of the third lactation and how with every health event or repeated breeding service this difference increased.

2.4.2 Construction of the Lifetime Profitability Curves

With the integrated datasets we created cumulative lifetime variables for all the profit-related traits, based on the information recorded and accumulated by rows on every event-date. Cumulative feed cost, cumulative milk revenue and lifetime profitability values were accumulated from the moment of first calving and were interpolated on a daily basis until the final recorded event for the animal in order to obtain means, grouped by cohort, by herd and by day of life to benchmark individual results are presented in Figure 2.4. By subtracting Feed-Cost from Milk-Value we obtained cumulative ROFC. Cumulating the information by event date, and interpolating it on a daily basis, allows a user to select information according to any particular interest, e.g. by last day of parity, or last recorded day of productive life, or the first 100 days of productive life, etc.

The costs of the different health events and breeding services were cumulated by lifetime. Figure 2.2 presents a visualization example of the cumulative costs incurred by all the health events and breeding services during the lifetime of an animal. These different events are presented as perpendicular bars to the x axis (age of life in days). By cumulating the costs, it can be observed how, with every breeding-service, the curve for cumulative breeding-services costs rises showing decision-makers the impact of repeated services. A similar situation occurs with the cumulative cost for health events. The combined costs of health events and extra breeding services (if there was more than one service by lactation) were named "extra-cost" and were cumulated to obtain the cumulative extra-cost as a benchmark variable.

The LTP curve for a selected animal is visualized in Figure 2.3, as well as the associated health and reproductive events. The dashed curve represents the potential LTP that could have been achieved in the absence of the extra-costs caused by the health events and the extra breeding-services. In the case presented in Figure 2.3, the difference between LTP and the LTP without the potentially avoidable losses was almost $3,000 at age in days 2,000 (x axis). This difference is explained by a case of retained placenta after the second calving, then repeated cases of clinical mastitis, a case of displaced abomasum after the third calving, followed by a cystic ovary case and finally eighteen extra breeding-services throughout the animal's life (twenty-one recorded inseminations for only three calvings). These curves give herd managers an idea of how the expected profit of one animal is affected by factors that need to be addressed or could be avoided.

2.4.3 Profitability Measures Results and Factors that have an effect on them

2.4.3.1 Profitability Results. Raw means and distribution results of the final cumulative records of the different profitability measures are presented in Table 2.5 by group and by formula. The results of ROFC and LTP (Group 1 and Group 2) showed greater variability compared to the results in Group 3. Similar results were presented by Kulak *et al.* (1997). From Group 2 (Table 2.3) formula 2.3 had the lowest mean, which is due to the interest charged for the Fat Quota. This formula is the most inclusive for this group and it allows the manager to identify if capital invested in year fat-quota is producing at least the return expected at commercial rates of interest. We found that the difference between means of Indexed Lifetime Cumulative Profitability (Formula 2.1) and Indexed Adjusted Lifetime Cumulative Profitability (Formula 2.2) (NPV adjustment to animal birth-date) was $1,051. This difference is explained by the effect of discounting the different returns and costs to the birth-date of the cow (net present value to birth-date) over a period of 51.1 months (from average birth-date to average last recorded age). The $1,051 difference in net present value amounted to 15%, in this period and indicates the importance of time-value of money in making profitability analyses. The effect of NPV adjustments on profitability has already been demonstrated in the literature (Kulak *et al.*,1997; Mulder and Jansen, 2001).

The mean of the fat-quota OC was $2,585 (Table 2.4). The effect of this variable is reflected in the results of LTP by comparing results in Table 2.5. The mean of LTP without the fat-quota OC was $5,479 versus the LTP including the fat-quota OC was $2.894. Decision-makers should be very aware of this cost which represents 25% of the variable costs included in this analysis which, if it had to be paid to external creditors, would reduce the profit margin to cover the fixed costs (not included in this analysis). While the supply management system provides a fixed revenue for the milk value, it also limits the capacity of a farmer to increase the size of the operation or the entrance of new entrepreneurs if there is a limited capacity to buy new quota with their own resources.

From the results of the correlation analysis adjusted for the herd-year cohort effect (Model 1), ROFC and LTP had the highest correlation (0.98 and $P < 0.0001$) while correlation between ROFC and LTP OC was 0.47 ($P < 0.0001$). The formulae from the ROFC group are simple but effective profit measures because they require less data but give a general idea about the overall profit (Bohmanova *et al.*, 2009). However, for detailed analysis of an individual cow, the formulae from the second group should be considered, specifically to test the impact of health or breeding-services costs on a lifetime basis. To consider the performance of the animal within the herd, formulae from the LTPOC Group can be used because they evaluate the marginal contribution of the animal to the herd's profitability or its profitability result compared to the postponed replacement (Van Arendonk, 1991).

2.4.4 Variables with an Effect on Profitability Measures

An important premise of this study was to work with variables that were available for the herd decision maker and were easy to access and analyze. For that reason data selected for this study was obtained from the animal and test-day datasets from DHI as well as the data provided by provincial health file. Usually these variables are registered in the form of a single recorded event or cumulated by lactation. However to analyze their overall lifetime impact, these variables were cumulated in the form of lifetime variables by event date such as cumDD or cumDIM. Using the data from the combined datasets we were interested in studying current results and observing if there was potential for improving profitability, especially due to those variables with negative correlations with profitability. Table 2.4 presents the summary of raw means and distributions for the returns and costs used to calculate the different profitability measures. Cumulative disease cost summarizes the direct costs of all the different health events that were recorded in the dataset and is presented in Table 2.2.

2.4.4.1 The Effect of Age at First Calving on Profitability Measures. Animals with AFC between 21 and 34 months were selected to be included in this study. The average AFC was 26.79 (SD 3.11) months. This result is slightly superior to that currently reported by Valacta (2014) of 26.4 months. This is explained because this study includes ten cohorts of animals, while the results presented by Valacta are for just 2013. The correlation between AFC and LTP was -0.066 ($P < .0001$), which is similar to the result found by Jagannatha *et al.* (1998). The correlation between LTPOC and AFC was also negative (-0. 055 and $P < .0001$). For both profitability measures (LTP and LTPOC) AFC had a better fit as a classification effect (Model 2). Least Square Means for AFC are presented in Table 2.6. It was noticed that the highest LTP result was for animals that calved for the first time at 24 months of age (LSM = \$3,198 ± 36 denominator df = 14,000). The lowest LTP result was for animals that calved for the first time at 34 months (2,581 ± 113). No significant differences were found for LTP results (adjusted Scheffé) among AFC at 24 months and AFC between 21 and 26 months. However animals that calved for the first time after 27 months showed significant negative differences (adjusted Scheffé) in LTP results compared to AFC at 24 months.

Kulak *et al.* (1997) found linear negative effects of AFC on the different Profitability models they tested. Considering that the average age at first calving for Holstein animals in the study was 26.7 months, there is room to improve profit by optimizing AFC, although, the biological constraints cannot be ignored, a study by Pietersma *et al.* (2006) noted that Québec heifers were large enough and heavy enough to be bred at 14 months (Cue *et al.*, 2012).

2.4.4.2 The Effect of Cumulative Days in Milk on Profitability Measures. Correlations between cumDIM and LTP and cumDIM and LTPOC adjusted for milk and fat production were 0.67 (P < .0001) and 0.33 (P < .0001) respectively. Cumulative Days in Milk had a better fit as a class effect in both models for LTP and for LTPOC. The cumulative numbers of days in milk (minimum 1 cumDIM and maximum 1985 cumDIM) were divided in 65 classes with the Proc Rank methodology (SAS 9.4). Table 2.7 presents the least square means and standard errors (including denominator degrees of freedom) for LTP and LTPOC for the first 31 cumDIM groups. As observed in Table 2.7 only animals with at least 422-438 lifetime cumulated days in milk (LSM \$97 ± 108) had positive results for LTP. All the classes that included a lower number of cumDIM showed negative values for LTP. However significant differences (adjusted Scheffé) in LTP results between the class cumDIM 422-438 and classes with a lower number of cumulative days in milk were observed only for cumDIM under 298-311. The difference in LTP between the 422-438 and LTP 298-311 intervals was -\$1,334 ± 145 (adjusted Scheffé P < .0001). Since the average number of days in milk for the first lactation in the province is 350 (Valacta, 2014), these results show that an animal removed from the herd before the end of the first lactation would not reach break-even. These results are consistent with those of Murray (2013) who found that dairy cows only become profitable during the second lactation.

The results for LTPOC (Table 2.7) showed that only animals that were removed from the herd after cumDIM 793-815 days had positive results (LTPOC \$226 ± 101). However differences for LTPOC (adjusted Scheffé) were only significant compared to animals that reached less than or equal to cumDIM range between 537 and 557 (-\$1,264 ± 138 adjusted Scheffé P < .0001). The main reason for the animals in the study leaving the herd before day 770 was production (19.72%) while for animals removed after day 770 the main reasons were mastitis (18.60%) and reproduction problems (16.35%) while production was only 9.44%. These data show that some younger animals were removed because they did not reach the expected production and their marginal contribution to the herd (LTPOC) was negative. It is also important to consider the applicability of the LTPOC measure. This variable compares the animal lifetime profitability result with the regressed result of an average animal in the herd at the same age. Therefore it is expected that the animal will be removed from the herd only when its performance is below $0 (animal's performance minus average herd animal performance) and not when the performance is positive.

2.4.4.3 Cumulative Days Dry and Profitability. For this study, lifetime cumulative days dry had a better fit as a class effect after testing with over-parameterized models and the cumulative number of days dry was divided into 15 classes. The objective was to test the impact of the total number of days when there was no production of milk on overall lifetime profitability. The correlation of cumDD adjusted for milk (kg) and fat (kg) with LTP was 0.15 ($P < .0001$) and with LTPOC was -0.47 ($P < .0001$). Least square means for LTP and LTPOC for the cumDD are presented in Table 2.8. The highest LTP results were for animals in the interval between cumDD 58-62 ($3,522 ± 52). Animals with more than cumDD 73-96 had significant differences (adjusted Scheffé) in LTP compared to the cumDD 58-62 interval.

One important aspect to consider is the balance between lifetime cumulative days in milk and cumulative number of days dry in order to optimize profitability. The need for optimizing the number of days dry was also found in a review of literature by Plaizier *et al.* (1997). In this study the effect of days dry on profit estimated that the reduction in profit varied between $0.40 to $3.60 per cow per extra day dry. It is clear that an excessive number of days dry has a negative effect on profit. However it is important to find the balance that will allow the animal to recover adequately for the next lactation without incurring avoidable losses (excessive number of days dry). Also a study by Santschi *et al.* (2011) testing 35 versus 60 days dry showed how shorter dry periods would be a more appropriate management strategy for today's high-producing dairy cows.

2.4.4.4 Health Events and Profitability. To compute the cumulative health events, different criteria were established to cumulate the different events and separate one from another (date of occurrence, time between events, source etc.) in order to avoid double counting (Kelton *et al.*, 1998). Correlations adjusted for cumulative milk and cumulative fat between LTP and REPR, CM and F&L were -0.08, -0.10 and -0.04 respectively ($P < .0001$). Partial correlations between LTPOC and health events adjusted for cumulative milk and cumulative fat were all negative and significant ($P <. 0001$) -0.10 for REPR, -0.15 for CM and -0.082 for F&L problems.

Classification and linear effects were tested for CM, REPR and F&L. Cumulative Reproductive Problems (REPR) had a significant linear fixed effect ($P < .0001$) on LTP and LTPOC. Estimated regression coefficients were -\$260 ± 21 for LTPOC and -\$366 ± 20 for LTP. Cumulative Feet & Legs Problems (F&LP) also had a significant linear fixed effect ($P < .0001$) on LTP and LTPOC. Partial regression coefficients were -\$217 ± 20 and -\$137 ± 19 respectively. Cumulative Clinical Mastitis (CM) had a significant linear fixed effect ($P < .0001$) on LTP and LTPOC and partial regression coefficients were -\$311 ± 16 and -\$178 ± 15 respectively (Table 2.9). No quadratic significant effects were found for health events in this study, however, Kulak *et al.* (1997) found clinical mastitis to have a significant quadratic effect on profitability if herd life (DPL) was excluded from the model. The difference in the results between this study and Kulak's could be explained by the methodology. Kulak tested the average number of mastitis and reproduction treatments per lactation while in this study we tested the cumulative number of health episodes from first calving to culling or the end of the fourth lactation.

Different studies with different methodologies have calculated the cost impacts caused by CM, F&L and REPR (Seegers *et al.*, 2003, Guard, 2008, Huijps *et al.*, 2008). The study presented by Huijps *et al.* (2008) about facts and perceptions of mastitis concluded that producers do not have a clear idea of the overall impact of mastitis. One of the objectives of this study was to find significant variables that have an effect on profitability and for that reason the average cumulative number of health events for CM, REPR and F&L during the lifetime of an animal was tested.

Considering the negative impact these health events have on profitability measures, constant monitoring of these events is required not only to provide specific attention to the animals but also to make important decisions about their stayability in the herd. A study by Heikkilä *et al.* (2012) on mastitis costs developed with a dynamic optimization model recommended treating cows with CM and keeping them in most cases until their fifth lactation. However in a Fat Quota model like the one we have in Canada it is very important to balance the two components, productive lifetime and herd marginal contribution. Early culling could affect profitability while keeping animals below the OC of postponed replacement for a long time could also affect herd efficiency and therefore profitability.

2.4.5 Applicability of LTP and LTPOC Curves for Decision Making Purposes

One of the potential uses of LTP and LTPOC curves in the process of decision-making is to visualize the profit results of one animal during its productive lifetime. The integrated datasets allow the calculation of LTP and LTPOC for any selected animal during its lifetime starting from the moment of first calving. Figures 2.4 and 2.5 present an example of visualization curves of LTP and LTPOC of an individual animal calculated by event date. Figure 2.4 shows the individual cow LTP compared to the herd mean LTP and the 90th and 10th percentiles data distribution curves (dashed lines). Figure 2.5 presents LTPOC for the same animal during the same period of time. As observed in Figure 2.4 the LTP performance of an individual cow can be benchmarked against the herd results and the herd-manager can monitor with this curve if the animal is reaching goals in terms of expected profit stated in terms of NPV. In Figure 2.5, the LTPOC curve allows the visualization of the marginal contribution of the animal to the herd. Average LTPOC tends to zero therefore if the curve presenting the profit of the animal is above zero, then the marginal contribution was positive. On the contrary if the analyzed situation is similar to that presented in Figure 2.5, where the contribution of the animal to herd profitability was below zero after the second lactation then the marginal contribution to the herd was negative. With a visualization tool, the herd manager would understand in a very simple way that those resources allocated to that specific animal could potentially be used in a more efficient way. For instance, if by the end of the second lactation the animal is underperforming, the animal could be flagged for potential culling. For the animal in Figure 2.5, the animal started underperforming at the beginning of the second lactation when the animal was affected by a retained placenta episode, followed by clinical mastitis. By the end of the second lactation the LTPOC result was -$2,000, however, the decision maker retained the animal for another cycle after the animal got pregnant at the eighth insemination attempt (Figure 2). Also at that time the difference between the LTP and the LTP without the avoidable cost was approximately $2,000 (about 1,700 days of age). During the beginning of the third lactation the animal was affected by an episode of displaced abomasum and after day of age 1,800 the LTPOC was under $3,000 (Figure 2.5). By observing the history of lifetime events of this particular animal (Figure 2.2) there were six more attempts to inseminate this animal during the third lactation without any success. Even if the producer decided to keep the animal for the third lactation, the decision to inseminate the animal was not the best one given its under performance (-$3,000 marginal contribution) and adding six more inseminations at an estimated cost of $70 each compounded the error. This type of decision-making supports the conclusion of Grohn and Rajala-Schultz (2000) about the need to have a valid estimation of the profitability of the animals considering factors such as age, production and lactation level, reproductive status and disease history in order to make rational decisions. The visualization of this information as presented in Figures 2.2, 2.3, 2.4 and 2.5 can show the producer a perspective that will help in the process of decision making. In other words in the absence of these curves, the herd manager does not have a resource that presents the LTP results and related factors by individual animal compared to the herd.

The use of the combined profitability formulae could provide useful information about the moment an animal should leave the herd. The LTPOC concept was initially proposed by Van Arendonk (1991) who identified the importance of being aware of removing the animals from the herd at the moment their production was below the profit of the average replacement. The replacement of the animal would be independent of the number of days in productive life. This conclusion was also supported by further studies (De Haan *et al.*, 1992; Weigel *et al.*, 1995). The use of the LTPOC formula with the regressed OC of the postponed replacement, as developed in this study, facilitates more suitable comparisons in those herds with insufficient numbers of animals to compare as proposed by (De Haan *et al.*, 1992).

In Figure 2.5 the LTPOC curve shows how the underperformance of the animal continued from day of life 1,200 to 2,100, or 900 days of negative performance until the animal was finally culled. The literature presents different points of view on this culling decision. As suggested by

(Jagannatha *et al.*, 1998) herd life could be overestimated by about 2.5 times when profit replacements were ignored. In contrast, other studies have recommended treating and keeping animals up to the fifth lactation instead of replacing them as concluded by Heikkilä *et al.* (2012) about animals affected with clinical mastitis. According to Murray (2013) the producer should make decisions on keeping or culling cows based on profitability, however sometimes it is necessary to consider situations when unprofitable cows are kept in the herd, such as in cases of poor reproductive performance, poor calf survival or late age at first calving.

As a consequence producers sometimes receive contradictory advice from different sources, leading to a low adoption rate of any measures. Literature on the efficacy of management measures mostly gives general advice, which is not applicable to a specific farm situation (Huijps, 2009). However the development of information systems, with dynamic programming techniques and with the improvement of the collection and management of data, has improved the availability of resources to help producers make better decisions and reach their own conclusions based on evidence.

An example of these information systems is the model to help Dutch producers estimate their costs caused by mastitis developed by the University of Utrecht (Huijps *et al.*, 2008). Cabrera (2012) from the University of Wisconsin developed a dynamic tool to help producers to assess the economic value of cow considering among other factors the age and the value of a new pregnancy in order to make decisions regarding culling. Kristensen *et al.* (2008) developed a meta-model using routinely collected management data to predict financial performance related to specific management changes in individual dairy herds characterized by certain technical performance indicators. A complex long-term simulation experiment was used to estimate the financial performance.

In synthesis with the help of dynamic programming or based on empirical methods producers have different resources to help them quantify the impact of health events on profitability and to help them estimate the value of an animal before flagging it for culling. In spite of the availability of these systems, to optimize the herd life process, it is also important to monitor the current profitability results of the animals in production, to benchmark them against the herd results and to identify factors affecting profitability in order not only to make decision about the current animals but also to set criteria and action plans for the future.

With this retrospective cohort-year study it was intended to explore how the selected variables have an effect on the cumulative lifetime profitability and therefore it was decided to include as many cohorts as possible for as long a time as possible (10 cohort-years of animals given the opportunity to stay in herd for at least four lactations). The cumulative lifetime results of these animals with complete information were also necessary to transform the data into visualization curves and observe if the variations in profitability caused by the analyzed variables could help decision makers understand their effects. As an outcome of this first exploratory study, it is expected that pilot project will be developed where the analysis of these variables as visualization curves will be included in a profitability report. For the pilot project, it is expected to test the use of these curves using those herds from DHI that collect and report complete data. However with the visualization results obtained in this study, we expect to demonstrate to DHI users the importance of accurately recording and reporting health and reproduction events in order to have a clear idea of their effects on profitability and their importance as decision making tools.

As a consequence of the conditions required to select the herds for this study, it is possible that there might be variations in management and production performance results of these herds compared to the original database. However, as discussed previously, the results and behavior of the different selected variables in this subset of herds were similar as those reported in the literature and the Valacta (2014) reports. An important outcome of this study is the integrated dataset, which was designed in a way that allows filtering and selecting herds and animals depending on the objectives and criteria of the study. It is expected that the integrated information will serve as the basis of future analyses.

The information used in this study was derived from the regular data obtained from a herd in a routine visit of the DHI advisor or the Veterinarian. Therefore it could be possible to include in the DHI report a sub-report on profitability combining both formulae (LTP and LTPOC), which would show not only the profit results but also how different factors, such as health and/or reproduction costs have an effect on profitability as it was demonstrated in this study. For example, an animal with multiple episodes of clinical mastitis might still be profitable, but is it underperforming compared to a replacement animal? What is the lowest level of underperformance acceptable before considering replacement? To answer these questions and others like them designing visualization curves showing the cumulative returns, costs and profit by day of life with their respective benchmarks would be a great help for farm managers and advisors in making optimal decisions in order to maximize profit.

2.5 CONCLUSIONS

The combined use of LTP and LTPOC results could help dairy producers in the difficult process of decision making by including relevant variables that affect profitability such as the cumulative number of clinical mastitis, reproductive and feet and legs problems. The direct costs caused by these health events and their impact on profit can be monitored by decision-makers with the use of simple visualization curves.

Animals that calved for the first time after 27 months of age showed a significantly lower LTP compared to animals that calved at 24 months of age. This gives producers and opportunity to increase profit given that the current age at first calving in the province is 26.4 months.

The break-even point for the variable costs included in this analysis is only reached after at least 422 cumDIM. This means that animals removed from the herd before the second lactation produce a negative return affecting the herd profit goals.

This project was developed with integrated information datasets with data collected in the herds of Québec for more than 10 years and integrate health and production. This information was the main supply of information not only for this study but will be of use for future analysis on this topic and on different topics related to production, health, management and genetics.

Acknowledgements

The authors of this study want to thank the Fonds de Recherche Québécois en Nature et Technologies (FRQNT), Novalait, the Ministère de l'Agriculture, des Pêcheries et de l' Alimentation du Québec (MAPAQ) and Agriculture and Agri-Food Canada for funding support, DHI Valacta and to the Dossier Santé Animale (DSA) for providing the data and also to the Hugh Blair Scholarship for providing funding to Hector Delgado.

Table 2.1 Fragment of cumulative feed cost, milk revenues and profitability and other costs recorded by event dates for an animal in the third lactation, including event and health codes. 2012 CDN$

Event Date	Event Code	Health Code	Age Days	Cumulative Feed Cost	Health Cost	Discarded Milk	Service Cost	Cumulative Milk Value	Lifetime Profit	Profit Without Avoidable Losses
02/12/2009	S		1,632	3,860				16,322	8,746	8,887
02/12/2009	H	DISPLACED ABOMASUM	1,632	3,860	236			16,322	8,511	8,887
15/01/2010	TD		1,676	4,179				17,544	9,414	9,790
27/01/2010	INT		1,688	4,257				17,912	9,704	10,080
28/01/2010	H	CYSTIC OVARY	1,689	4,264	55			17,943	9,673	10,104
16/02/2010	TD		1,708	4,388				18,525	10,131	10,562
07/03/2010	INT		1,727	4,522				19,167	10,639	11,070
08/03/2010	I		1,728	4,529			70	19,201	10,596	11,027
18/03/2010	TD		1,738	4,600				19,539	10,863	11,294
17/04/2010	INT		1,768	4,807				20,484	11,601	12,032
18/04/2010	I		1,769	4,814			70	20,516	11,556	12,057
19/04/2010	I		1,770	4,821			70	20,548	11,511	12,082
27/04/2010	TD		1,778	4,876				20,800	11,708	12,279
30/05/2010	INT		1,811	5,097				21,832	12,519	13,090
31/05/2010	H	CYSTIC OVARY	1,812	5,104	55			21,863	12,488	13,114
04/06/2010	TD		1,816	5,131				21,988	12,586	13,212
17/06/2010	INT		1,829	5,211				22,367	12,885	13,511
18/06/2010	I		1,830	5,217			70	22,396	12,838	13,534
19/06/2010	I		1,831	5,223			70	22,425	12,791	13,557
16/07/2010	TD		1,858	5,390				23,213	13,412	14,178
20/07/2010	INT		1,862	5,416				23,321	13,494	14,260
21/07/2010	H	CYSTIC OVARY	1,863	5,422	55			23,348	13,460	14,281
12/08/2010	TD		1,885	5,564				23,941	13,911	14,732
24/08/2010	INT		1,897	5,641				24,232	14,125	14,946
25/08/2010	I		1,898	5,648			70	24,256	14,072	14,963
26/08/2010	I		1,899	5,654			70	24,280	14,020	14,981
16/09/2010	TD		1,920	5,788				24,789	14,395	15,356
19/09/2010	INT		1,923	5,806				24,847	14,435	15,396
20/09/2010	H	CLINICAL MASTITIS	1,924	5,812	124			24,866	14,324	15,409
04/10/2010	DM		1,938	5,896		276		25,135	14,240	15,594

Table 2.2 Summary of the different variable costs included to compute cost by event for the selected health issues recorded in the integrated dataset, including number of days for discarded milk if required. 2012 CDN$

	Milk Fever	Dystocia	Reproductive Problems (REPR)	Ketosis	Displaced Abomasum	Clinical Mastitis (CM)	Feet & Legs Problems (F&L)
Veterinarian costs	$25.00	$38.00	$7.00	$5.00	$106.00	$25.00	$35.00
Associated Labor	$11.00	$22.00	$16.00	$16.00	$22.00	$19.00	$11.00
Medicine costs	$20.00	$30.00	$15.00	$15.00	$10.00	$40.00	$20.00
Laboratory analyses			$10.00			$10.00	
Discarded milk?	No	Yes	Yes	No	Yes	Yes	Yes
Treatment and withdrawal period (days)		14	14		14	14	14

Table 2.3 Different profitability groups and description of the profitability formulae (indexed and with net present value to birth date adjustment) included in this study

Group	Formula	Description	Sources
1-Margin Over Feed Cost (ROFC)	1.1- ROFC	Cumulative milk revenue minus cumulative feed cost (Indexed Prices)	Valacta (2011), Van Arendonk (1991)
	1.2- ROFC (Net Present Value - NPV) [a]	Cumulative milk revenue minus cumulative feed cost (Indexed Prices and Adjusted to Birth Date)	
2- Cumulative Lifetime Profit (LTP)	2.1- LTP	Cumulative returns minus cumulative variable costs, except quota interest (Indexed Prices)	Balaine *et al.* (1981), Kulak *et al.* (1997), Mulder and Jansen (2001)
	2.2- LTP (NPV) [a]	Cumulative returns minus cumulative variable costs, except quota interest (Indexed Prices and Adjusted to Birth Date)	
	2.3- LTP (NPV, quota interest)[a]	Cumulative returns minus cumulative variable costs, including fat quota interest (Indexed Prices and Adjusted to Birth Date)	
3-Cumulative Lifetime Profit adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC)	3.1- LTPOC [b]	Cumulative Lifetime Profitability minus Regressed Average Cumulative Lifetime Profitability of the Herd (Indexed Prices)	De Haan *et al.* (1992), Weigel *et al.* (1995), Kulak *et al.* (1997)
	3.2- LTPOC (NPV) [a-b]	Cumulative Lifetime Profitability minus Regressed Average Cumulative Lifetime Profitability of the Herd (Indexed Prices and Adjusted to Birth Date)	
	3.3- LTPOC (NPV, quota interest)[a-b]	Cumulative Lifetime Profitability – minus Regressed Average Cumulative Lifetime Profitability of the Herd, including fat quota interest (Indexed Prices and Adjusted to Birth Date)	

[a] Adjusted to net present value (NPV) evaluates profitability of the dairy cow acknowledging that costs and revenues occur at different times during a cow's lifetime. Discounting allows for comparison of profits of cows at a common base time, which is an important characteristic of a profit measure, Kulak *et al.* (1997).

[b] Regressed opportunity cost used regressed means for LTP and days of productive life because of the large number of herd-year of first calving cohorts that contained few cows as posed by De Haan *et al.* (1992).

Table 2.4 Raw means and distribution results of the different returns and variable costs included in this study to compute the different profitability measures. Results for 113 herds and 13,668 animals. 2012 CDN$

	Variable	Mean	Standard Deviation	Minimum	Maximum
Revenues	Cumulative Milk revenue	13,173	8,849	0	58,774
	Salvage Value	701	198	0	1,190
	Cumulative Calves Value	300	145	0	556
Variable Costs	Heifer Cost	3,227	234	2,726	3,912
	Cumulative Feed Cost	3,591	2365	0	14,365
	Cumulative Disease Cost	411	560	0	4,842
	Cumulative Service Cost	413	281	70	2,310
	Quota Interest	2,585	1,395	0	7,682

Table 2.5 Raw means and distribution results of the different profitability formulae variations by groups included in this study. Results for 113 herds and 13,668 animals. 2012 $CDN

Group	Formula	Mean	Standard Deviation	Minimum	Maximum
1-Margin Over Feed Cost (ROFC)	1.1- ROFC	9,559	6,586	-988	44,409
	1.2- ROFC (Net Present Value)[a]	8,175	5,410	-966	34,955
2- Cumulative Lifetime Profit (LTP)	2.1- LTP	6,530	6,348	-4,313	40,419
	2.2- LTP (NPV)[a]	5,479	5,301	-3,983	31,837
	2.3- LTP (NPV, fat quota interest)[a]	2,894	4,114	-5,284	24,931
3-Cumulative Lifetime Profit adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC)	3.1- LTPOC[b]	-128	1,954	-8,477	10,714
	3.2- LTPOC (NPV)[a-b]	-66	1,682	-6,713	9,741
	3.3- LTPOC (NPV, fat quota interest)[a-b]	-131	2,061	-7,538	12,811

[a] Adjusted to net present value (NPV) evaluates profitability of the dairy cow acknowledging that costs and revenues occur at different times during a cow's lifetime. Discounting allows for comparison of profits of cows at a common base time, which is an important characteristic of a profit measure, Kulak *et al.* (1997).

[b] Regressed opportunity cost used regressed means for LTP and days of productive life because of the large number of herd-year of first calving cohorts that contained few cows as posed by De Haan *et al.* (1992).

Table 2.6 Least square means and standard errors for Cumulative Lifetime Profitability (LTP) and Cumulative Lifetime Profitability Adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC) by Age at First Calving (AFC). 2012 $CDN

	LTP		LTPOC		
Age at First Calving	Estimated Value	Standard Error	Estimated Value	Standard Error	Degrees of Freedom
21	2,938	215	-817	207	14,000
22	3,171	126	-761	122	14,000
23	3,140	59	-1,067	57	14,000
24	3,198	36	-1,071	34	14,000
25	3,148	34	-1,075	33	14,000
26	3,085	35	-1,086	34	14,000
27	3,016	41	-1,157	39	14,000
28	2,924	46	-1,250	44	14,000
29	2,801	54	-1,316	53	14,000
30	2,874	62	-1,223	60	14,000
31	2,755	76	-1,356	73	14,000
32	2,783	84	-1,207	81	14,000
33	2,561	99	-1,201	95	14,000
34	2,581	113	-1,201	95	14,000

Table 2.7 Least square means and standard errors for Cumulative Lifetime Profitability (LTP) and Cumulative Lifetime Profitability Adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC) presented by Cumulative Days in Milk (cumDIM) intervals. 2012 $CDN

	LTP		LTPOC		
Cumulative Days in Milk	Estimated Value	Standard Error	Estimated Value	Standard Error	Degrees of Freedom
258-281	-1,737	113	-3,350	110	14,000
282-297	-1,370	111	-2,603	107	14,000
298-311	-1,237	110	-2,604	106	14,000
312-325	-1,103	109	-2,599	105	14,000
326-339	-1,048	108	-2,635	105	14,000
340-352	-968	109	-2,545	105	14,000
353-368	-720	109	-2,408	105	14,000
369-384	-689	109	-2,526	105	14,000
385-402	-330	108	-2,165	104	14,000
403-421	-184	106	-1,952	102	14,000
422-438	97	108	-1,951	104	14,000
439-456	273	106	-1,801	102	14,000
457-475	389	106	-1,691	102	14,000
476-495	640	105	-1,680	101	14,000
496-516	996	106	-1,465	102	14,000
517-536	1,153	102	-1,315	99	14,000
537-557	1,554	106	-978	102	14,000
558-578	1,710	106	-1,116	102	14,000
579-598	1,920	103	-1,014	99	14,000
599-616	2,197	102	-731	99	14,000
617-634	2,467	101	-733	98	14,000
635-651	2,554	104	-615	100	14,000
652-669	2,846	99	-566	95	14,000
670-686	3,178	102	-328	98	14,000
687-705	3,194	101	-520	97	14,000
706-725	3,425	101	-261	97	14,000
726-745	3,649	104	-157	100	14,000
746-769	3,932	101	-145	98	14,000
770-792	4,168	105	-50	101	14,000
793-815	4,554	101	226	97	14,000
816-840	4,817	102	296	99	14,000

Table 2.8 Least square means and standard errors for Cumulative Lifetime Profitability (LTP) and Cumulative Lifetime Profitability Adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC) presented by classification intervals for Cumulative Days Dry (cumDD). 2012 $CDN

	LTP		LTPOC		
Cumulative Days Dry	Estimated Value	Standard Error	Estimated Value	Standard Error	Degrees of Freedom
1-43	3,445	68	-25	65	14,000
44-52	3,447	60	-26	58	14,000
53-57	3,427	61	2	58	14,000
58-62	3,522	62	-17	60	14,000
63-72	3,436	62	-97	60	14,000
73-96	3,107	60	-838	58	14,000
97-110	2,898	64	-1,374	61	14,000
111-121	2,945	62	-1,396	60	14,000
122-138	2,880	64	-1,549	61	14,000
139-162	2,555	64	-2,077	62	14,000
163-182	2,425	68	-2,443	65	14,000
183-209	2,181	72	-2,725	69	14,000

Table 2.9 Estimated regression coefficients and standard errors for average cumulative Clinical Mastitis (CM), Reproductive Problems (REPR) and Feet and Legs Problems (F&L) for Cumulative Lifetime Profitability (LTP) and Cumulative Lifetime Profitability Adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC)

	Health Problem	Estimate	Standard Error	Degrees of Freedom of the Denominator	t value	Pr > |t|
	CM	-311	16	14,000	-20	<.0001
LTP	REPR	-366	22	14,000	-17	<.0001
	F&L	-217	20	14,000	-11	<.0001
	CM	-178	15	14,000	-12	<.0001
LTPOC	REPR	-260	21	14,000	-13	<.0001
	F&L	-137	19	14,000	-7	<.0001

Figure 2.1 Effect of different health episodes and repeated breeding services costs on Cumulative Lifetime Profitability, presented as a curve interpolated by event-dates, compared to the Cumulative Lifetime Profitability curve without computing health and repeated breeding costs for an animal in the third lactation

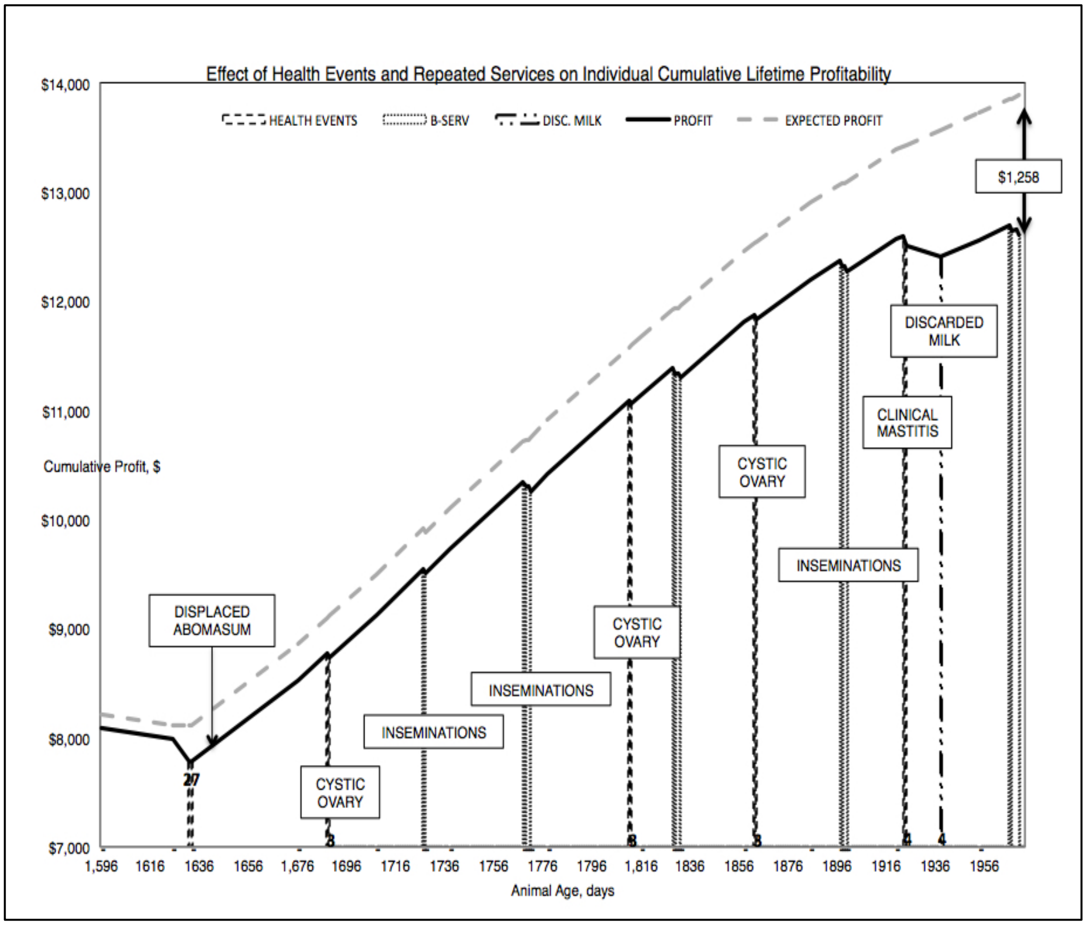


Figure 2.2 Curve of cumulative costs caused by different health events and by cumulative repeated inseminations costs, denominated as "extra-cost"curve, and also separate curves for health events costs and breeding services costs cumulated by event-dates and by lifetime of a dairy cow.

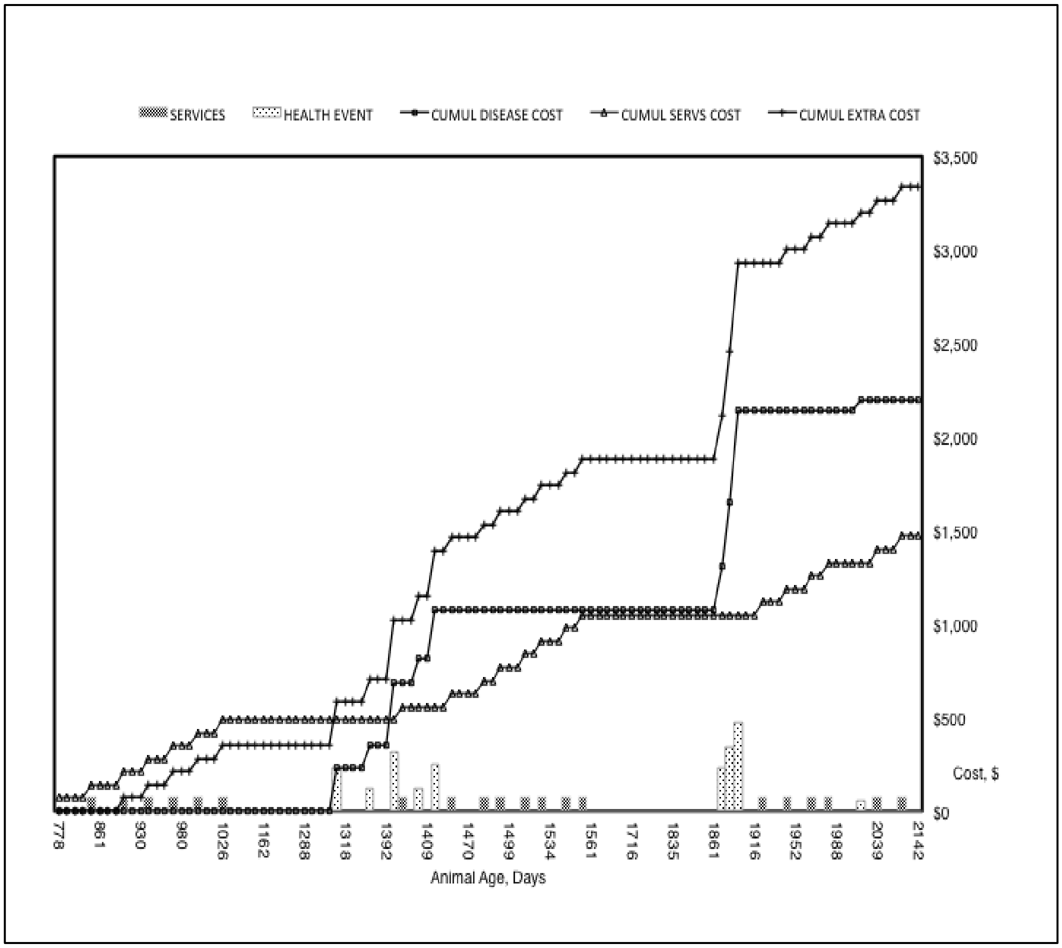


Figure 2.3 Curves of the Cumulative Lifetime Profitability (LTP) for an individual animal interpolated by day of life including the effect of multiple breeding services and health events costs and compared to the LTP curve without these costs

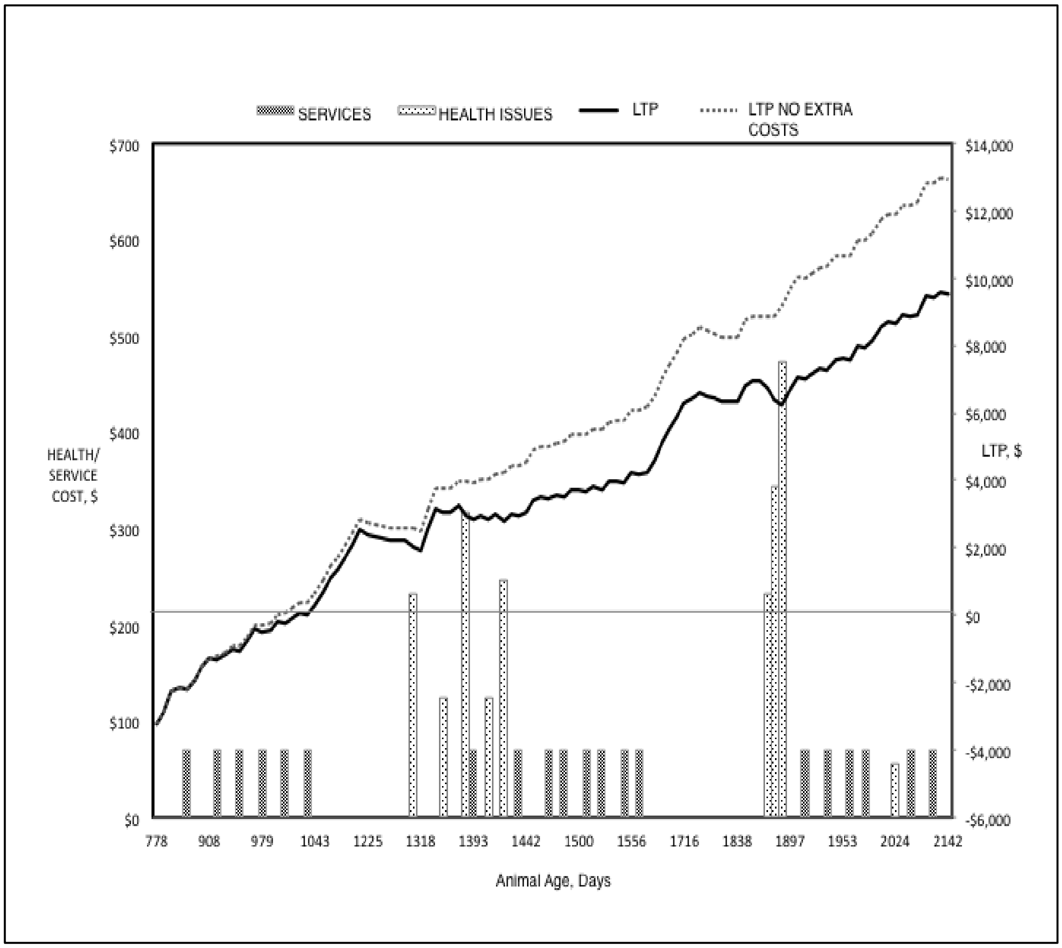


Figure 2.4 Cumulative Lifetime Profitability (LTP) curve interpolated by day of life of an animal within a herd and benchmark curves of the average herd LTP interpolated by day of life and the respective top 90% and bottom 10% distribution curves (dashed lines)

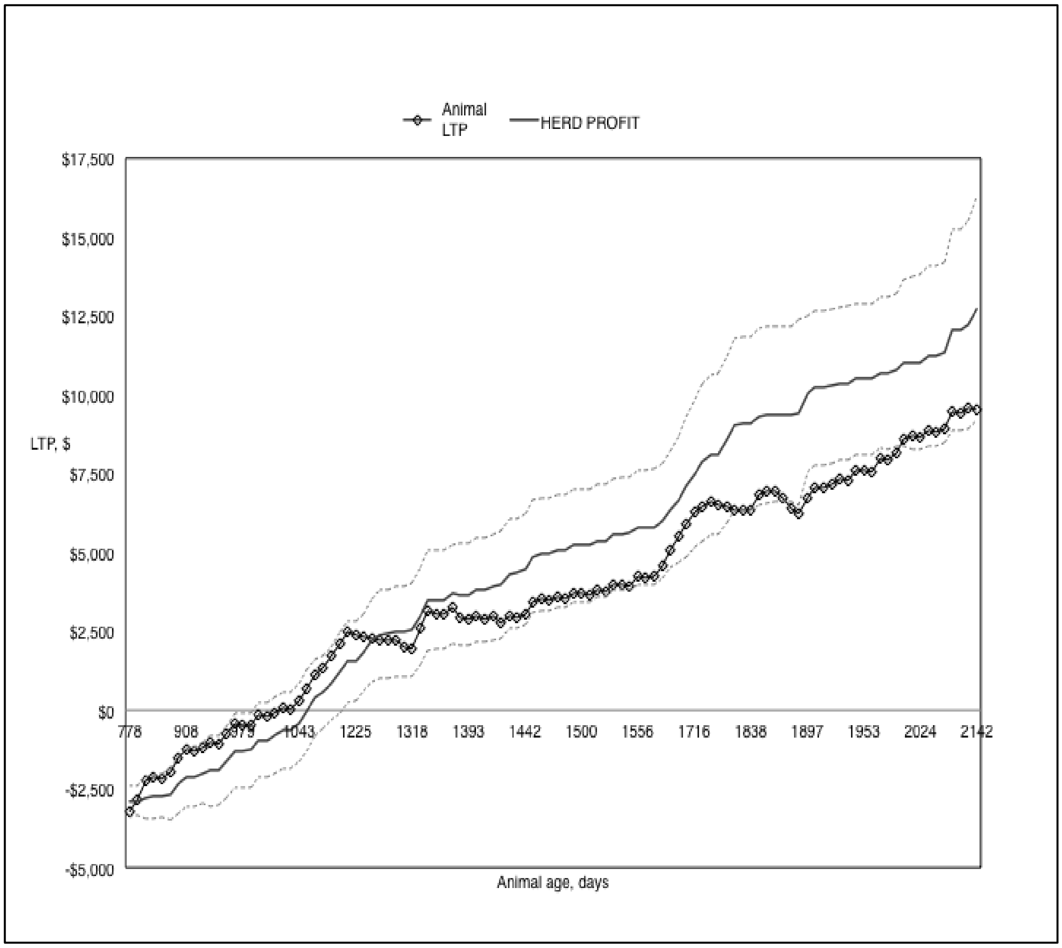
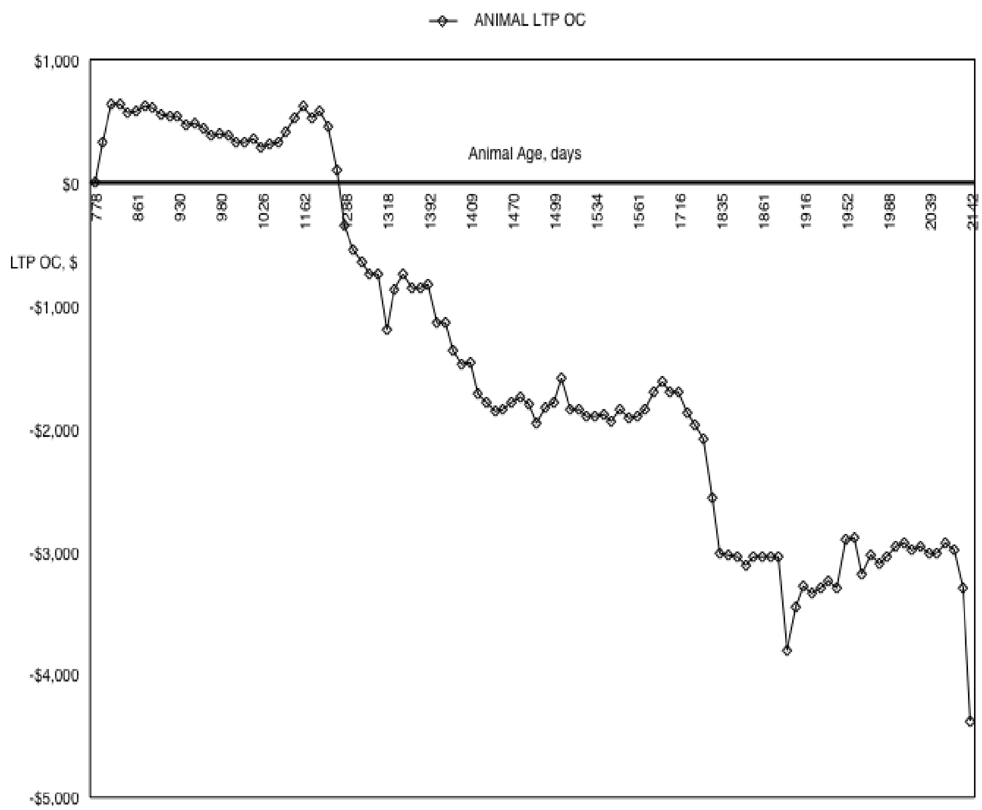


Figure 2.5 Cumulative Lifetime Profitability adjusted for the Regressed Opportunity Cost of the Postponed Replacement (LTPOC) curve interpolated by day of life of a cow during her productive life



2.6 REFERENCES

Agriculture and Agri-Food Canada. 2014. Slaughter reports. Statistcs and Market Information Service. Accessed Oct. 13, 2014. http://www.agr.gc.ca/redmeat-vianderouge/sla-aba_eng.htm

Atzori, A. S., L. O. Tedeschi, and A. Cannas. 2013. A multivariate and stochastic approach to identify key variables to rank dairy farms on profitability. J. Dairy Sci. 96:3378-3387.

Beauregard, G. 2012. Élever une taure laitière coûte maintenant plus de 3000 dollars …! Octobre 2012 ed, Agri-Nouvelles. http://issuu.com/dominic.simard/docs/60914_agrinouv_oct12_appro_haute

Beck, T. 2008. How Does Cost Efficiency Affect Farm Profitability?. Accessed June 5 2012. http://www.das.psu.edu/research-extension/dairy/capitalregion/news/df-200712-01

Bhowmik, B. 2010. Dynamic Programming–Its Principles, Applications, Strengths, and Limitations. International Journal of Engineering Science and Technology 2:4822-4826.

Bohmanova, J., F. Miglior, J. Jamrozik, B. J. Van Doormaal, K. J. Hand, and D. Lazenby. 2009. Genetic analysis of return over feed in Canadian Holsteins. Animal 4:173.

Booth, C. J., L. D. Warnick, Y. T. Gröhn, D. O. Maizon, C. L. Guard, and D. Janssen. 2004. Effect of lameness on culling in dairy cows. J. Dairy Sci. 87:4115-4122.

Cabrera, V. E. 2012. A simple formulation and solution to the replacement problem: A practical tool to assess the economic cow value, the value of a new pregnancy, and the cost of a pregnancy loss. J. Dairy Sci. 95:4683-4698.

Canada, S. 2014a. Farm Input Price Index (FIPI). Definitions, data sources and methods. Accessed Sept. 7, 2014. http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getInstanceList&SDDS=2305&InstaId=14940&SurvId=65019

Canada, S. 2014b. Prices and Price Indexes. Statistics by Subject. Accessed Sept. 7, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=3956&lang=eng&id=998&more=0&type=ARRAY&pageNum=1

Canada, S. 2014c. Statistics by subject, Livestock and acquaculture. Farm financial statistics. Accessed Oct. 10, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=920&id=2553&lang=eng&type=ARRAY&pageNum=1&more=0

Cha, E., D. Bar, J. A. Hertl, L. W. Tauer, G. Bennett, R. N. Gonzalez, Y. H. Schukken, F. L. Welcome, and Y. T. Grohn. 2011. The cost and management of different types of clinical mastitis in dairy cows estimated by dynamic programming. J. Dairy Sci. 94:4476-4487.

Cue, R., D. Pietersma, D. Lefebvre, R. Lacroix, K. Wade, D. Pellerin, A. de Passillé, and J. Rushen. 2012. Growth modeling of dairy heifers in Québec based on random regression. Can. J. Anim. Sci. 92:33-47.

De Haan, M. H. A., B. G. Cassell, R. E. Pearson, and B. B. Smith. 1992. Relationships between net income, days of productive life, production, and linear type traits in grade and registered Holsteins. J. Dairy Sci. 75:3553-3561.

Dekkers, J. C. M. and J. P. Gibson. 1998. Applying breeding objectives to dairy cattle improvement. J. Dairy Sci. 81:19-35.

Enting, H., D. Kooij, A. A. Dijkhuizen, R. B. M. Huirne, and E. N. Noordhuizen-Stassen. 1997. Economic losses due to clinical lameness in dairy cattle. Livest. Sci. 49:259-267.

Fleischer, P., M. Metzner, M. Beyerbach, M. Hoedemaker, and W. Klee. 2001. The relationship between milk yield and the incidence of some diseases in dairy cows. J. Dairy Sci. 84:2025-2035.

FPBQ. 2014. Fédération des producteurs de bovins du Québec, Prices-Info. Page Market data updated by the Fédération des producteurs de bovins du Québec. Accessed Sep. 9, 2014. FPBQ. http://www.bovin.qc.ca/en/price-info/cull-cattle-and-bob-calves/daily.php

Geary, U., N. Lopez-Villalobos, N. Begley, F. McCoy, B. O'Brien, L. O'Grady, and L. Shalloo. 2012. Estimating the effect of mastitis on the profitability of Irish dairy farms. J. Dairy Sci. 95:3662-3673.

Giguère, M. 2011. Inséminer ou comment augmenter ses performances. in Élevage. Portal Agricole du Quebec, La Terre de chez nous. http://www.laterre.ca/elevage/inseminer-ou-comment-augmenter-ses-performances/

Grohn, Y. T. and P. J. Rajala-Schultz. 2000. Epidemiology of reproductive performance in dairy cows. Anim. Reprod. Sci. 60-61:60-61.

Guard, C. 2008. The costs of common diseases of dairy cattle (Proceedings). In Proceedings of the Central Veterinary Conference West, San Diego, Ca. Accessed Oct. 08 2013. http://veterinarycalendar.dvm360.com/avhc/Veterinary+Food+Animal/The-costs-of-common-diseases-of-dairy-cattle-Proce/ArticleStandard/Article/detail/586496

Hadley, G. L., C. A. Wolf, and S. B. Harsh. 2006. Dairy Cattle Culling Patterns, Explanations, and Implications. J. Dairy Sci. 89:2286-2296.

Heikkilä, A. M., J. I. Nousiainen, and S. Pyörälä. 2012. Costs of clinical mastitis with special reference to premature culling. J. Dairy Sci. 95:139-150.

Huijps, K. 2009. Economic decisions in mastitis management. Dissertation Faculty of Veterinary Medicine. Utrecht University, the Netherlands.

Huijps, K., T. J. G. M. Lam, and H. Hogeveen. 2008. Costs of mastitis: facts and perception. J Dairy Res. 75:113-120.

Jagannatha, S., J. F. Keown, and L. D. Van Vleck. 1998. Estimation of relative economic value for herd life of dairy cattle from profile equations. J. Dairy Sci. 81:1702-1708.

Kelton, D. F., K. D. Lissemore, and R. E. Martin. 1998. Recommendations for recording and calculating the incidence of selected clinical diseases of dairy cattle. J. Dairy Sci. 81:2502-2509.

Kossaibati, M. A. and R. J. Esslemont. 1997. The costs of production diseases in dairy herds in England. Vet. J. 154:41-51.

Kristensen, E., S. Østergaard, M. A. Krogh, and C. Enevoldsen. 2008. Technical indicators of financial performance in the dairy herd. J. Dairy Sci. 91:620-631.

Kulak, K. K., J. C. M. Dekkers, A. J. McAllister, and A. J. Lee. 1997. Lifetime profitability measures for dairy cows and their relationships to lifetime performance traits. Can. J. Anim. Sci.77:609.

Lefebvre, D. 2009. D'une lactation à l'autre: pour une transition réussie. In Proceedings of the Symposium sur les Bovins Laitiers,CPAQ.Drummondville.QC. Accessed Nov. 15, 2014. http://www.agrireseau.qc.ca/bovinslaitiers/documents/lefebvre_d_ar.pdf

Lehenbauer, T. W. and J. W. Oltjen. 1998. Dairy Cow Culling Strategies: Making Economical Culling Decisions. J. Dairy Sci. 81:264-271.

Levallois, R. 1989. Analyse des résultats technico-économiques d'une entreprise laitière par un système expert. Canadian Journal of Agricultural Economics/Revue canadienne d'agroéconomie 37:681-694.

Levallois, R., Y. Allard, P. Carle, S. Gagnon, D. Pellerin, R. Roy, and A. Thériault. 1997. L'augmentation de la production par vache est-elle rentable. Pages 129-162 in Proceedings of the Sympsium sur les Bovins Laitiers, CPAQ,.Drummondville QC.

McKean, E. 2005. The new Oxford American dictionary. Oxford University Press, New York, N.Y.

McLaren, C. J., K. D. Lissemore, T. F. Duffield, K. E. Leslie, D. F. Kelton, and B. Grexton. 2006. The relationship between herd level disease incidence and a return over feed index in Ontario dairy herds. Can. Vet. J. 47:767.

Mulder, H., & Jansen, G. 2001. Derivation of economic values using lifetime profitability of Canadian Holstein cows. Parity, 1 no. 3:1.

Murray, B. 2013. Finding the Tools to Achieve Longevity in Canadian Dairy Cows. WCDS Advances in Dairy Technology 25:15-28.

Perez-Cabal, M. A. and R. Alenda. 2003. Lifetime Profit as an Individual Trait and Prediction of its Breeding Values in Spanish Holstein Cows. J. Dairy Sci. 86:4115-4122.

Pietersma, D., R. Lacroix, and K. M. Wade. 1998. A Framework for the Development of Computerized Management and Control Systems for Use in Dairy Farming. J. Dairy Sci. 81:2962–2972.

Pietersma, D., R. Lacroix, D. Lefebvre, R. Cue, and K. M. Wade. 2006. Trends in growth and age at first calving for Holstein and Ayrshire heifers in Quebec. Can J. Anim. Sci. 86:325-336.

Plaizier, J. C. B., G. J. King, J. C. M. Dekkers, and K. Lissemore. 1997. Estimation of Economic Values of Indices for Reproductive Performance in Dairy Herds Using Computer Simulation. J. Dairy Sci. 80:2775-2783.

Roy, R. 2011. Les temps c'est de l'argent … et bien plus! In Proceedings of Symposium sur le Bovin Laitiers, CPAQ, Drummondville, QC. http://www.agrireseau.qc.ca/bovinslaitiers/documents/Roy_Rene.pdf

Ruegg, P. L. 2011. Managing mastitis and producing quality milk. In: "Dairy Cattle Production Medicine" (eds. C. Risco and P. Melendez), Wiley-Blackwell Publishing Ltd, Ames, Iowa, USA.

Santschi, D. E., Lefebvre, D. M., Cue, R. I., Girard, C. L., & Pellerin, D. 2011. Complete-lactation milk and component yields following a short (35-d) or a conventional (60-d) dry period management strategy in commercial Holstein herds. J. Dairy Sci. 94:2302-2311.

Schroeder, J. 1996. Feeding for Milk Components and Profit. NDSU Extension Service, North Dakota State University of Agriculture and Applied Science. Accessed Sept. 07 2013. https://library.ndsu.edu/repository/bitstream/handle/10365/5400/as1118.pdf?sequence=

St-Onge, A. 2000. Economic values of traits for dairy cattle improvement estimated using field recorded data. in Animal Science. MS Thesis. McGill University, Montreal, Canada.

St-Onge, A., J. F. Hayes, and R. I. Cue. 2002. Economic values of traits for dairy cattle improvement estimated using field-recorded data. Can. J. Anim. Sci. 82:29-39.

Statistics Canada. 1996. Your guide to the Consumer Price Index. Catalogue No. 62-557-XPB

Valacta. 2011. Évolution de laproduction laitière québécoise2010. Le producteur de lait québécois. Vol. may 2011. Fédération des producteurs de lait du Québec (FPLQ), Longueuil, Quebec.

Valacta. 2014. Évolution de la production laitière québécoise 2013. Le producteur de lait québécois. Vol. Numéro spécial, mai 2014. Fédération des producteurs de lait du Québec (FPLQ)Longueuil,Québec.

Van Arendonk, J. A. M. 1991. Use of Profit Equations to Determine Relative Economic Value of Dairy Cattle Herd Life and Production from Field Data. J. Dairy Sci. 74:1101-1107.

Van Doormaal, B. J. 2009. Health data recording in Canada. C. D. Network, ed. CDN, Canada. Accessed Sept. 21, 2014. http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.cdn.ca%2Fdocument.php%3Fid%3D160&ei=mAi9VJ_xEOyTsQS20YHYBA&usg=AFQjCNHx_G0RKifTGME4xsf2agxs0tR1MQ&sig2=Hjq861clmZgix3xhCBJwmw&bvm=bv.83829542,d.cWc

Visscher, P. M. 1995. Genetic analyses of profit for Australian dairy cattle. Anim. Sci. (Pencaitland) 61:9-18.

Weigel, D. J., B. G. Cassell, and R. E. Pearson. 1995. Adjustment of a net income function for opportunity cost of postponed replacement on a lactation basis. J. Dairy Sci. 78(3):648-654.

Appendix 1. List of Event Codes for the lifetime dataset

EVENT CODE	VARIABLE	SOURCE	OBSERVATIONS
S	Lactation Start Date	Lactation	
E	Lactation End Date	Lactation	To include the final cumulative milk revenue by lactation.
LR	Lactation last record	Lactation	To include the complete cumulative feed cost by lactation.
LH	Animal Left Herd	Animal	If recorded in the Animal file.
TD	Test date	Test day	
INT	INTERPOLATION		Created one day before health or breeding events, to calculate the impact of these events.
I	Service	Breeding	
H	Health event	Health DSA or Valacta	
DM	Discarded milk		If recorded a health event that requires DM. (14 days after H date)

CONNECTING STATEMENT 1

On a dairy farm in order to maximize profit the focus needs to be not only on optimizing results of one animal but also of the entire herd. Factors such as age at first calving, longevity and health have a significant effect on profitability and therefore should be constantly considered by management. However these management plans cannot be standardized because the herds have different characteristics. Independent of these variations, the main goal is to keep a consistently well performing herd, in other words, healthy and high producing animals that provide financial returns high enough not only to equal the opportunity cost but also to meet profit goals.

Some of these management differences are related to infrastructure and equipment. When herd managers consider changes in housing and/or milking systems, assessment is not an easy task, not only because of the financial challenge but also because changes in routines have an effect on animal behaviour and production thereby affecting profit results. The third chapter presents a study of differences in profitability and variations in key profitability factors associated with common housing and milking systems in selected herds of the province. It is expected that the use of these differences transformed into visualization curves would give managers benchmark tools to assess the impact on profit of potential changes in housing and milking systems. These curves would also provide more accurate benchmark references to analyze different situations of a herd in terms of profit or cost factors when compared to the mean and distribution results of other herds with similar management characteristics.

CHAPTER III

DIFFERENCES IN PROFITABILITY ASSOCIATED WITH HOUSING AND MILKING SYSTEMS IN QUÉBEC DAIRY HERDS

Differences in Profitability Associated with Housing and Milking Systems by *Delgado et Al.* Selected dairy herds from Québec, Canada were grouped by their housing and their milking system in two different analyses to study if there were differences in profitability and in selected variable costs associated with them and if those differences could be used as management benchmarks. Significant differences in lifetime cumulative profitability were found to be associated with the milking systems groups. Given these differences, the introduction of specific benchmark tools by Dairy Herd Improvement to facilitate the process of decision-making is recommended.

Running Title: Our Industry Today

Differences in Profitability Associated with Housing and Milking Systems in Québec Dairy Herds

H. A. Delgado*, R. I. Cue*, D. Haine#, A. Sewalem‡§, R. Lacroix*†, D. Lefebvre*†, J. Dubuc#, E. Bouchard#, K. M. Wade*

*Department of Animal Science, McGill University, Macdonald-Stewart Building, Room MS1-084, Macdonald Campus 21111 Lakeshore Road Ste. Anne de Bellevue, QC H9X 3V9
†Valacta, 555 boul. des Anciens-Combattants, Sainte-Anne-de-Bellevue, QC H9X 3R4
‡Agriculture and Agri-Food Canada §Canadian Dairy Network, 660 Speedvale Avenue West, Suite 102 Guelph, Ontario, Canada N1K 1E5
#Université de Montréal, Département de sciences cliniques, 3200, rue Sicotte, CP. 5000, Saint-Hyacinthe (Québec) Canada J2S 7C6

Corresponding author: K. M. Wade

Contact address: kevin.wade@mcgill.ca

3.1 ABSTRACT

The main objectives of this study were 1) to develop an empirical analysis of the differences in profitability and associated factors among common housing and milking systems in Québec Holstein dairy herds, and 2) to explore, with visual information techniques, the use of the significant statistical results related to these differences as potential benchmarks.

The information for this study was obtained from datasets with combined production and health information obtained from Quebec Dairy Herd Improvement (**DHI**) and the Provincial Health Files. Herds included were required to have complete production data as well as records for clinical mastitis, reproductive problems, and feet and legs problems during the time of the study. Seventy-three herds were included in the housing analysis and 104 herds for the milking systems analysis. Using mixed models analyses, lifetime profitability (**LTP**) and lifetime profitability adjusted for the regressed opportunity cost of the postponed replacement (**LTPOC**), as well as different components of the related variable costs, were tested as dependent variables and the different housing and milking systems as independent class effects.

At the housing level the group of herds associated with free-stall had the highest LTP ($3,418 ± 338). The higher profitability results of the free-stall group are in part explained by lower feed cost ($3,907 ± 227) and lower cumulative health costs ($456 ± 79) although these results were non-significant between both systems. At the milking systems level the group of herds using automatic milking system (**AMS**) showed the lowest LTP result ($1,473 ± 395) compared to the milk-line and milking parlor groups. This result was explained in part by the lowest cumulative milk value ($10,670 ± 806) and also by the lowest number of cumulative days in milk (545 ± 28).

Using the results that showed significant differences, visualization curves cumulated by day of lifetime were developed to allow comparisons between herds and their related groups. In this exploratory visualization analysis it was found that the significant differences in factors that affect profitability among the management groups justify the development of the alternative benchmarks which will allow dairy producers to visualize, monitor and compare their profit results with other herds that share similar management characteristics and thereby optimize their decisions and set more appropriate goals.

(Keywords: Profitability, Management, Dairy cows)

3.2 INTRODUCTION

Important advances in different fields of the dairy industry including genetics, nutrition and reproductive management have led to a 6-fold increase in average production per cow in the last 100 years and a drastic reduction in the total dairy-herd population from the beginning of the 1900's to the present day (Jacobs and Siegford, 2012b).

Genetics and management are responsible for the milk production performance of a dairy cow and her profit. Forty-five percent of the production-profit results of the herd will depend on management factors (Schroeder, 1996). Therefore it is important to develop adequate tools to help herd managers to understand their results and allow them to make decisions supported by relevant information. Management is the combination of different resources (logistic and physical) and herd managers should always seek to optimize the use of their resources with the intention of maximizing profit without sacrificing the wellbeing of the animals. This task of optimization is not easy since dairy-farm management involves an extensive combination of knowledge and skills (Ford and Shonkwiler, 1994).

One of the main goals of any herd manager is to achieve the survival and success of the business in the long term and in order to do so different strategies must be considered, including increasing productivity and lowering input costs (Winsten *et al.*, 2000). Some of these strategies are straightforward to implement while others require deeper analysis of the logistics and financial resources to optimize the cost-benefit ratio. The profile of the Herd Manager plays a very important role in the adoption of new technologies and information-planning strategies. According to the results presented by Winsten *et al.* (2000), a mail survey of Pennsylvania and Vermont dairy producers showed that farms using confinement feeding systems were more likely to use technologies capital-intensive technologies and/or enhanced per cow milk production. Farms using management-intensive grazing were more likely to use technologies related to information and planning (e.g. farm computers and written farm plans/goals). Farms using traditional grazing generally lagged the pace of technological adoption.

Housing for dairy cattle is receiving a growing amount of attention in both the scientific literature and in the dairy industry (Tucker *et al.*, 2009). In Québec 89.5% of the dairy herds house their animals using tie-stall systems and the remaining 10.5% use free-stall barns. These variations in housing not only affect the area and individual space of the animal, but also imply differences in the selected equipment for milking as well as the relevant management practices. Tie-stall housing systems are usually associated with milk-line (**ML**) equipment, while free-stall systems use Milking Parlors (**MP**) or Robot / Automatic Milking System (**AMS**): 6.7% and 3.8% respectively (Statistics Canada, 2013).

There are extensive reviews about differences in housing system management (Haley *et al.*, 2000; Bewley *et al.*, 2001; Tucker *et al.*, 2009) and how these differences in infrastructure and routines have an effect on the animals at different levels, which affect profitability. Grouping of dairy cows may affect their normal behavioral routines and their time budgets (Grant *et al.*, 2000). Alterations in these routines, because of poorly designed or mismanaged housing facilities, have been demonstrated to affect the time cows have available for eating and lying behaviors (Leonard *et al.*, 1994; Deming *et al.*, 2013). These situations have an effect on cow comfort, production maximization and as a consequence profitability could also be jeopardized.

An important component affecting profitability related to housing systems management is the alteration in production caused by health issues. Events such as clinical mastitis and feet and legs problems have been associated with different housing systems and have been reported in the literature (Sogstad *et al.*, 2005; Olde Riekerink *et al.*; 2008, Gordon *et al.*, 2013). A study of the incidence rate of clinical mastitis (IRCM) in Canada (Olde Riekerink *et al.*, 2008) found that herds in Ontario and Québec had a higher IRCM than herds in other regions. More than half of the barns in the central provinces were tie-stall and were positively associated with higher IRCM, however free-stall housing for lactating cows was associated with a significantly higher mortality rate (Dechow *et al.*, 2011). Valde *et al.* (1996) concluded that differences in disease incidence and fertility problems made free-stall a more desirable housing system than tie-stall barns.

No less important than housing systems, milking technology has dramatically changed over the last 100 years, with the goals of maximizing yield and profit. An important approach has been the introduction of robot milkers. Automatic milking systems (AMS) might potentially increase time-use effectiveness by decreasing labor by as much as 18%, increase milk production by up to 12%, and also might improve the animal welfare by allowing cows to be milked at the moment they prefer (Jacobs and Siegford, 2012b). All these components should have an impact on profitability however an AMS by itself will not guarantee an increase in production and/or productivity because this would be more the combined result of housing, management and cow characteristics (Deming *et al.*, 2013).

AMS offer relief from the demanding routine of milking (Rotz *et al.*, 2003) and they should be considered not only as a new milking system, but rather as a completely new management system (Svennersten-Sjaunja and Pettersson, 2008). One big difference between conventional parlor milking systems and AMS lies in the daily routine. Parlor routine is more structured while an AMS provides more flexibility for the cows (Wagner-Storch and Palmer, 2003). Maintenance requirements of AMS could present a potential disadvantage because the level of technology is higher and relies on a more skilled operator for daily maintenance. Service provided by a highly skilled technician must also be available on short notice and a ready supply of spare parts is required to avoid extended periods of inactivity (Svennersten-Sjaunja and Pettersson, 2008).

The development of record systems and monitoring tools have allowed dairy producers to make decisions and evaluate their success on an on-going basis, for example, the early detection of critical problems such as clinical mastitis (LeBlanc *et al.*, 2006). The AMS supports these record systems because of the data collected about each cow using automatic sensors that monitor different variables such as number of milkings, milk volume, udder health and reproductive status, among others (Spahr and Maltz, 1997). However, data provided by the sensors still need to be complemented with the expertise of the herd manager (Spahr and Maltz, 1997). Because of the immense amount of data collected and provided by AMS, herd managers must develop extra skills to interpret and use the data correctly. Routine tasks and skills, necessary to run a regular dairy herd, might change or even disappear in the future because of the introduction of AMS (Jacobs and Siegford, 2012). However the collection of data recorded either by AMS sensors or by traditional methods is the main source for herd-managers of necessary information for analysis and feedback.

Although there are difficulties in collecting empirical data for a sufficient number of years and there could be some doubts about its reliability for analysis (Kristensen et al., 2008), with the use of techniques to overcome these issues such as indexed prices and statistical mixed models, the data collected from reliable sources such as DHI and the Provincial Animal Health Files gives the unique opportunity to obtain and analyze different components of the dairy herd including profitability results and their variations at various management levels and to develop new and specific benchmarks according to the herd management characteristics. Studies by Bijl et al. (2007) and Steeneveld et al. (2012) with empirical studies have evaluated differences between automatic and conventional milking systems with information collected at herd and DHI levels. The results of those studies will be discussed in the results and discussion section. The main objective of this study was to determine if there were differences in lifetime profitability and its associated cost components among selected common housing and milking systems in Québec that could be used as control benchmarks for herd decision makers; and the specific objectives were: a) To compute cumulative daily profit for individual animals across herds, grouped by management combinations identified in the integrated datasets (housing – milking system); b) To calculate different profitability measures, based on current Canadian costs and estimated health costs, and determine if there were significant differences among the identified management groups and c) To create visualization curves allowing comparisons of lifetime profitability and cumulative costs by management groups and to determine if these curves could be used as potential benchmarks for decision makers.

3.3 MATERIALS AND METHODS

Two retrospective cohort studies were conducted with the information from the combined integrated datasets to test differences in profitability associated with housing systems and milking systems in selected Holstein dairy herds in Québec.

3.3.1 Selection of herds and cows

In order to create a dataset of lifetime profit information, test-day records and animal information were obtained from Québec DHI and health records were obtained from the Provincial Animal Health File or the Dossier Santé Animal (DSA), software owned and operated by the Association of Veterinarians of Québec (AMVPQ). Only herds and animals with complete information for production including feed costs (feed advisory is an optional service offered by Québec DHI) and milk value were considered. Only herds that reported at least one case of clinical mastitis (**CM**), one case of reproductive problems (**REPR**) and one case of feet and legs (**F&L**) problems every year, during the selected years of each analysis, were considered for this study.

For the analysis of housing systems, a total of seventy-three herds from 1,106 herds included in the integrated dataset met the inclusion requirements. Among the reasons why the number of herds was low compared to the total number of herds recorded in the dataset were: lack of feed cost information for one or more years of the study, herds with less than ten calvings per year and incomplete health records for the period of the analysis. For the period 2005-2013, sixty-four herds (88%) were grouped as tie-stall housing system, while the remaining nine herds (12%) were identified as free-stall housing system. In 2013 there were fourteen herds identified as free-stall herds, however, after checking the herd characteristics information over time, five of these herds had been moved by the herd manager from tie-stall to free-stall systems during the analysis period and therefore they were discarded from the analysis.

In order to give all the animals the opportunity to have at least four lactations, but at the same time to work with the most current information we selected cohorts (year when the animal calved for the first time) from 2005 to 2010 inclusive. In Canada the quota year runs from September to August, and considering that management practices maybe related to quota issues, the selected cohorts make reference to this period of “quota years”. Animals from cohorts after 2010 were not included because of the truncation effect. The number of animals included in the study was 8,255. The proportion of animals by housing system was 75% for free-stall and the remaining 25% for free-stall.

For the second part of the study, the objective was to identify differences in profitability at the milking systems level. To include herds and animals in this analysis the same conditions described previously were used, however because the introduction of AMS in Québec is a relatively new management practice, there were time limitations and the analysis only included the 2009 – 2013 period in order to obtain groups of herds with consistent information and at least three cohorts of animals with a life opportunity of at least three lactations. A total of 104 herds met these criteria. Eighty-nine herds were grouped in the ML milking system, nine were grouped under MP and the remaining six herds were classified as AMS. Initially nine herds were identified as AMS however three were discarded because their milking system was changed during the period of the analysis. Considering the limitation in the number of years required, but in order to give all the animals the opportunity to have at least three lactations, we selected cohorts of animals from 2009 to 2011 inclusive. Animals from cohorts after 2012 were not included because of the truncation effect. A total of 6,288 animals were included in the second study.

To adjust for the differences in the value of the money over time all the different returns and costs were converted into constant Canadian Dollars. The methodology used was the one described by Statistics Canada (1996). Farm Input Prices Index (**FIPI**) and Farm Product Price Index (**FPPI**) were obtained from the Statistics Canada website (Statistics Canada, 2014c, a, b). The methodology for the construction and analysis of constant prices was as described by St-Onge (2000).

3.3.2 Costs calculation of the different variable components

The cost of raising a heifer to first calving is variable, depending on herd practices and because not all the animals calve at the same age. For this research it was decided to adopt the costs presented by Beauregard (2012). The estimated cost for the heifer at the moment of first calving was $3,000 for the first 24 months of age and $3 per extra day from that moment until the moment of first lactation. If the animal calved before 24 months of age, an amount of $3 was deducted per day.

For breeding services the estimated cost was $70, assuming that the services were hired and the method was artificial insemination (Giguère, 2011; Roy, 2011). It was observed that for some animals there were no records of breeding-services for a registered lactation. If this was the case, the cost of one service was included to account for the service cost of the next calving.

Eight different health events were recorded in the combined DHI-Health Files dataset. These diseases were selected in 2007 by the Canadian dairy cattle improvement industry to be recorded by DHI or Provincial Animal Health programs run by veterinarians in order to examine their current status and economic impact (Van Doormaal, 2009). In this study we included separate frequencies and costs of REPR, CM and F&L since these were the health events most frequently recorded in the combined DHI-Health Files health dataset. We did not intend in this study to calculate prevalence of diseases or perform any other epidemiological analysis. The means of the lifetime cumulative health events represent the average number of any specific health event recorded for an animal within a herd within a specific management system during its lifetime.

Once the health events counting system was sorted, the costs of the different health events recorded were estimated. To do so different sources for costs-estimates were consulted (St-Onge, 2000; Guard, 2008; Lefebvre, 2009). The health costs included in this study were veterinarian cost, medication, laboratory tests and hand labor and discarded milk in case required. Table 3.1 presents the cost estimates of the different health events recorded in the integrated dataset.

To account for differences in hand labor associated with the milking systems, the cost of hand labor by milking system was included in estimating cumulative lifetime profitability. The variable costs of hand labor were obtained from DHI Valacta (2014). Fat quota opportunity cost was included by charging interest on the market value of fat quota as a marginal cost for the product under quota (Dekkers and Gibson, 1998; Mulder and Jansen, 2001). The value of one kilogram of quota was estimated at the commercial value in Québec ($25,000) and the interest quota was set at 5% per year.

Revenues included in this study were the milk value obtained from Québec DHI, an estimated income for every newborn calf and an estimated cow salvage value following methodology described in St-Onge (2000). Prices used to estimate these values were obtained from the tables of market values published and updated by the Fédération des producteurs de bovins du Québec (FPBQ, 2014) and Agriculture and Agri-Food Canada (AAFC, 2014).

All the returns and costs were computed on a lifetime cumulative basis based on the nature of the different revenues and costs recorded at each event-date and included in a single row. All the costs and revenues were discounted back to the animal's birth date to obtain a net present value (**NPV**) using a 3% discount rate per year. Two profitability formulae were calculated for this study: LTP and LTPOC (Table 3.2). Details of these formulae are described in De Haan *et al.*, 1992 and Kulak *et al.*, 1997.

3.3.3 Statistical Analysis

The goal of the statistical models was to analyze if there were significant differences in the selected profitability formulae and factors affecting costs among the different housing and milking systems groups. The number of health events (REPR, CM and F&L) and the number of breeding-services were cumulated over lifetime by cow and the final cumulative number of each of these health events and reproductive events as well as the age at the moment of first calving (**AFC**), the lifetime cumulative number of days in milk **(cumDIM),** the lifetime cumulative feed cost and the lifetime cumulative milk return were tested as a dependent variables to identify if there were differences in these components associated with the different management groups.

Studies by Kulak *et al.* (1997) and Enting *et al.* (1997) used linear regression models to test the effect of lifetime traits on lifetime profitability measures. Cook (2003) tested differences in prevalence of lameness in different housing systems with One-way ANOVA methodology and used least squares to compare means prevalence among the different tested combinations. For this study a mixed model was fitted to the data using the MIXED procedure of SAS 9.4. Least

Square Means were calculated for the different dependent variables. The random effect of the interaction of year of cohort-herd nested within the management system was included in all the different models in order to calculate not only the variance between the different housing or milking systems but also the variance within them.

To test the significance of the different traits on the different Lifetime Profitability measurements, the general proposed model was defined as:

Model 1: Effect of Management Groups on Profitability and Other Selected Traits

$$y_{\mathrm{isn}} = \mu + HY_{is} + Sys_s + e_{isn}$$

Where y_{isn} is the profitability or profitability-related measure of the *n*th cow, first calving in the *ith* season-year and herd, and in the *s* housing or milking system; HY_i is the random effect of the *ith* year of cohort and herd nested within the housing or milking system group s; Sys_s is the fixed effect of the Housing or Milking system group s, and e_{isn} is the random error, assumed distributed identically, and independently normal.

Lifetime cumulative records per animal within herd and year of cohort and herd within housing/milking management group were tested with the previously described model for both housing and milking systems studies. Values of $p \leq 0.05$ were considered significant. Multiple comparisons among the groups were evaluated using Bonferroni's adjustment test. To test if there were differences in cumulative feed value among the different feeding equipment reported as used by the herds in the combined dataset, the independent variable feed equipment within management group, was included in the Model 1. To test differences in LTP and LTPOC among the herds registered as using Total Mixed Ration (**TMR**) as feeding equipment a subset of herds within this category was selected for analysis.

To obtain partial correlations for profitability results and other selected traits adjusted for the interaction of the herd and year of quota and the management system the same Model 1 was used following the Multivariate Analysis of General Linear Methods in SAS 9.4. This correlation analysis was designed to understand the relationship among the different profitability measures and selected traits related to reproduction and health that showed differences by management group.

3.3.4 Development of benchmark curves

To explore the applicability of different potential benchmarks to be used as analysis tools for herd managers, visualization curves were developed. The first step was to calculate the selected cumulative value means by day of lifetime with the purpose of creating visualization curves. To achieve this all the values were interpolated by animal from Event-date to the next Event-date on a daily basis using the Proc-Expand method in SAS 9.4. The obtained interpolated values per day of life were filtered by the different Category-groups and sorted in chronological order (Days of Life) to calculate means and standard deviations. Scatter plots in SAS 9.4 were used to explore the visualization of these benchmarks.

3.4 RESULTS AND DISCUSSION

The raw means and standard deviations for the lifetime cumulative revenues and costs for the different groups associated with the housing and milking systems are presented in Table 3.3. Results for both analyses (housing and milking systems) are presented by variable and by group of housing systems or milking systems.

3.4.1 Differences in Profitability Results Among the Management Groups

3.4.1.1 Cumulative Lifetime Profitability (LTP). The least squares mean result (**LSM**) for LTP for the group of herds associated with free-stall was \$3,418 ± 338 versus \$3,292 ± 160 for the herds in the tie-stall system although there was a difference of \$126 ± 351 in favor of free-stall these difference was non significant (P = 0.72). Factors that cause this difference are discussed throughout this analysis (Table 3).

The LTP results for the milking systems showed significant differences (P = 0.04). The group of herds associated with AMS had the lowest LTP \$1,479 ± 395 (Table 4). This result was \$1,052 ± 503 below the result obtained by MP herds (Bonferroni adjustment P = 0.11) and \$1,020 ± 410 below when compared with ML (Bonferroni adjustment P = 0.04). There was no significant difference (Bonferroni adjustment P = 1) between the LTP results for ML (\$2,494 ± 106) and MP (\$2,526 ± 311). When the costs associated with labor were included in the LTP formula, the group of herds associated with MP had the highest LTP \$79 ± 259. The difference with AMS was \$198 ± 416 (Bonferroni adjustment P = 1) and with ML \$403 ± 273 (Bonferroni adjustment P = 0.43). However, when labor costs were excluded, there was a significant negative difference in the AMS LTP result compared to the other two groups. One of the reasons why the LTP results for AMS were lower could be the recent introduction of these systems to the farm. According to Steeneveld *et al.* (2012) it is expected that there would need to an adjustment period to the new routines.

Steeneveld *et al.* (2012) used empirical data obtained from dairy farms in the Netherlands to determine economic differences between 63 AMS farms and 337 conventional milking systems (**CMS**) farms. There were no major differences in general farm characteristics included in this study, such as, the number of cows, number of hectares and the amount of milk quota. The aim of that study was to test if there was a shift in the capital:labor ratio in AMS where an increase in capital would later turn into a decrease in labor cost. Although there were variations in the use of capital and other inputs, no important differences were found in terms of revenue generation and profitability between AMS and CMS.

Rotz *et al.* (2003) working on a on farm-simulation model to determine the long-term, whole-farm effect of implementing AMS on farm sizes of 30 to 270 cows found no economic benefit in moving from CMS to AMS for most of the studied farm scenarios. For instance, when comparing the return on investment in an AMS or a new MP system, the return was similar to that of new parlor systems on smaller farms when the milking capacity of the AMS was well matched to herd size and milk production level.

As mentioned before studies by Rotz *et al.* (2003) and Steeneveld *et al.* (2012) concluded that there were no important differences in the overall economic return in most cases between AMS and CMS. However in this study our interest was focused on identifying factors that could be associated with management systems (housing or milking systems) and which could have an effect on lifetime profitability, such as cumulative health cost. Even if the results in LTP were similar, the factors identified would need to be monitored in different ways according to the management system in order to improve the decision making process as will be discussed later in this paper.

3.4.1.2 Lifetime Profit Adjusted for the Regressed Opportunity cost of the Postponed Replacement. The concept of profit adjusted for the postponed replacement is that the profitability of the producing cow has to be compared with the opportunity cost of the postponed replacement within herd because there is a profit sacrificed on the replacement cow (heifer) by keeping the current producing cow (Van Arendonk, 1991).

For housing systems there were no significant differences (P = 0.48) for the LTPOC. The LTPOC result was -\$117 ± 56 for free-stall and -\$162 ± 30 for tie stall (Table 3). The results at the milking systems level were also not significant.

For instance, if LTPOC is considered as part of the decision making process to cull or keep animals in the herd, animals would stay only until their contribution to the herd is not surpassed by another animal with a higher performance and the overall herd profitability would be optimized because the space used by the cow with the lower profit can be used by another animal with better performance.

3.4.2 Differences in Age at First Calving and Heifer Cost among the Management Groups

The group associated with free-stall had the lowest AFC 25.9 ± 0.44 (age expressed in months) and a heifer cost at the moment of first calving of \$3,179 ± 40, while the group associated with tie-stall showed the highest AFC 26.7 ± 0.6 and a cost of \$3,247 ± 15 (Table 3). The difference between the two housing systems was \$68 ± 43 (Bonferroni adjustment P = 0.012).

Although the milking systems are only introduced after the first calving, including the cost of the heifer to this moment is important for profitability analysis because of its negative correlation with LTP and because it could indicate a management trend. There was a significant difference for AFC between the MP group, and ML. The first one showed the lowest result for AFC (25.3 ± 0.07 months) and a heifer cost of \$3,118 ± 32, while for the AMS group the AFC was 25.75 ± 0.44 months and a heifer cost of \$3,160 ± 40. Finally the highest result was for the ML group with an AFC of 26.2 ± 0.11 months with a heifer cost of \$3,201 ± 10 (Table 4). The differences between ML and were significant for both AFC and for the cost of the heifer (P = 0.05) with the Bonferroni adjustment.

3.4.3 Differences in Cumulative Days in Milk among the Management Groups

For the housing systems we found no significant differences for cumDIM (P = 0.36), however the group associated with tie-stall was kept in production for a lower number of days, cumDIM 708 ± 11 compared to the group associated with free-stall 699 ± 28 (Table 3).

At milking system level there was no significant difference (P = 0.08) in the results obtained for cumDIM. However the cumDIM result for AMS was 545 ± 28 compared to 612 ± 8 cumDIM for the group of herds associated with ML and 612 ± 22 cumDIM for the MP group (Table 4). The difference between AMS and ML was -67 ± 30 days (Bonferroni adjustment P= 0.08) and with MP -67 ± 36 days (Bonferroni adjustment P = 0.08).

The high correlation between LTP and cumDIM (0.91) explains in part the lower LTP result obtained by the herds grouped as AMS. The animals in the AMS group had 67 fewer production days compared to the ML group. The milk value per day for AMS was on average $19.5. This value multiplied by 67 days equals $1,300 that was not obtained because of the shorter number of cumDIM. However it is also important to note that the LSM result of LTPOC for this group was LSM -$353 ± 99. This result indicates that, although the animals were removed from the herd when their performance was negative, they could have been removed even earlier since keeping them in the herd for a longer period was not going to help to increase the overall herd profitability.

3.4.4 Milk Value, Feed Cost and Impact on Profitability among the Management Groups

3.4.4.1 Cumulative Milk Value. For the housing systems analysis the group associated with tie-stall produced the highest milk value $14,835 ± 286 versus the group of herds associated with free-stall $14,335 ± 699 (Table 3.3). These results did not show significant differences (P = 0.51). Similar non-significant results (P = 0.7) were found for cumulative milk production and for cumulative fat production (P = 0.56) between the two housing systems.

For milking systems the cumulative milk value LSM results were $12,766 ± 217 for ML, $12,422 ± 634 for MP and $10,670 ± 806 for AMS (Table 4) (P = 0.04). This difference also helps to explain the lower result obtained for LTP considering that milk is the most important revenue for dairy herds.

3.4.4.2 Cumulative Feed Cost Results. For housing systems the group of herds associated with tie-stall had the highest cumulative feed cost $4,163 ± 90 versus $3,907 ± 227 for free -stall (Table 3.3). These results showed no significant difference (P = 0.3). As mentioned before the main focus of this study was to identify differences in management groups by the nature of the housing and the milking systems although Québec DHI also records feeding equipment by herd. Table 3.5 presents the number of herds by the different feeding equipment associated with the two housing systems. Since Total Mixed Ration (TMR) represents almost 50% of the herds selected in this study, as a sensitivity analysis, we have tested profitability results and other dependent variables using only those herds from the housing groups that have implemented TMR (all the herds grouped as free-stall use TMR). We also wanted to test if there were differences in the cumulative feed cost associated with the feeding equipment within the housing groups. To do so the independent variable, feeding equipment within management group, was introduced in Model 1. We found no significant differences in the result of cumulative feed cost for the tie-stall herds grouped by feeding equipment.

Three feeding equipment sub-groups (TMR, traditional manual feeding and automatic concentrate distributor) were used by 80% of the total number of herds on tie-stall while 100% of the herds on free-stall use TMR. Forty percent of the herds in tie-stall were associated with TMR, 20% with manual traditional feeding and another 20% with automatic concentrate distributor. There were no significant differences for the cumulative feed cost among these three feeding systems within tie-stall. For TMR within tie-stall the cumulative feed cost LSM \$4,322 ± 133. The LSM cumulative feed cost for the herds associated with automatic concentrate distributor was \$4,737 ± 208. For the traditional manual feeding system the LSM for cumulative feed cost was \$4,491 ± 284. We found no significant differences (P = 0.12) among LTP results for the different feeding equipment sub-groups within tie-stall. Although this differences were statistically non significant, at the herd level it is crucial to closely monitor variations in feed costs in order to maximize profit without affecting production.

At the milking systems level we found no significant differences for the cumulative feed cost, however the AMS group showed the lowest result (\$3,262 ± 261), explained in part by a lower cumulative number of days in milk (Table 3.4). The difference between AMS and MP was -\$412 ± 344 (Bonferroni adjustment P = 0.4) and between AMS and ML -\$424 ± 271 (Bonferroni adjustment P = 0.26). We have observed that that both conventional milking systems CMS (ML and MP) obtained higher revenues but also higher cumulative feed costs. However there was a significant difference in LTP when comparing the conventional systems with the AMS group, the latter being less profitable when hand labor costs were not included. Bijl *et al.* (2007) carried out an economic comparison between AMS and CMS using empirical data. Results showed that farms under CMS had larger revenues (€7,899), but farms with an AMS had lower costs, especially livestock (€2,354) and feeding costs (€2,918). In that study, no differences in profit margins were detected between the two milking systems.

3.4.5 Cumulative Number of Inseminations and Their Cumulative Cost

At the housing systems level we did not obtain a significant difference ($p = 0.27$) for the cumulative number of breeding services when tested as a dependent variable. For tie-stall the cumulative number of services was 6.39 ± 0.17 and cumulative cost of $475 ± 11, while for free-stall the cumulative number of services was 5.8 ± 0.44 and a cumulative cost of $449 ± 28 (Table 3.3).

At the milking systems level, the lowest cumulative number of breeding services was for the group associated with MP with an LSM of 5.9 ± 0.3 and an estimated cost of cumulative breeding services of $428 ± 23. The group associated with ML had 6.18 ± 0.12 cumulative breeding services and a cost of $444 ± 8 and finally the cumulative number of breeding services for the group associated with AMS was 6.19± 0.4 with a cumulative cost of $441 ± 30 (Table 3.4). There were no significant differences among the three groups for both the cumulative number of breeding-services and their respective cumulative costs ($P = 0.81$).

Considering the higher number of breeding services in AMS in comparison with their shorter number of cumDIM, Jacobs and Siegford (2012) concluded that further research is needed in the estrus detection area, especially longer-term trials to observe if the automated estrus detection mechanisms improve and, if not, producers need to devote more time to observe cow behavior once they have adapted to the new milking system.

In both studies (housing system and milking system) the number of breeding services by lactation suggests that herd managers have an opportunity to work on the reduction of the costs caused by these services. This item is very important from the management point of view, if we consider one service per conception as the optimal scenario, all the groups are far from reaching this goal. The repeated services result not only in the extra cost of the insemination (in the study \$70 per insemination service), but also the productive cycle of the animal is delayed and as a consequence the whole herd planning system is affected.

3.4.6 Cumulative Health Costs

The combined health-production dataset offered the possibility to analyze the cumulative health cost, which summarizes the variable costs of the different health events recorded in the integrated dataset and presented in Table 3.1. At housing system level herds associated with free -stall had the lowest lifetime cumulative health cost \$456 ± 79 contributing to its better LTP performance, while the LSM for the group associated with tie-stall was \$539 ± 30 (Table 3). However this difference was non significant (P = 0.30).

For milking groups, the group associated with AMS had the highest cost \$475 ± 116 followed by the ML group \$472 ± 30 and MP \$ 307 ± 94 (Table 4). The difference between the ML and MP was \$165 ± 99 (Bonferroni adjustment P = 0.27) and \$67 ± 150 (Bonferroni adjustment P = 1) between AMS and MP.

To help explain the differences in the health costs we obtained the means of the lifetime cumulative number of health events and standard deviations for CM, REPR and F&L, which are presented in Table 3.5. The means of the lifetime cumulative health events represent the average number of times the specific health event occurred by animals within the herds associated with the specific management group.

3.4.6.1 Costs of Clinical Mastitis. Starting with CM, the LSM of cumulative cases of CM was 0.61 ± 0.05 for the group associated with tie-stall with an estimated cost of $233 ± 21 and the LSM for the cumulative number of cases of CM for groups associated with free-stall housing was considerably lower 0.39 ± 0.14 events and the estimated cost caused by CM was $145 ± 54. Although statistically non significant (P = 0.12). This study did not aim to calculate incidences of diseases but only to calculate their impact on profitability, these results are in line with the study of the incidence rate of clinical mastitis (IRCM) in Canada that found that herds in the central provinces (Ontario and Quebec) using tie-stall were positively associated with higher IRCM (Olde Riekerink *et al.*, 2008).

At the milking system level we found significant differences for the cumulative number of CM events (P = 0.03), herds associated with milk-line presented the highest number of cumulative events 0.56 ± 0.04 with a cumulative cost of $216 ± 12, followed by MP 0.27 ± 0.13 and a cumulative cost of $94 ± 55 and finally AMS with an estimate of 0.23 ± 0.17 cumulative cases per animal and an estimated cumulative cost of 90 ± 68 (Table 3.4). The differences between AMS with the other two milking groups were significant both for the cumulative number of events (0.29 ± 0.14 between ML and MP and 0.33 ± 0.17 between ML and AMS) and for the difference in cumulative cost ($122 ± 58 between ML and MP and $125 ± 70 between ML and AMS). Considering that the herds grouped in AMS and MP were also under free-stall housing, these results were consistent with the results obtained by the herds associated with free-stall (lower number of cumulative events and cumulative costs).

Similar to Québec, in Switzerland tie-stall is the most common type of housing system. A study presented by Gordon *et al.* (2013) about clinical mastitis in that country showed that farms with tie-stall systems had a significantly higher number of cases for this problem compared to free-stall.

3.4.6.2 Costs of Reproductive Problems. The difference for cumulative reproductive problems (REPR) between tie-stall and free-stall systems non significant (P = 0.32), where the group associated with tie-stall showed an LSM of 0.30 ± 0.02 and the groups associated with free-stall 0.39 ± 0.13 (Table 3.3). The respective estimate for REPR cumulative cost was $123 ± 11 for free-stall and $153 ± 28 for tie-stall. This difference in the cumulative number of REPR events represented a difference in costs caused by REPR of $30 ± 30 (P = 0.32) in favor of free-stall. At the Milking system level, herds associated with ML showed the highest number of cumulative reproductive events 0.31 ± 0.02, followed by AMS with 0.3 ± 0.09 and finally MP with 0.21 ± 0.07 (Table 4). This higher average cumulative number of reproductive problems in ML resulted in higher costs for the herds associated with ML $132 ± 44, compared to $117 ± 5 for AMS and $84 ± 90 for MP (P = 0.44).

3.4.6.3 Costs of Feet and Legs Problems. Systems associated with free-stall showed a cumulative number of events for F&L problems of 0.38 ± 0.08 and a cumulative cost of $86 ± 18 while the LSM for the group associated with tie-stall was 0.27 ± 0.03 and a cumulative cost of $60 ± 7 (P= 0.27) for the same health issue (Table 3.3). This difference in the cumulative number of F&L problems represented a significant additional cost of $25 ± 19 (P = 0.20) for the free-stall herds compared to the tie-stall group of herds. Sogstad *et al.* (2005) in their study of the prevalence of claw lesions in Norwegian dairy cattle showed that there were significant differences between tie-stall and free-stall systems. The prevalence of claw lesions was 1.5

times higher for free-stall systems compared to tie-stall systems. Cook (2003) also found a higher prevalence of lameness throughout the year in free-stall herds with non-sand stalls in Wisconsin dairy herds.

Although, according to Jacobs and Siegford (2012), lameness problems are probably more closely associated with management and facility design rather than the type of milking system, herds in ML system had the lowest number of cumulative F&L events 0.22 ± 0.02 compared to the results of those milking systems associated with free-stall housing, MP 0.31 ± 0.02 and AMS 0.32 ± 0.11 ($P = 0.44$), and the costs associated with this problem were $73 ± 25 for AMS, $73 ± 20 for MP and $ 51 ± 6 for ML (Table 4). These costs were non significantly different among the milking groups ($P = 0.44$).

3.4.7 Use of Different Variables as Potential Benchmarks

As important as the statistical findings in this study was the visualization component, which allows dairy producers and stakeholders to better understand the impact of their decisions, such as, the effect of health or reproduction costs on profitability. As the adage says: a picture is worth a thousand words. Québec DHI provides their customers with monthly reports with their herd's production information and their rankings by breed and region. However the statistical results in this study have shown that there were significant differences among the commonly used management systems in Québec in the different components of variable costs supporting the idea that it is necessary to develop additional benchmarking tools.

With the development of new technologies and with the data collected by Québec DHI and the Provincial Health Files, it is possible to create benchmark curves on a routine basis to allow herd managers to monitor and compare their profitability results in a flexible way adjusted to their needs. These benchmark curves, showing cumulative results by day of lifetime, reflect in a visual way the statistical differences previously found creating a management-decision tool which allows the herd managers to compare their results. For example, the benchmark curves could help in the process of decision-making by allowing a comparison of the impact on profitability caused by the presence of a health problem, and the longitudinal evolution of profit, costs or events that cause avoidable costs such as repeated breeding services or health events. Another example, would be the analysis of a change in housing systems, e.g. from tie stall to free stall by comparing the current profitability results to the results of the potential system to be adopted in the context of a cost/benefit analysis.

Figure 3.1 shows the use of such a benchmark in a comparative analysis of cumulative profit after variable cost including curves of performance for two cohorts of animals from the same herd that is managed under the combined Free-stall and MP systems. This Figure shows mean, 10 and 90 percentiles curves of LTP for the group of herds associated with MP as benchmark reference. By comparing with the benchmarks it can be observed how the cumulative profit after variable cost for the cohort of 2010 reached the top 90 percentile curve, however after day of life 1,500 the average cumulative profit lost some ground and falls around the mean, however after day 1,850 the cumulative profit started ascending again to reach the top performers of these management group. In contrast the 2007 cohort whose performance was very close to the mean during almost all the cycle, only after day 2,000 the average LTP seems to increase above the mean. This situation could be explained because the animals from that cohort that stayed in herd after day 2,000 were the best performers compared to the removed ones therefore the average LTP improved. Comparing the evolution between both cohorts the evolution in the profitability curves could indicate to the dairy producer that the goal of increasing profitability is being accomplished not only because the performance of the newer cohort is better, but also because this result is outstanding compared to herds with similar characteristics of management (top 90%). If the situation were the opposite then it would be time to review the decisions made.

The visualization curves reflecting the significant differences caused by the cumulative cost of CM are presented in Figure 3.2 and show the need to use specific benchmark curves, in this case relating to groups associated with the different milking systems. This figure shows as benchmarks the curves of the means for the cumulative cost of CM interpolated by age in days for the groups associated with ML and AMS. The dotted curves show the upper 90% of the distribution of the data for both groups. If the average cumulative cost caused by CM was $400 at day of life 1,500, for a herd in the group associated with ML, although the cost is above the mean it is not close to the 90% curve. On the contrary if this was the case for a herd associated with AMS there would be an urgent need for this dairy producer to address this issue because the cost caused by CM is located at the top of the distribution (90% of the curve for AMS) and as a result the profitability could be seriously affected compared to other herds with similar management characteristics.

A different conclusion could be made for F&L problems. Figure 3.3 shows the benchmark curves of the means and top 90% of the distributions for the cumulative costs caused by F&L problems interpolated by day for groups associated with ML and AMS. If the average cumulative cost caused by F&L was $150 at day 1,500 for a herd associated with tie-stall and ML, the situation would require urgent revision of management practices because this cost is at the top of the distribution, while the same average cost at the same age for a herd associated with free-stall and MP would require attention, since the cost is above the mean but not located at the top of the distribution.

One of the doubts that should be answered in future studies is the reason why the profitability performance for AMS systems is significantly lower compared to the CMS. Is it because the herds are just adjusting to a new management system and they require more time to adapt and to achieve equivalent results? In the future with more herds using AMS and with longer data series we could expect to make a clearer assessment of AMS profitability in agreement with the conclusion presented by Jacobs and Siegford (2012) about the need to continue the research on milking systems to understand their differences as well as the impacts of the different facilities and management systems on dairy cow health, welfare and therefore profitability.

One limitation of this study was the low number of herds working with AMS with complete data to be included in a longitudinal study due to the fact that these systems have only recently been introduced. However, despite this limitation in data, in this exploratory study we have found significant differences in factors that affect profitability among the management groups specifically at milking system level. Although we used a limited subset of the data the significant differences found in the statistical analysis justified the development of the alternative benchmarks, for the preliminary study, in order to allow decision-makers to visualize, monitor and compare their profit results with other herds that share similar management characteristics.

The limitation in the number of herds using AMS as well as for herds using tie-stall systems reflects the availability of data. Also, only herds that did not change management systems and with complete information for the duration of the analyses were included. Both these factors were important in order to avoid inconsistencies in the profitability results by groups and to develop accurate benchmark curves. As a consequence of the conditions required to select the herds for this study, it is possible that there might be differences in management and production performance results of these herds compared to the original integrated dataset.

In summary at the housing level the results in LTP were non-significant between both groups. At the milking systems level, the AMS group showed the lowest LTP when labor costs were excluded. This result is explained by the shorter number of days in milk and higher health costs. However, AMS have only recently been introduced and this lower profit outcome caused by higher costs might be caused by adjustments in the different management factors.

The different curves showing the results of the different variables (curves for means and distributions) in the form of visualization benchmarks by housing and milking groups developed in this study are expected to be used in the future as the base of a pilot project analyzing information for herds where complete data is collected and reported to DHI.

3.5 CONCLUSIONS

There were no significant differences in LTP or LTPOC between the housing systems (tie-stall and free-stall). However there were variations in the different cost components such as AFC. The result of this variable for herds associated with tie-stall (26.9 months ± 0.6) identifies an opportunity to increase profit.

At the milking systems level, herds associated with AMS had the lowest LTP result ($1,479 ± 395) when no labor costs were included. This result in part explained by lower milk revenue $10,670 ± 806 compared with the other two milking systems.

With the current information collected by Québec DHI, it is possible to create specific benchmarks, either in tables or as visualization curves, to help decision-makers understand current problems in their herds based on their results obtained and compared with other herds with similar management characteristics. This kind of more relevant benchmark contributes to the setting of more realistic goals and profit optimization based on the characteristics of the herd.

This is the first exploratory study using Québec dairy herds data for the development of different benchmarks in the form of visualization curves as part of dairy herd management. This field is still is a work in progress, but offers a promising tool to help in the decision making process.

Acknowledgements

The authors of this study would like to thank the Fonds de Recherche Nature et Technologies de Quebec (FRQNT), Novalait, the Ministère de l'Agriculture, des Pêcheries et de l' Alimentation du Québec (MAPAQ) and Agriculture and Agri-Food Canada for funding support (FRQNT project LT-163341), DHI Valacta, the Dossier Santé Animal (DSA) for providing the data and also the Hugh Blair Scholarship for providing funding to Hector Delgado.

Table 3.1 Summary of the variable costs for the different health events recorded in the integrated dataset and included in the different profitability measures. 2012, $CDN

	Milk Fever	Dystocia	Reproductive Problems	Ketosis	Displaced Abomasum	Clinical Mastitis	Feet & Legs
Direct Costs	$56	$90	$48	$36	$138	$94	$55
Discarded Milk	No	Yes	Yes	No	Yes	Yes	Yes

Table 3.2 Description of the different profitability formulae used in this study, including sources and descriptions.

GROUP	DESCRIPTION	SOURCES
1- Cumulative Lifetime Profitability **(LTP)**[a]	Cumulative returns minus cumulative variable costs, including fat quota interest (indexed prices and net present value to birth date)	(Mulder and Jansen, 2001)
2- Cumulative Lifetime Profitability adjusted for the Regressed Opportunity Cost of the Postponed Replacement **(LTPOC)**[b]	Cumulative Lifetime Profitability minus Regressed Average Cumulative Lifetime Profitability of the Herd, including fat quota interest (indexed prices and adjusted to birth date)	(De Haan *et al.*, 1992, Weigel *et al.*, 1995, St-Onge, 2000)

[a] Adjusted to net present value (NPV) evaluates profitability of the dairy cow acknowledging that costs and revenues occur at different times during a cow's lifetime. Discounting allows for comparison of profits of cows at a common base time, which is an important characteristic of a profit measure, Kulak *et al.* (1997).

[b] Regressed opportunity cost used regressed means for LTP and days of productive life because of the large number of herd-year of first calving cohorts that contained few cows as posed by De Haan *et al.* (1992).

Table 3.3 Least Square Means for profitability results and other variables affecting profitability grouped by the housing systems. Results for 73 herds with animals with a life opportunity to the fourth lactation and cohorts from 2005 to 2010. 2012, $CDN

		TIE-STALL			FREE-STALL		
		Estimate	Standard Error	DF	Estimate	Standard Error	DF
Profitability	LTP	3,292	160	22	3,418	338	59
	LTPOC	-162	30	464	-117	56	121
Reproduction Traits	Age at First Calving	26.7	0.16	65	25.9	0.44	61
	Cumulative Days in Milk	708	11.57	69	699	28.37	24
	Cumulative Breeding Services	6.39	0.17	71	5.86	0.44	62
Revenues & Costs	Cumulative Milk Revenue	$14,835	286	73	$14,335	699	55
	Cumulative Feed Cost	$4,163	90	67	$3,907	227	56
	Heifer cost at first calving	$3,203	11	110	$3,193	25	98
	Cumulative breeding services cost	$475	11	72	$449	28	61
	Cumulative Health cost	$539	30	70	$456	79	63
Health Events & Costs	Cumulative clinical mastitis	0.61	0.05	70	0.39	0.13	64
	Clinical Mastitis cost	$233	21	70	$145	54	64
	Cumulative reproductive problems	0.30	0.02	73	0.39	0.63	63
	Reproductive Problems cost	$123	11	73	$153	28	63
	Feet and Legs problems	0.24	0.03	69	0.29	0.08	63
	Feet and Legs problems cost	$55	7	69	$66	18	63

Table 3.4 Least Square Means for profitability results and other variables affecting profitability grouped by the different milking systems. Results for 104 herds with animals with life opportunity from the third lactation and cohorts from 2009 -2011. 2012, $CDN

		MILK LINE			MILKING PARLOR			AUTOMATIC MILKING SYSTEMS		
		Estimate	Standard Error	DF	Estimate	Standard Error	DF	Estimate	Standard Error	DF
Profitability	LTP	$2,494	106	108	$2,526	311	77	$1,473	395	89
	LTP + Hand Labor	-$324	86	108	$79	259	85	-$119	325	93
	LTPOC	-$81	46	103	-$211	122	52	-$353	163	69
Reproduction Traits	Age at First Calving	26.2	0.11	97	25.3	0.35	97	25.7	0.44	101
	Cumulative Days in Milk	613	7	111	612	22	71	545	29	86
	Cumulative Breeding Services	6.18	0.12	112	5.90	0.37	88	6.19	0.47	97
Revenues & Costs	Cumulative Milk Revenue	$12,766	217	104	$12,422	634	75	$10,670	806	86
	Cumulative Feed Cost	$3,686	69	102	$3,675	208	79	$3,262	261	88
	Heifer cost at first calving	$3,201	10	108	$3,118	32	96	$3,160	40	101
	Cumulative breeding services cost	$444	8	113	$428	23	85	$441	30	96
	Cumulative Health cost	$472	30	102	$307	94	92	$475	116	96
Health Events & Costs	Cumulative clinical mastitis	0.56	0.04	103	0.27	0.13	90	0.23	0.17	95
	Clinical Mastitis cost	$216	17	103	$94	55	90	$90	68	95
	Cumulative reproductive problems	0.31	0.02	101	0.21	0.07	85	0.30	0.09	90
	Reproductive Problems cost	$123	10	101	$79	33	85	$103	41	90
	Feet and Legs problems	0.21	0.02	101	0.32	0.09	88	0.32	0.11	92
	Feet and Legs problems cost	$51	6	101	$73	20	88	$73	25	92

Table 3.5 Number of herds by the different feeding equipment used grouped by housing system

Feeding equipment	Tie-stall	Free-Stall
Traditional Manual Feeding	12	
Automatic Forage Distributor	2	
Automatic Concentrate Distributor	12	
Computerized Automatic Concentrate Distributor	8	
Automatic Silage and Concentrate Distributor	4	
Total Mixed Ration	26	9
TOTAL	64	9

Figure 3.1. Cumulative Lifetime Profitability (LTP) comparisons between two different cohorts (2007 and 2010) of the same herd and with Milking Parlor (MP) system, mean and distribution curves (10 and 90%) for benchmark. 2012, $CDN

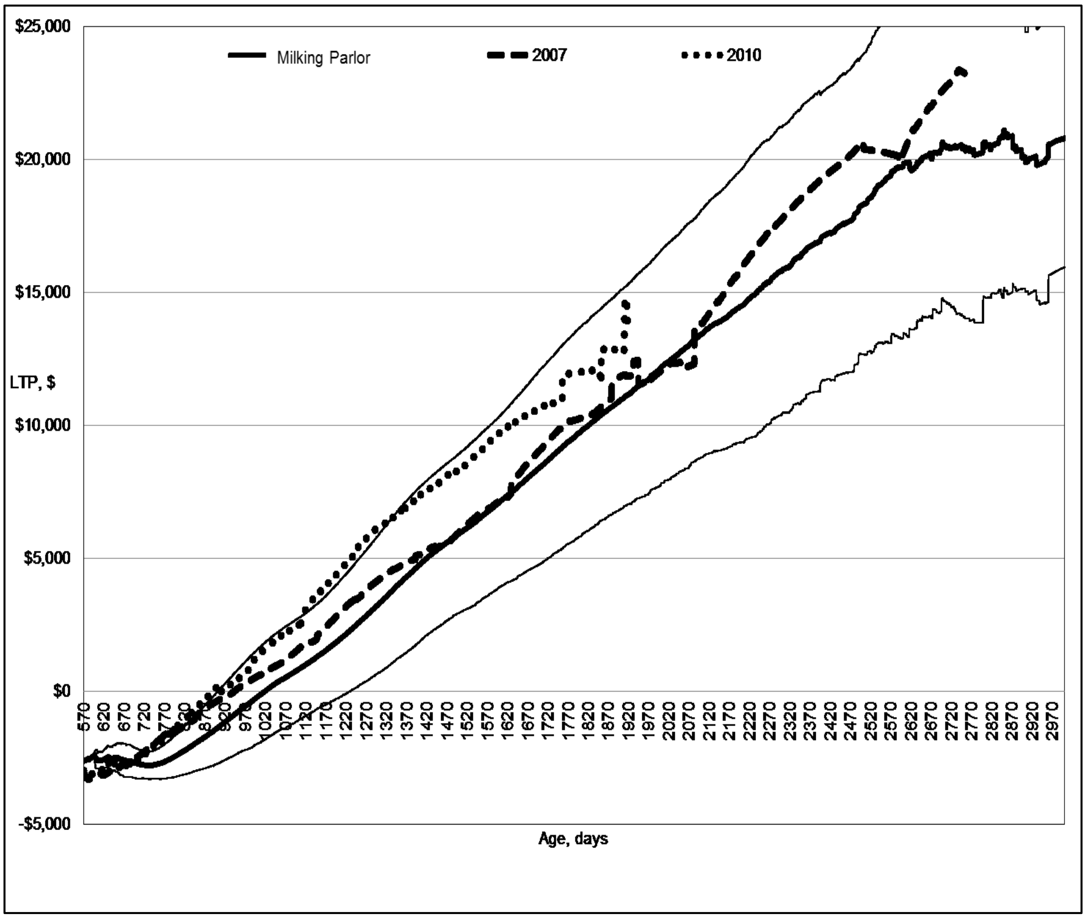


Figure 3.2. Curves of average cumulative costs of clinical mastitis (CM) by age of life (days) for group of herds associated with milk line (ML) and group of herds associated with automatic milk systems/robots (AMS) including 90% distribution curves for both groups. 2012, $CDN

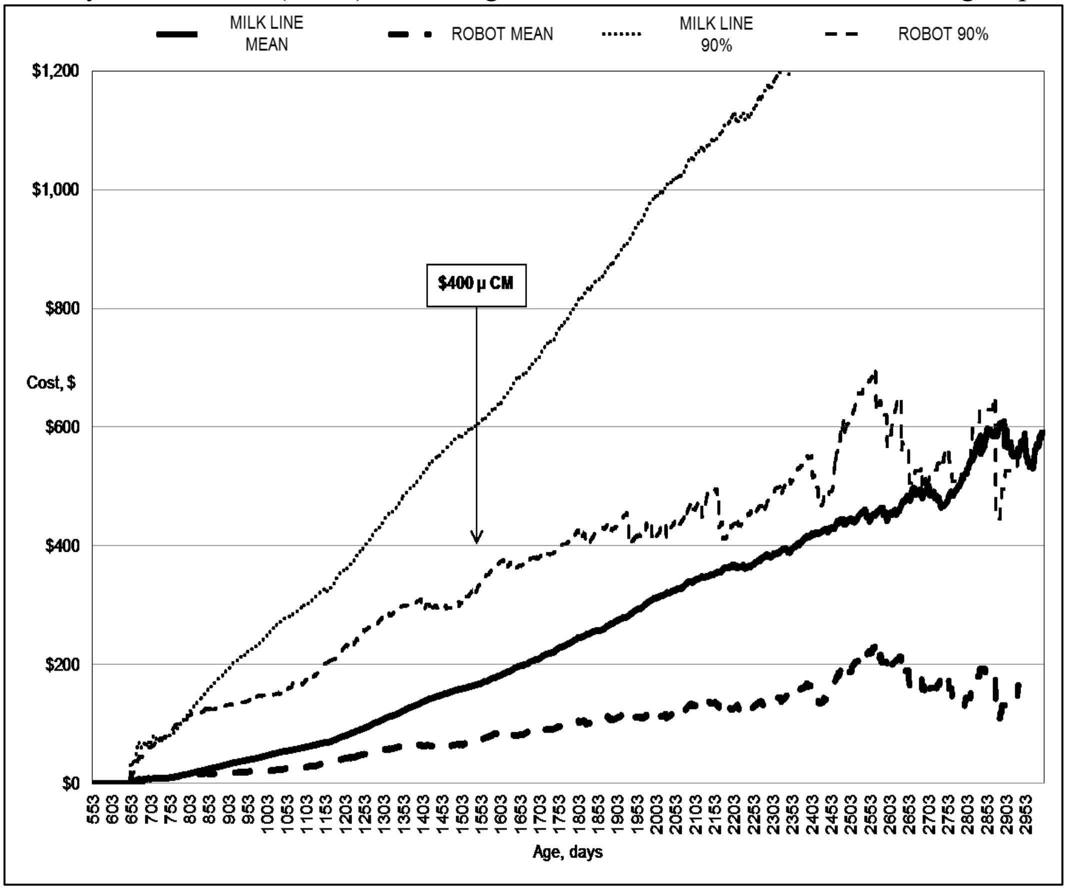
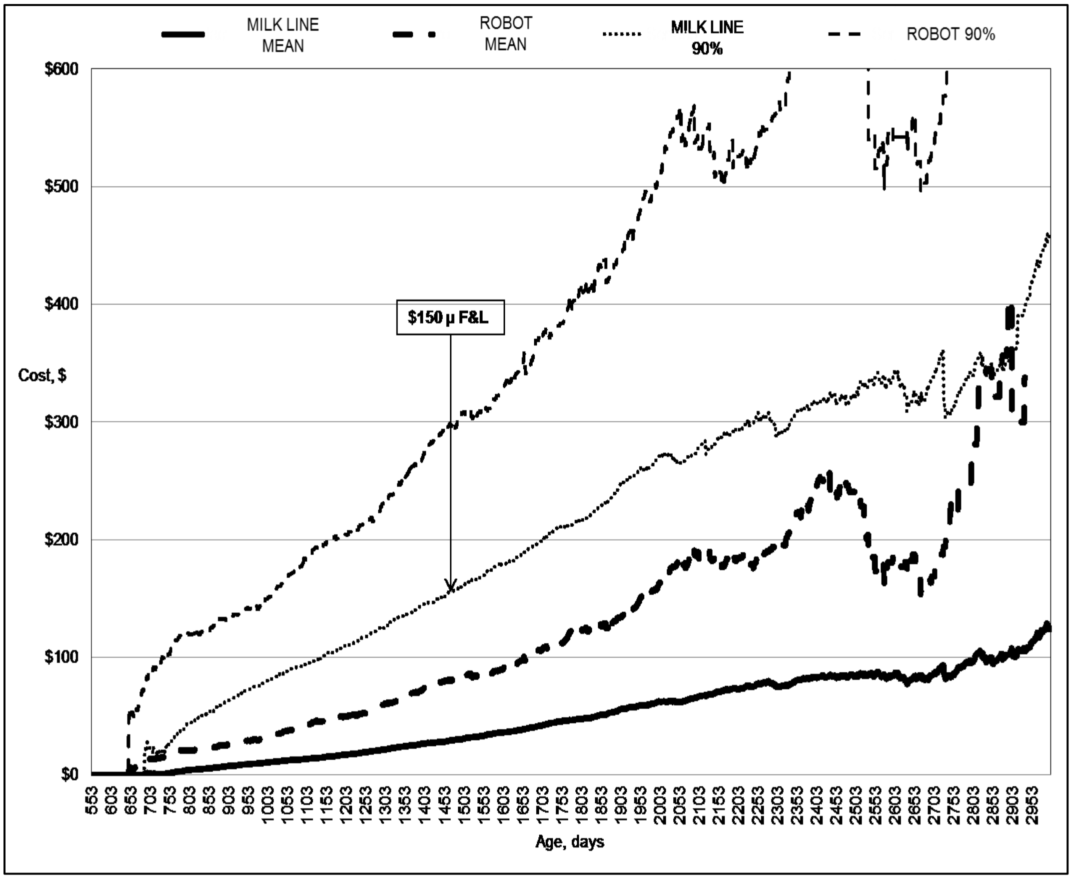


Figure 3.3 Curves of average cumulative costs of Feet & Legs Problems (F&L) by age of life (days) for the group of herds associated with milk line (ML) and the group of herds associated automatic milk systems/robots (AMS) with 90% distribution curves for both groups. 2012, $CDN



3.6 REFERENCES

Agri-Food Canada. 2014. Slaughter reports. Statistcs and Market Information Service. Accessed Oct. 13, 2014. http://www.agr.gc.ca/redmeat-vianderouge/sla-aba_eng.htm

Beauregard, G. 2012. Élever une taure laitière coûte maintenant plus de 3000 dollars …! Octobre 2012 ed, Agri-Nouvelles. http://issuu.com/dominic.simard/docs/60914_agrinouv_oct12_appro_haute

Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001. A comparison of free-stall barns used by modernized Wisconsin dairies. J. Dairy Sci. 84:528-541.

Bijl, R., S. R. Kooistra, and H. Hogeveen. 2007. The profitability of automatic milking on Dutch dairy farms. J. Dairy Sci. 90:239-248.

Canada, G. o. 2013. Dairy Barns by Type in Canada. in Dairy Facts and Figures. Vol. 2014. http://www.dairyinfo.gc.ca

Canada, S. 2014a. Farm Input Price Index (FIPI). Definitions, data sources and methods. Accessed Sept. 7, 2014. http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getInstanceList&SDDS=2305&InstaId=14940&SurvId=65019

Canada, S. 2014b. Prices and Price Indexes. Statistics by Subject. Accessed Sept. 7, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=3956&lang=eng&id=998&more=0&type=ARRAY&pageNum=1

Canada, S. 2014c. Statistics by subject, Livestock and acquaculture. Farm financial statistics. Accessed Oct. 10 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=920&id=2553&lang=eng&type=ARRAY&pageNum=1&more=0

Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. J. Am. Vet. Medical Assoc. 223:1324-1328.

De Haan, M. H. A., B. G. Cassell, R. E. Pearson, and B. B. Smith. 1992. Relationships between net income, days of productive life, production, and linear type traits in grade and registered Holsteins. J. Dairy Sci. 75:3553-3561.

Dechow, C. D., E. A. Smith, and R. C. Goodling. 2011. The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds. Anim. Welf. 20:145-158.

Dekkers, J. C. M. and J. P. Gibson. 1998. Applying breeding objectives to dairy cattle improvement. J. Dairy Sci. 81:19-35.

Deming, J. A., R. Bergeron, K. E. Leslie, and T. J. DeVries. 2013. Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. J. Dairy Sci. 96:344-351.

Enting, H., D. Kooij, A. A. Dijkhuizen, R. B. M. Huirne, and E. N. Noordhuizen-Stassen. 1997. Economic losses due to clinical lameness in dairy cattle. Livest. Prod. Sci. 49:259-267.

Ford, S. A. and J. S. Shonkwiler. 1994. The effect of managerial ability on farm financial success. Agr. and Resour. Econ. Rev. 23:150-157.

FPBQ. 2014. Fédération des producteurs de bovins du Québec, Prices-Info. Page Market data updated by the Fédération des producteurs de bovins du Québec. Accessed Sep. 9, 2014. FPBQ. http://www.bovin.qc.ca/en/price-info/cull-cattle-and-bob-calves/daily.php

Giguère, M. 2011. Inséminer ou comment augmenter ses performances. in Élevage. Portal Agricole du Quebec, La Terre de chez nous. http://www.laterre.ca/elevage/inseminer-ou-comment-augmenter-ses-performances/

Gordon, P. F., B. H. P. Van den Borne, M. Reist, S. Kohler, and M. G. Doherr. 2013. Questionnaire-based study to assess the association between management practices and mastitis within tie-stall and free-stall dairy housing systems in Switzerland. BMC veterinary research 9:200.

Grant, R. J., J. L. Albright, and J. P. F. D'Mello. 2000. Feeding behaviour. Farm Animal Metabolism and Nutrition:365-382.

Guard, C. 2008. The costs of common diseases of dairy cattle (Proceedings). In Proceedings of the Central Veterinary Conference West, San Diego, Ca. Accessed Oct. 08 2013. http://veterinarycalendar.dvm360.com/avhc/Veterinary+Food+Animal/The-costs-of-common-diseases-of-dairy-cattle-Proce/ArticleStandard/Article/detail/586496

Haley, D. B., J. Rushen, and A. M. d. Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci. 80:257-263.

Jacobs, J. A. and J. M. Siegford. 2012. Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. J. Dairy Sci. 95:2227-2247.

Kristensen, E., S. Østergaard, M. A. Krogh, and C. Enevoldsen. 2008. Technical indicators of financial performance in the dairy herd. J. Dairy Sci. 91:620-631.

Kulak, K. K., J. C. M. Dekkers, A. J. McAllister, and A. J. Lee. 1997. Lifetime profitability measures for dairy cows and their relationships to lifetime performance traits. Can. J. Anim. Sci. 77:609.

LeBlanc, S. J., K. D. Lissemore, D. F. Kelton, T. F. Duffield, and K. E. Leslie. 2006. Major advances in disease prevention in dairy cattle. J. Dairy Sci. 89:1267-1279.

Lefebvre, D. 2009. D'une lactation à l'autre: pour une transition réussie. In Proceedings of the Symposium sur les Bovins Laitiers,CPAQ.Drummondville.QC. Accessed Nov. 15, 2014. http://www.agrireseau.qc.ca/bovinslaitiers/documents/lefebvre_d_ar.pdf

Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

Mulder, H., & Jansen, G. 2001. Derivation of economic values using lifetime profitability of Canadian Holstein cows. Parity, 1 no. 3:1.

Olde Riekerink, R. G. M., H. W. Barkema, D. F. Kelton, and D. T. Scholl. 2008. Incidence rate of clinical mastitis on Canadian dairy farms. J. Dairy Sci. 91:1366-1377.

Rotz, C. A., C. U. Coiner, and K. J. Soder. 2003. Automatic milking systems, farm size, and milk production. J. Dairy Sci. 86:4167-4177.

Roy, R. 2011. Les temps c'est de l'argent … et bien plus! In Proceedings of Symposium sur le Bovin Laitiers, CPAQ, Drummondville, QC. http://www.agrireseau.qc.ca/bovinslaitiers/documents/Roy_Rene.pdf

Schroeder, J. 1996. Feeding for Milk Components and Profit. NDSU Extension Service, North Dakota State University of Agriculture and Applied Science. Accessed Sept. 07 2013. https://library.ndsu.edu/repository/bitstream/handle/10365/5400/as1118.pdf?sequence=1

Sogstad, Å., T. Fjeldaas, O. Østerås, and K. Forshell. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Prev. Veterinary. Med. 70:191-209.

Spahr, S. L. and E. Maltz. 1997. Herd management for robot milking. Comput. Electron. Agricu. 17:53-62.

St-Onge, A. 2000. Economic values of traits for dairy cattle improvement estimated using field recorded data. in Animal Science. MS Thesis. McGill University, Montreal, Canada.

Statistics Canada. 1996. Your guide to the Consumer Price Index. Catalogue No. 62-557-XPB Journal Articles

Steeneveld, W., L. W. Tauer, H. Hogeveen, and A. O. Lansink. 2012. Comparing technical efficiency of farms with an automatic milking system and a conventional milking system. J. Dairy Sci. 95:7391-7398.

Svennersten-Sjaunja, K. M. and G. Pettersson. 2008. Pros and cons of automatic milking in Europe. J. Anim. Sci. 86:37-46.

Tucker, C. B., D. M. Weary, M. A. G. von Keyserlingk, and K. A. Beauchemin. 2009. Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. J. Dairy Sci. 92:2684-2690.

Valde, J. P., D. W. Hird, M. C. Thurmond, and O. Osterås. 1996. Comparison of ketosis, clinical mastitis, somatic cell count, and reproductive performance between free stall and tie stall barns in Norwegian dairy herds with automatic feeding. Acta Vet. Scan. 38:181-192.

Van Arendonk, J. A. M. 1991. Use of Profit Equations to Determine Relative Economic Value of Dairy Cattle Herd Life and Production from Field Data. J. Dairy Sci. 74:1101-1107.

Van Doormaal, B. J. 2009. Health data recording in Canada. C. D. Network, ed. CDN, Canada. Accessed Sept. 21, 2014. http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.cdn.ca%2Fdocument.php%3Fid%3D160&ei=mAi9VJ_xEOyTsQS20YHYBA&usg=AFQjCNHx_G0RKifTGME4xsf2agxs0tR1MQ&sig2=Hjq861clmZgix3xhCBJwmw&bvm=bv.83829542,d.cWc

Wagner-Storch, A. M. and R. W. Palmer. 2003. Feeding behavior, milking behavior, and milk yields of cows milked in a parlor versus an automatic milking system. J. Dairy Sci. 86:1494-1502.

Weigel, D. J., B. G. Cassell, and R. E. Pearson. 1995. Adjustment of a net income function for opportunity cost of postponed replacement on a lactation basis. J. Dairy Sci. 78:648-654.

Winsten, J. R., R. L. Parsons, and G. D. Hanson. 2000. A profitability analysis of dairy feeding systems in the northeast. Agr. and Resour. Econ. Rev. 29:220-228.

Valacta. 2014. Évolution de la production laitière québécoise 2013. Le producteur de lait québécois. Vol. Numéro spécial, mai 2014. Fédération des producteurs de lait du Québec (FPLQ)Longueuil,Québec.

CONNECTING STATEMENT 2

As presented in Chapter III, there are differences in factors that have an effect in profitability associated with the nature of the housing and/or milking systems, such as the cost of feet and legs problems that have a higher impact in tie-stall compared to free-stall systems. The information provided through visualization methods of these differences showed the importance of providing decision makers with more flexible and appropriate benchmarks according to the nature of their herds.

In Chapter IV the development of a prototype tool to monitor profitability based on information visualization methods is described. This information visualization system includes the use of alternative benchmarks such as milking or feeding systems in order to provide decision makers with comparison tools adjusted to the characteristics and nature of their herds. Results can be presented at different hierarchical level and time sequences to allow flexibility and the capacity to compare the situation of their herds and animals with other groups of herds with similar management characteristics.

CHAPTER IV

PROTOTYPE OF A PROFITABILITY ANALYSIS TOOL WITH MULTIDIMENSIONAL BENCHMARKS FOR DAIRY HERDS

H. A. Delgado[a], R. I. Cue[a], D. Haine[e], A. Sewalem[cd], R. Lacroix[ab], D. Lefebvre[ab], J. Dubuc[e], E. Bouchard[e], K. M. Wade[a]

[a] Department of Animal Science, McGill University, Macdonald-Stewart Building, Room MS1-084, Macdonald Campus 21111 Lakeshore Road Ste. Anne de Bellevue, QC H9X 3V9
[b] Valacta, 555 boul. des Anciens-Combattants, Sainte-Anne-de-Bellevue, QC H9X 3R4
[c] Agriculture and Agri-Food Canada [d] Canadian Dairy Network, 660 Speedvale Avenue West, Suite 102 Guelph, Ontario, Canada N1K 1E5
[e] Université de Montréal, Département de sciences cliniques, 3200, rue Sicotte, CP. 5000, Saint-Hyacinthe (Québec) Canada J2S 7C6

Corresponding author: K. M. Wade
Contact address: kevin.wade@mcgill.ca

4.1 ABSTRACT

The main objective of this study was to develop an information visualization tool prototype to support decision-makers in the analysis and comparison of profitability results and factors affecting them at the dairy-herd and individual-cow levels. The starting point was the construction of a relational database, with cumulative variables to analyze results using different profitability measure that combined production, health and reproductive data obtained from an integration of the Québec Centre of Dairy Expertise, (Valacta) and the Provincial Animal Health Files databases (DSA). The visualization interface was developed in MS Excel and connected to the relational database via Open Database Connectivity (ODBC).

The visualization tool prototype was divided into three hierarchical categories to facilitate the multidimensional analysis: 1- Category analysis, to compare profitability performance among and within benchmark groups such as provincial regions and breeds; 2- Herd analysis to compare the evolution of any selected herd across animal cohorts, and also over time, by calculating average daily profit and average profit per day of productive lifetime; and 3- Individual animal analysis to visualize lifetime curves including the detailed effects of health costs and breeding-service costs on profitability. Lifetime cumulative profit curves were benchmarked with average herd results and the selected category to facilitate the analysis.

This information visualization system was created in a simple, but precise, way to offer, through benchmarking curves in different graphs, the possibility to identify factors affecting profitability at the herd and individual level, and also to monitor - in a longitudinal way - the effect of decisions made in the past regarding profit or its components. At the herd level, multiple comparisons allow herd managers to assess the overall results of the herd compared to the region, the breed or any other benchmark category included in the analysis tool, and also to visualize how factors such as health events, breeding-services or age at first calving affect the expected profitability. At the individual level, the visualization of different profitability curves allows herd managers to make decisions based not only on final profit, but also to consider factors such as the cost of the heifer at the moment of first calving, the cumulative cost of feeds and the milk value as well as individual marginal contribution to profit of the herd and profitability ranking among all the animals in the herd. It is hoped that Dairy Herd Improvement agencies can adapt and adopt useful profitability reports, based on the ideas developed in this prototype.

Key Words: Profitability, management information system, information visualization tool, dairy cow.

Highlights

- Data routinely obtained from herds was transformed into a visualization prototype.
- Visualization curves of lifetime profitability are used for decision-making.
- Benchmarks at herd level allow evaluating results of tactical decisions over time.
- Comparative visualization of profitability simplifies a long complicated process.

Abbreviations

AFC = age at first calving, **CM** = clinical mastitis, **DD** = days dry, **DIM** = days in milk production, **DSS =** Decision Support Systems, **INFOVIS** = Information Visualization Tool, **IT** = Information Technologies, **LTP** = lifetime profitability, **LTPOC** = lifetime profitability adjusted for the regressed opportunity cost of the postponed replacement, **MIS** = Management Information System, **MOFC**= margin over feed cost, RP = reproductive problems.

4.2 INTRODUCTION

Farm managers are challenged by multiple factors that affect herd profitability. Milk production and feed costs are the most important components in the profit equation (Beck, 2008), and any farm trying to thrive and succeed has to keep comprehensive records of them. The proliferation of automation in the modern dairy herd for daily tasks, such as milking and oestrus detection, means that large quantities of data are being routinely collected and could be used to support dairy producers in making operational and tactical decisions on the farm. Analysis of these data can be undertaken at both a herd level and an individual cow level, in the form of economic decision-making tools (Roche *et al.*, 2009). This information is generated on-farm and off-farm and their combination creates the so-called info-fog. The info-fog could be used as useful tool in the in the complex process of on-farm decision-making (St-Onge, 2004).

Unfortunately, due to well-known cognitive and perceptual limitations, the quantity of information a user can examine and handle at a given instant is very limited, therefore there is a risk of not taking advantage of these increasingly large amounts of data. There is also the risk of being overwhelmed by them, particularly if computer applications do not provide an effective presentation and do not permit interaction with the data (Chittaro, 2001).

In daily practice, advice given on profitability-related management decisions is often intuitively based. As a consequence, producers sometimes receive contradictory advice from different sources, leading to low adoption rates. Literature on the efficacy of management measures mostly gives general advice which is not applicable in a specific farm situation (Huijps, 2009). Computerized information systems can potentially help a dairy producer to deal with the increased complexity of decision making and availability of information in dairy farming (Pietersma *et al.*, 1998).

Reproductive performance and herd health condition are among the major factors influencing the profitability of a dairy herd: it is, therefore, important for decision-makers to have reliable information to help them balance the cost-benefit equation. These decisions have an effect on both current and expected future returns and need to be based on information originating on-farm, but also require reliable reference benchmarks for an effective assessment. Therefore it is important to use tools able to properly combine data from the farm with external data (St-Onge, 2004) in order to provide usable information.

Frohlich (1997) proposed the development of visual and interactive tools as one of the solutions to help with the processing of relevant information since profitable decision-making depends on interpreting all of the inputs accurately. But important as good quality data and top-notch technology are, a visual analysis involves posing questions, formulating hypotheses and discovering results (Eick, 2000).

Information visualization methods research explores not only the space of successful designs and techniques, but also moves into the application of accumulated knowledge in a principled manner (Heer *et al.*, 2005). According to Wright (1997) one of the advantages of information visualization systems is the ability to solve real-world problems because, “used effectively, these methods can accelerate perception, provide insight and control, and harness the flood of valuable data to gain a competitive advantage in making business decisions”, because as the old adage says: a picture is worth a thousand words.

To transform the collected raw data into a graph that can be automated and understood, there are different steps to treat the data and convert it into knowledge information. Chi (2000) identified four distinct stages in the construction of the visualization process: Value, Analytical Abstraction, Visualization Abstraction, and View. In addition, the process of converting data from one stage to another requires one of the three types of Data Transformation operators: Data Transformation, Visualization Transformation and Visual Mapping Transformation.

In summary, Ware (2013) summarized the process as: 1-The collection and storage of data; 2- The pre-processing designed to transform the data into something that can be understood; 3- The display hardware and the graphics algorithms that produce an image on the screen; and 4- The human perceptual and cognitive system (the perceiver).

The objective of this study was to develop a prototype of an information visualization tool that will provide farm managers and their advisors in the process of decision-making with visual reports to aid their understanding of the effects of past decisions and to identify resources and actions to optimize profitability.

4.3 MATERIAL AND METHODS

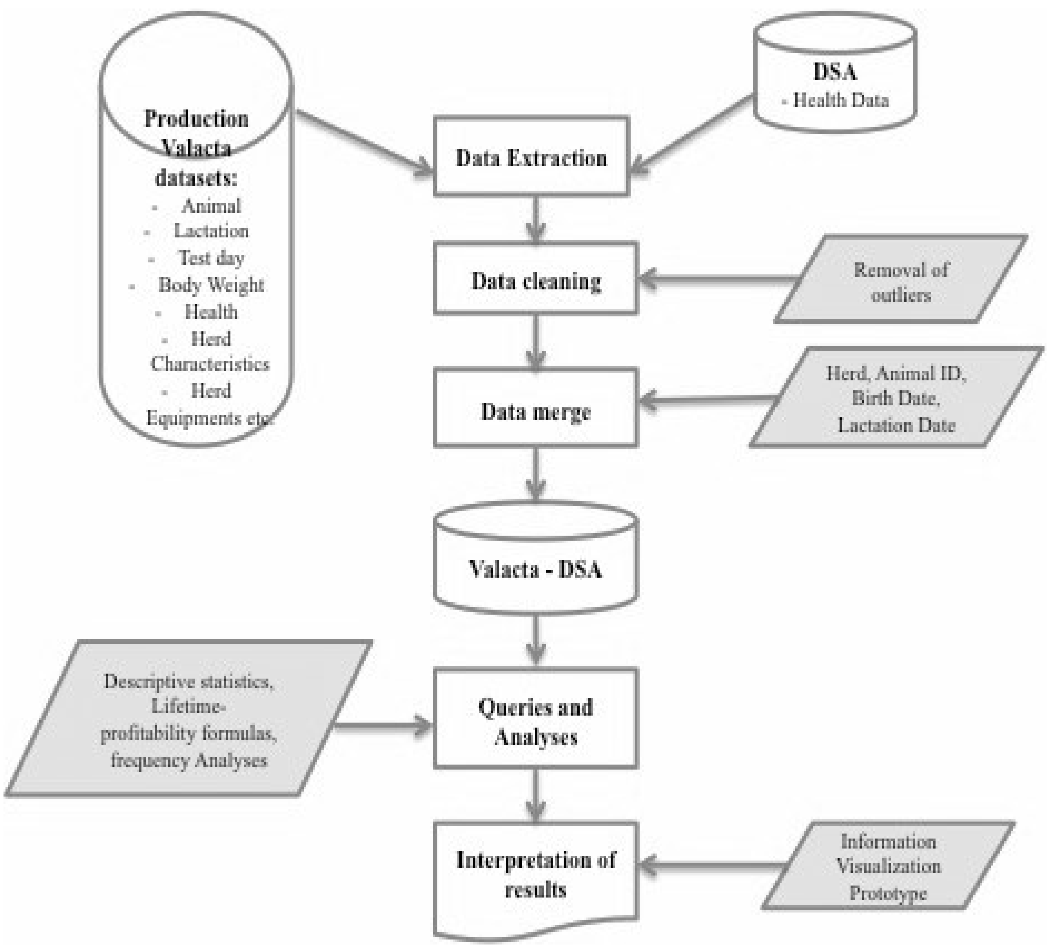
4.3.1 Data Integration and Analysis

To start the process eleven (11) flat files that registered different aspects of milk production (animal identification and herd, test-day, lactation, body weight, etc.) were obtained from the Québec Centre of Dairy Expertise – see Diagram 4.1. All of these datasets were in the form of SAS files, and included herd and cow information from the province of Québec, collected between 2000 and 2013 inclusive. SAS 9.4 software was used for data validation and editing (e.g., abnormal values for age, age at calving, lactation length, duplicate recording of events, etc.). While many of these tasks can be accomplished through automated rules, a significant portion of the cleaning and transformation work must often be done manually (Rahm and Do, 2000). Since these data files are recorded, various edit checks were carried out to detect and then remove invalid data (Cue, 2011). It is important to note that this data extraction was the main source of information to develop the visualization prototype, however in the future it is envisaged that the data will be extracted directly from the relevant data provider (milk recording, veterinary databank, etc.).

For the construction of an integrated lifetime dataset, health data were obtained from the Provincial Animal Health Files (DSA). This dataset consisted of a collection of health records from previously selected and identified herds. The edited DSA dataset was comprised of a total of 591,406 records (including health and reproductive events) for 163,826 animals and 1,106 herds.

The fundamental principle of the data integration process was that similar data obtained from separate sources must match and also exhibit biologically plausible values (Cole *et al.*, 2012). With the integrated lifetime dataset sorted chronologically, and with all the information organized by event-dates in single rows, prices and costs were estimated using the methodology described by Statistics Canada (1996). Farm Input Prices Indices (FIPI) and Farm Product Price Indices (FPPI) were obtained from the Statistics Canada website (Statistics Canada, 2014c, a, b). The methodology for the construction and analysis of constant prices has been described by St-Onge (2000).

Diagram 4.1 Process of integration and transformation of the data provided by Québec DHI (Valacta) and Provincial Health Files (DSA)



4.3.2 Selection Criteria of Benchmark Categories

The Québec DHI records included different qualitative characteristics of the herds and animals (e.g. Region, Breed). These characteristics were considered of potential interest as benchmark tools based on the finding of significant statistical differences among them. Currently available reports often provide herd managers with comparisons by region and by breed, while other characteristics such as Feeding Equipment, Milking System or Herd Size might also have an important use as benchmarks of interest. Five qualitative categories were selected to group the data: Breed, Feeding Equipment, Milking System, Region and Herd Size. The Regions selected correspond to agricultural administrative regions defined by the Québec Ministry of Agriculture. The selected breeds correspond to the top five dairy breeds in the Province. Table 4.1 presents the categories selected and their respective groups.

Table 4.1 Categories and groups selected for benchmarking

CATEGORY	GROUP
REGION	Bas Saint Laurent Centre du Québec Chaudière Appalaches Estrie Lanaudière Mauricie Montérégie Est Montérégie Ouest Québec Capitale Nationale Saguenay Lac Saint Jean
BREED	Ayrshire Brown Swiss Canadienne Holstein Jersey Ayrshire Brown Swiss
MILKING SYSTEM	Milk line Milking parlor Robot N/A
FEEDING EQUIPMENT	Traditional manual individual feeding Auto forage distributor Auto concentrate distributor Computer automatic concentrate distributor Auto silage concentrate distributor Total mixed ration Manual forage distributor Manual concentrate distributor
SIZE*	Small Medium Large

* Small herds ≤ 40 calvings/quota year, Medium herds > 41 and ≤ 60 calvings/ quota year, Large herds ≥ 60 calvings/quota year.

4.3.3 Data Transformation

Different procedures were required to transform the data and create variables that created suitable visualization points at the different hierarchy levels, including individual cow levels, mean herd-level values, and different category-group levels. To calculate the selected cumulative value means and standard deviations by day of lifetime, all values were interpolated by animal from Event-date intervals to a daily basis using the Proc-Expand method in SAS 9.4. The obtained interpolated values per day of life were filtered by the different Category-groups (Table 4.1), sorted in chronological order (Days of Life), and used to calculate means and standard deviations by Category-group per day of life. The same procedure was used for herd values per day of life. As stated by Ware (2013), the main goal of using these transformed data was to observe correlations between variables or clusters of data values, or to postulate certain underlying mechanisms that are not immediately evident from the raw format.

4.3.4 Construction of the Relational Database

With the lifetime integrated dataset constructed and the qualitative benchmarks defined and stored in datasets (Table 4.1) a relational database for decision support was developed as a repository of information to develop different hierarchical analyses. To facilitate complex analyses and visualizations, the data were modeled, using three main hierarchical categories – Animal, Herd, and Category-group – that permit the rolling up and drilling down of the information. In order to select time variables, the information was modeled in days of life, parity cycles and calendar date using slice and dice functions.

To facilitate the visualization and management of data, the Animal category variables were separated into three main datasets. The first one, or Animal file, contained the various records, registered by event-date with the integrated health and production information, and all the different selected variables cumulated by event-date. The second file for animals included all the cumulated information by parities, which allowed for the construction of tables showing summaries of the different variables included, cumulated by parity. The final dataset for the animals contained lifetime information.

For the Herd category, events were viewed and analysed both chronologically and by day-of-life. Selecting by day of life allows benchmarking the evolution in results for the different groups of animals at specific moments in their lifetime (e.g., average milk return for animals that reached 1,000 days of life within the herd compared with the average milk return in the region). Selecting variables by chronological dates allows for the monitoring of their evolution during a period of time and the examination of the impact of decisions made. For instance a new breeding-insemination program might have an impact on the breeding-service cost for the animals in the herd. This will be reflected in the selected population (cohort) and in the overall average daily cost of breeding-services.

The software selected to develop the data relational database was MS Access 2010. Although its storage capacity is limited (2Gb per database) this software offered multiple advantages for the development of the conceptual prototype, among them, the ease of exporting information to other software such as the SQL server or MS Excel for visualization purposes, or of importing updates from SAS.

4.3.5 Development of the Visualization Interface

To develop the graphs and the interface prototype, it was our intention to select software which allows Rapid Application Development and testing (RAD). Various software options were considered such as SAS/GRAPH 9.3 (Elliott and Woodward, 2010), MS Excel (Office 2010, Microsoft Corporation, Redmond, WA), Visual Basic VB 9.0 or VB 10.0 (Microsoft Corporation, Redmond, WA) and Impure Alpha 0.9 by Bestiario, Barcelona, Spain (Ortiz and Cid, 2010). Excel 2010 was chosen to develop the visualization interface because its user interface is very familiar to millions of users worldwide and it permits easy connection to MS Access with the ODBC system. Although Excel is a powerful tool for data visualization (Evergreen, 2013) and is commonly used for data reporting and analysis in businesses (Clark and Heckenbach, 2005), for the final version different alternatives of visualization will be considered.

The information included in the relational database developed in MS Access 2010 was connected to MS Excel with the Open Database Connectivity (ODBC) query system. One of the advantages of the interface is that it allows the user to develop queries and obtain results through MS Excel that are processed in the background by MS Access without the user having to be familiar with database management or SQL language programming. To allow users to select and display the different graphs contained in the same spreadsheet in an organized way, different macros programmed in Visual Basic were developed.

4.3.6 Graphics Design

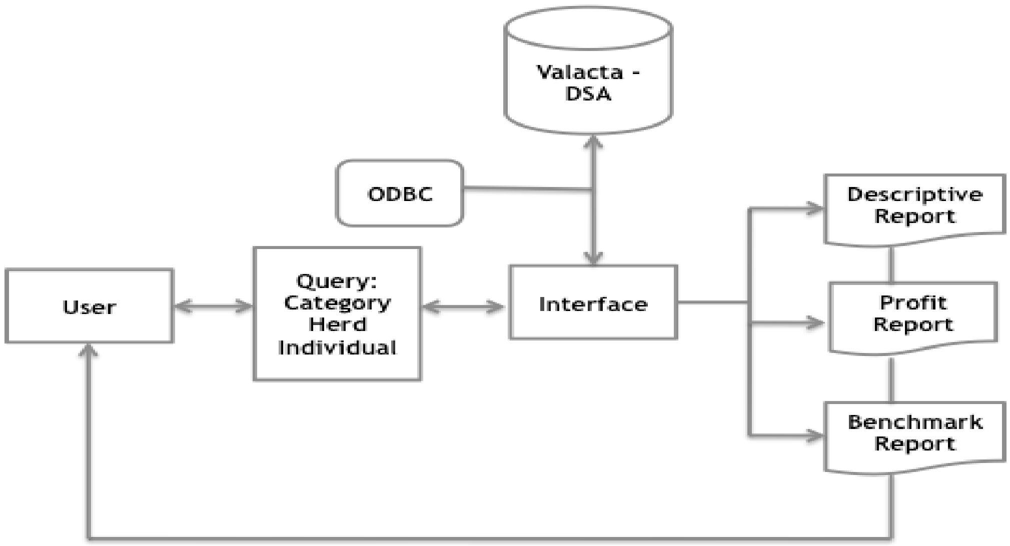
All the graphs were developed as proposed by Evergreen (2013): The main goal of the graphic design was to present the different graphs using "simplification strategies". These included discouraging three-dimensional displays, removing extraneous gridlines and decimals, and avoiding color gradation. In other words there was an attempt to keep graphs simple, but effective, removing all that did not aid the understanding of the data in the display.

Because of the need of longitudinal analysis to make decisions, time series were considered, according to Tufte and Graves-Morris (1983): a time series plot is a frequently-used graph because the natural order of the time scale gives this design strength and efficiency of interpretation. The challenge with time-series is that the simple passage of time is not necessarily a good explanatory variable: descriptive chronology is not causal explanation, however time-series plots can be moved toward causal explanation by introducing additional variables into the graphic design. An especially effective device for enhancing the explanatory power of the time series display is to add spatial dimensions to the design of the graphic, so the data are moving over space as well as over time.

4.3.7 Generating Database Queries

The end-user selects the subsets of information to visualize directly from the interface with the help of ribbon lists as explained in section 2.8. These subsets of information are loaded into sheets from the database and the user can select or filter the desired type of graph or table before passing the information to the graphics encoding process. The detailed process is similar to the one described in Stolte *et al.* (2002). Diagram 4.1 shows the flow of information among the database, the interface and the user. Queries can be posed to obtain reports at the category, herd or individual level (Table 4.2), and the reports are presented in the form of descriptive tables and performance visualization curves. If selected, benchmarks are also included.

Diagram 4.2 Information flow among end-users the interface and the relational database.



4.3.8 Target Users

The objective of the visualization prototype was to use the information tools to help decision-makers achieve profitability goals. However to reach the final end-user it was first necessary to explore which information to use and to assess how to present the information in the most effective way. In this case the goal was to visualize and analyze profitability with two objectives, the first of which was to explore meaningful information that otherwise could be difficult to access and manage, and the second of which was to facilitate the decision-making process.

The operation of the interactive system has been kept simple, so as to avoid providing distractions to the user from the goal (Johnson, 2010) which, in this case, was profitability analysis. To refine the process there were several meetings and discussions with experts from the Québec Centre of Dairy Expertise as well the University of Montréal to obtain their input and develop a more effective interface.

The challenge was to design an interface visualization prototype to explore and test different ways to present the information, with the idea that subsequent versions would be written/developed for the use of herd-managers and advisors to help them make decisions regarding profitability and profit components through the visualization of different graphs taking into consideration the different stages during the productive lifetime of the animals (longitudinal analysis).

For the development of the profitability prototype, a total of 43 herds and 7,850 animals belonging to cohorts (year when the animal calved for the first time) from 2005 to 2013 inclusive were selected from the database. In Canada the quota year runs from September to August, and considering that management practices may be related to quota issues, the selected cohorts are associated with these periods of "quota years". In general a cohort will be any group of similar, contemporary animals.

The integrated dataset contained 114 herds with the complete data required for the development of the prototype (complete feed information and health information for all the required quota years), however only herds with at least 20 calvings per year were selected from the integrated Québec DHI and the Provincial Animal Health Files dataset to feed the database. Due to this restriction only 43 herds were included in the relational database. However it is important to note that the prototype interface allows the visualization of information from any herd that was included in the combined dataset. The interface was designed to read the information provided by the relational database created in MS Access, which was connected by the ODBC query system. This connection system gives the flexibility to visualize new updated data or different herds according to the specific needs of the end-user.

The prototype allows a user to extract information by selecting the identification variables (category, herd or animal identification), with output graphs and/or tables depending on his/her selection. To facilitate the choice process, ribbon lists with the selection options were included for every input cell. During the iterative development of the prototype several options were considered for the selection of the information, among them ribbon lists, table menus and selection buttons, however a ribbon list option was the easiest and most compact, so that as little space on the display was taken up by non-visual display information. The ribbon list was also selected thinking on level of expertise because presenting only the possible and permissible choices may be more appropriate for a regular (non-expert) user to focus on the visual information and not to get confused for instance with an advanced SQL window which could be more powerful, however it would require a higher level of knowledge and expertise to select the information.

During the different iterations of the prototype, and to facilitate the process of comparison and analysis, different curves were included in the same graph and in some cases in the same MS Excel sheet. These graphs showing different data subsets were arranged according to technical and/or biological repetitions or other aspects (Vaas *et al.*, 2012) to allow better comprehension and analysis.

4.4. RESULTS

4.4.1 Description of the Information Visualization Tool Prototype

The developed visualization tool prototype consists of thirteen interactive modules, divided into the three main components previously described. The user has the possibility to filter the information using seven different categories including the main five category-groups, herd identification and animal number. Table 4.2 presents the different variables included for the selection of the information. Because the information is categorical only ribbons with the specific lists requested will be displayed (e.g. only the animals from the selected herd). Table 4.3 presents the thirteen different profitability-related variables that can be selected in the interface for visualization including production, cost and revenue variables. Milk volume and milk components were also included for visualization.

Table 4.2 Variables for selection of the data for visualization included in the Prototype tool

Variable	Name	Description	Use
Herd code	HRD_ID	Code used by DHI to identify the herd (One per herd)	SELECTION
Animal identification	ANM_ID	Code used by DHI to identify the animal (One per animal)	SELECTION
Animal breed	ANB_CD	Breeds registered in the animal file provided by DHI	SELECTION
Region in Québec	REGION	Region where the selected herd is located.	SELECTION
Feeding equipment	EQUIPMENT	Categories of feeding equipment registered by DHI (according to the latest data provided)	SELECTION
Milking system	SYSTEM	Categories of milking system registered by DHI (according to the latest data provided)	SELECTION
Herd Size	SIZE	Categories by the number of calvings per year.	SELECTION

Table 4.3 Variables included in the prototype tool for visualization purpose

VARIABLE	UNIT	DESCRIPTION	USE
Age of lifetime	Days	"X AXIS"	VISUALIZATION
Cumulative Profit after Variable Cost	CDN $	Lifetime income deducted heifer cost, feed cost, service-breeding and health cost	VISUALIZATION
Cumulative Milk Value	CDN $	Lifetime milk value	VISUALIZATION
Cumulative Feed Cost	CDN $	Lifetime feed cost	VISUALIZATION
Cumulative Service-breeding cost	CDN $	Estimated cost of services based on recorded events	VISUALIZATION
Cumulative Disease cost	CDN $	Summary of the estimated cost of all the recorded health events, including discarded milk.	VISUALIZATION
Cumulative Fat Production	KG	Cumulative fat production expressed in kg.	VISUALIZATION
Cumulative Milk Production	KG	Cumulative milk production in kg.	VISUALIZATION
Cumulative Milk Protein	KG	Cumulative milk production in kg.	VISUALIZATION
Cumulative F&L problems cost	CDN $	Estimated cost of recorded Feet and Legs problems	VISUALIZATION
Cumulative Reproduction Problems cost	CDN $	Estimated cost of recorded reproductive health issues	VISUALIZATION
Cumulative Mastitis Cost	CDN $	Estimated cost of recorded clinical mastitis issues	VISUALIZATION
Cumulative Margin over Feed Cost	CDN $	Cumulative milk value minus cumulative feed cost	VISUALIZATION
Cumulative Optimal Profit	CDN $	Cumulative milk value minus (heifer cost, feed cost and one service by lactation)	VISUALIZATION

4.4.2 Categories and Visualization Groups for Benchmark

The capabilities of the Profitability prototype as a decision support system tool can be demonstrated by an example of how the multidimensional components, transformed into information visualization graphs, can present the end-user with the information required to analyze the current profit of the herd and its evolution over time as well as management decisions that might be affecting profitability.

4.4.3 Category-group dimension

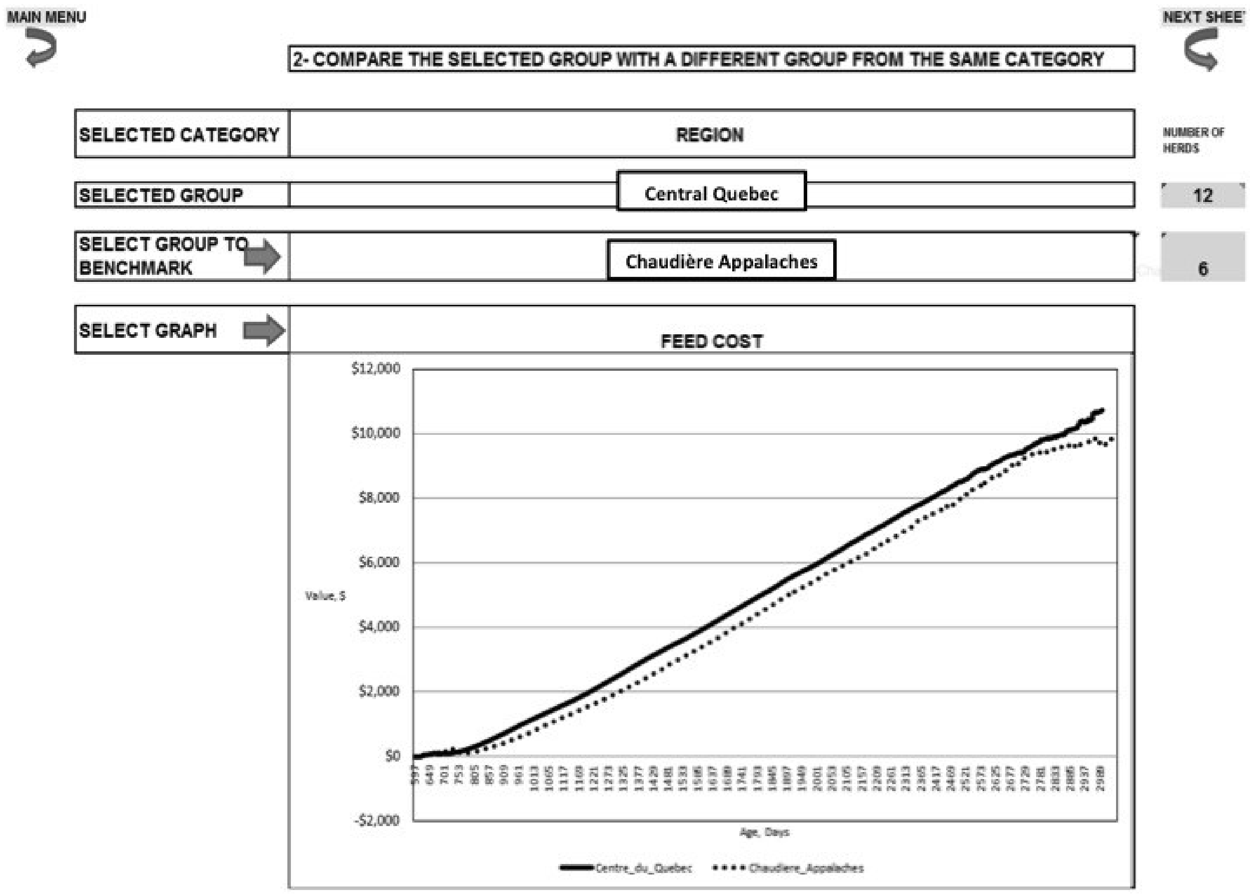
For any herd-manager the first requirement is to understand what the current profitability of the herd is, how its profitability compares to its peers (benchmark by Categories) and which factors are affecting profitability that require management attention (Individual analysis). Table 4.4 shows the different levels and options the end-users of the prototype are presented with to visualize the information according to their needs. For instance, depending on the user interests the prototype can be accessed from different starting points like Category or herd or animals within the selected herd. If the end-user priority is to visualize herd profitability results and compare them to herds with similar characteristics such as region or breed, the end-user should first select a Category-group for benchmarking purposes (e.g. Region – List 1.1 from Table 4.4), then secondly select the herd and cohort year (List 2.1 from Table 4.4) to visualize the different reports and curves designed for herd profitability analysis.

Table 4.4 Menu list of the different levels and visualization curves for Profitability analysis

1- CATEGORY AND GROUP LEVEL
List 1.1 – Selection of the General Category: Breed, Region, System, Feeding Equipment, Herd Size
1.2 – Compare the selected Group with a different Group from the same category
2- HERD LEVEL
List 2.1- List of herds and main descriptive characteristics from the selected group
2.1- Select a herd and year cohort from the selected Category and Group
2.2- Benchmark the selected year cohort with different year cohorts from the same herd
2.3- Reports of average number of animals in production, age in days and profit-related values for a selected period of time
3- ANIMAL LEVEL
List 3.1- List of animals from the selected herd and year cohort
3.1 – Select an animal to visualize profitability curves, margin over feed cost and cumulative extra cost curves
3.2 – Benchmark curves among individual performance, herd and selected Category
3.3 - Opportunity cost curve for the selected animal
List 3.2- List of animals and cumulative results from the same herd to compare with the selected animal
3.4 - Benchmark curves between two animals from the same herd
3.5 – Benchmark opportunity cost curves

If the end-user has an interest in benchmarking groups from Categories, the prototype was designed in a way that benchmarking between groups of the same Category is allowed (Table 4.4, numeral 1- Category and Group Level). An example is shown in Graph 4.1 where Region was selected for benchmarking and Central Quebec and Chaudière Appalaches were the selected regions in the Province for comparison. Each curve in Figure 4.1 represents the mean cumulative Feed-cost for all the animals in the selected regions per day of life. This means that for an average animal located in the Chaudière Appalaches region in Québec that lived 1800 days, the mean cumulative Feed-cost was $4,400 versus $4,900 for an average animal that lived the same number of days, but was located in the Central Québec region. The user can visualize the information of thirteen different variables relevant to Profitability (Table 4.3). All the cumulative curves are presented in a similar way as described for the cumulative mean Feed-cost. Each of the curves represents the mean of the cumulative value of the selected variable for all the animals in the same Category-group at that specific age in days. Once the Category-group is selected, the user can select the herd and cohorts to visualize and benchmark.

Figure 4.1 Cumulative Feed Cost benchmark between two regions of the Province of Québec
This figure shows the cumulative feed cost means by day of lifetime for two groups of the same category. In this case the selected category was Region (Table1) and the two selected regions to visualize were Chaudière Appalaches and Central Québec. The numbers on the right of the figure indicate the total number of herds in each group. The means obtained to develop the visualization curves for the group Central Québec correspond to animals belonging to the twelve herds indicated on the right.



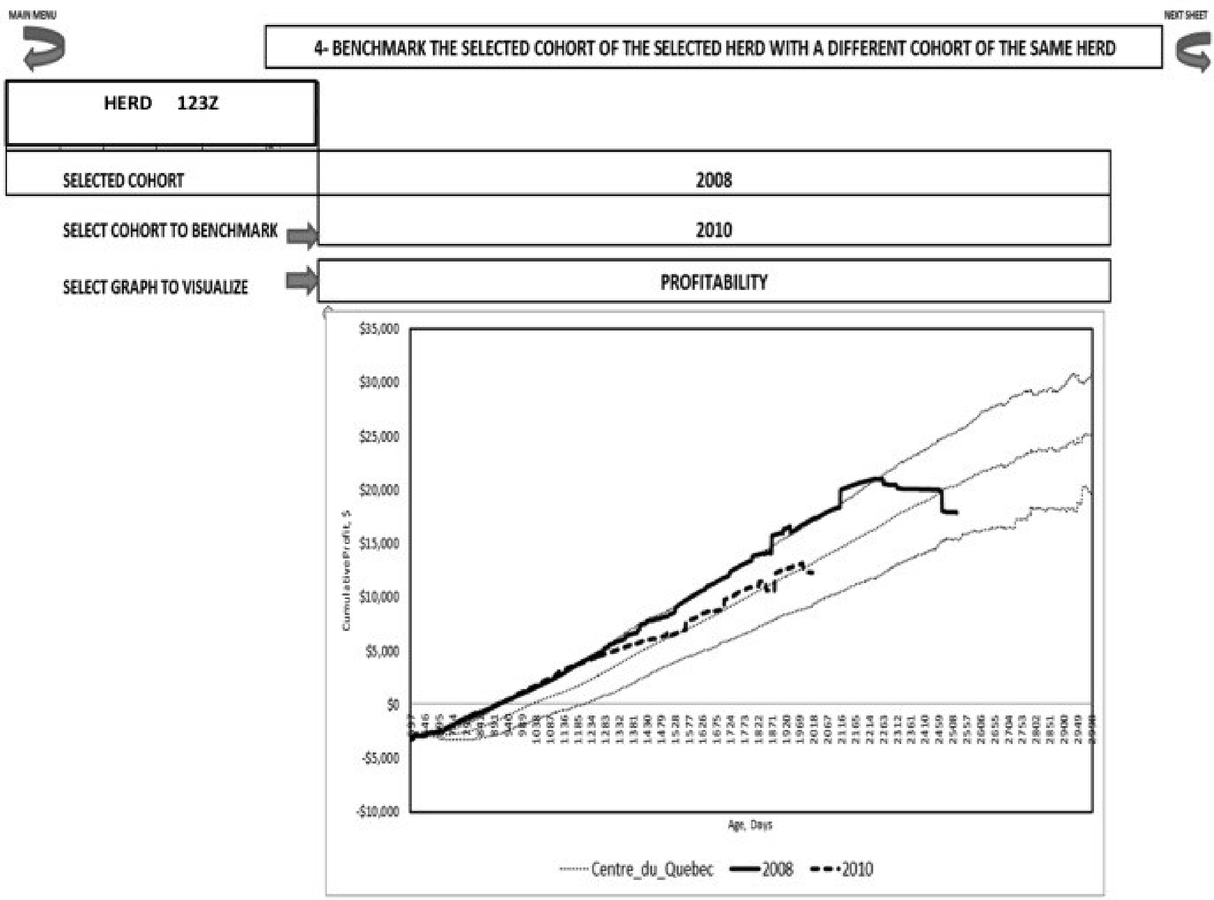
4.4.4 Herd Dimension

To analyze the impact of different variables at the herd level, the visualization results of herd profitability performance were divided into two categories. The first category was the analysis by year of cohort. The cohort year refers to the group of animals that started their first lactation in the same milk quota-year (September to August). Cohort years from 2005 to 2013 were included in the prototype allowing the analysis not only of the results of one selected year, but also to monitor the evolution in the results of profitability and the different included variables over time. This analysis would be facilitated by presenting these comparisons among cohorts in graphics. The second category considers the day-by-day profit evolution by presenting average by day herd results for selected period of times.

For the first category, Figure 4.2 presents the mean Cumulative Profitability after Variable Cost by day of Lifetime for two different year cohorts of the same herd located in the Central Québec region including the mean and distribution curves (10 and 90 percentiles) for the selected Category-group (benchmark). The Cumulative Profitability for the animals of the 2008 cohort closely followed the top 10% curve for animals with the best profitability in the Centre of Québec region (the selected Category-group was Region), while the profitability performance for the 2010 cohort approximated the average profitability of the region. Here is where the herd-manager might be interested in understanding why the profit of the latest cohort was inferior to the 2008 cohort to the extent that – as an example – an animal that reached 1900 days of lifetime and belonging to the 2008 cohort made $14,000 versus only $11,000 for an animal of the 2010 cohort at the same age.

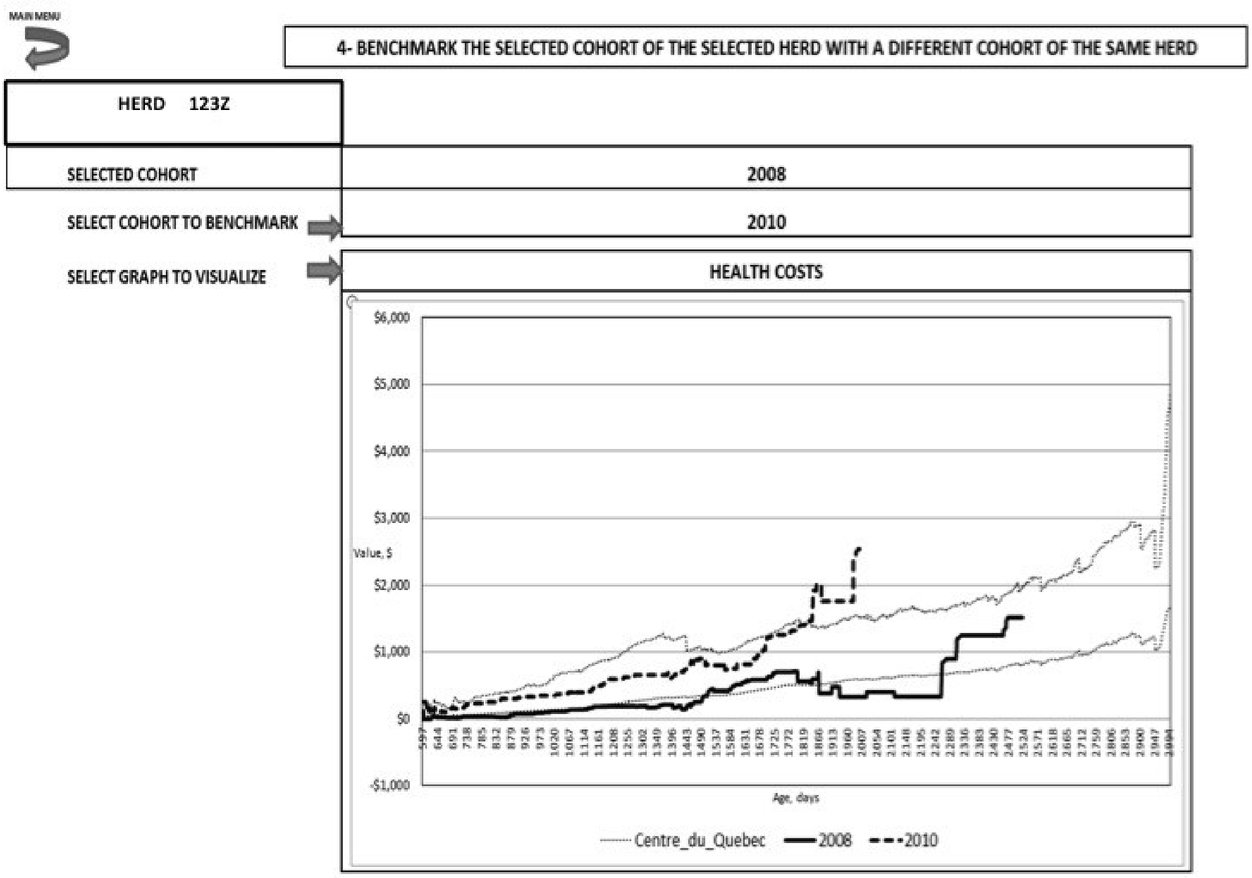
Visualization will not provide the end-users with the final answers to their management questions, however it will show the results of profit and profit-related variables in a way that will help them to understand and explore factors that affected profitability.

Figure 4.2 Profitability benchmarks between two year-cohorts of the same herd and Category-group



The interface included in the same MS Excel in the same sheet twelve additional graphs to help the end-user to visualize and possibly find explanations of the cause of the difference in profit. These graphs can be selected to be visualized by the end-user with the help of a ribbon list menu. The graphs included in the visualization tool were the cumulative values for milk revenue, feed-cost, milk and milk components, health costs (including cumulative clinical mastitis costs and cumulative reproductive problems costs) and breeding-service costs, among others. For the selected herd and cohorts, the health cost graph. Figure 4.3 shows an important difference between both cohorts. While the 2008 cohort health cost tracked the mean curve for the region, the 2010 cohort Health approximated the top 10% of the highest costs for the region. This graph indicates to the herd manager that it is necessary to pay attention to the health issues of the 2010 cohort.

Figure 4.3 Comparison of cumulative health costs between two cohorts of the same herd with benchmarks by Category-group



The information by herd by cohort is useful when the herd-manager is analyzing the overall performance of the animals selected for production in the herd every year and in particular, concerning strategic and tactical decisions about reproduction and selection. However it is also important to consider the day-by-day profit evolution to analyze the consequences of decisions made or situations that might be affecting the herd, such as health events or low volume of production.

The second category of the herd analysis evaluates the evolution of a herd during a selected period of time by presenting average day results. The prototype presents the end-user with two different comparative graphs in a single MS Excel sheet (Figure 4.4). The first graph shows the number of animals in production in the herd during the selected period of time. The second graph presents the mean age in days for the same group of animals. These graphs allow monitoring the relationship between age and cumulative profit, given that a very young herd will have had fewer chances to increase the cumulative profit while an older herd might be foregoing the potential returns of postponed replacement therefore it is important to keep the balance between age and number of animals.

The analysis of variables per day is presented in two different scenarios. The first one was developed with estimates of the means per day of productive life (days after the moment of first calving) for all the animals in production during a selected period of time. For example profit per day of productive life is equal to the cumulative profit divided by the number of days in production after the moment of first calving and likewise for the other selected variables (feed cost, health cost etc.). The scatter plot of this information (average per day of productive life by date in time) will present the average profit per day of productive life (or any other selected variable) for the animals in production in the selected herd at that specific period of time.

The means per day of productive life give the user an idea over time of how the policies about use of supplies or any other management aspect had an impact on the performance of the animals in production and affected profitability. For instance, in Figure 4.5 for almost a year and a half the feed cost was stable between $4.5 and $5.0 per day of productive life. If the producer knows the average number of days in production of the herd (the prototype provides this data), this information gives him at a glance the cumulative feed cost of his cows in production and allows him to detect situations that would affect the overall herd profitability. In the case shown in Figure 4.5, after August 2012 the mean cost per day of productive life was above $5. If that extra cost were $0.30 per day of productive life, and the average number of days of productive life were 500 days, then the feed cost for each cow in production increased by an extra $150 during its productive life.

Figure 4.4 Number of animals by selected dates and their average age in days

In this figure the upper graph, shows the evolution of the number of animals in production for a selected period of time (x axis). The lower graph shows the curve of the average age in days for the animals in production during the selected period of time.

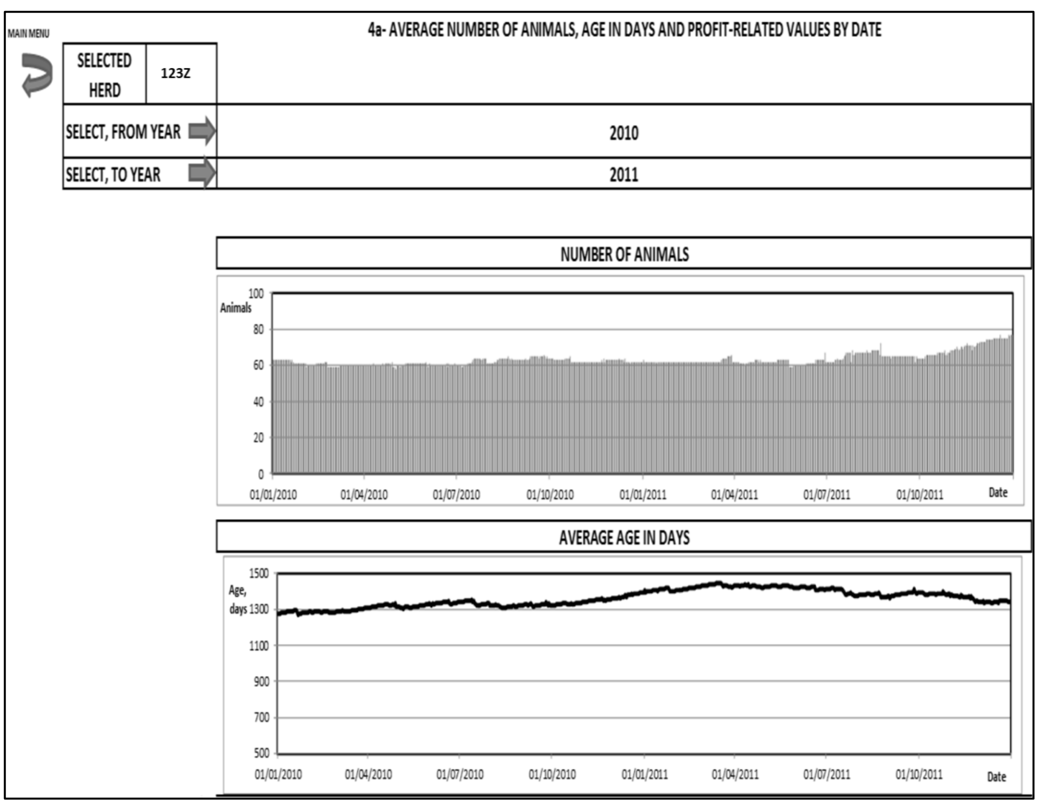
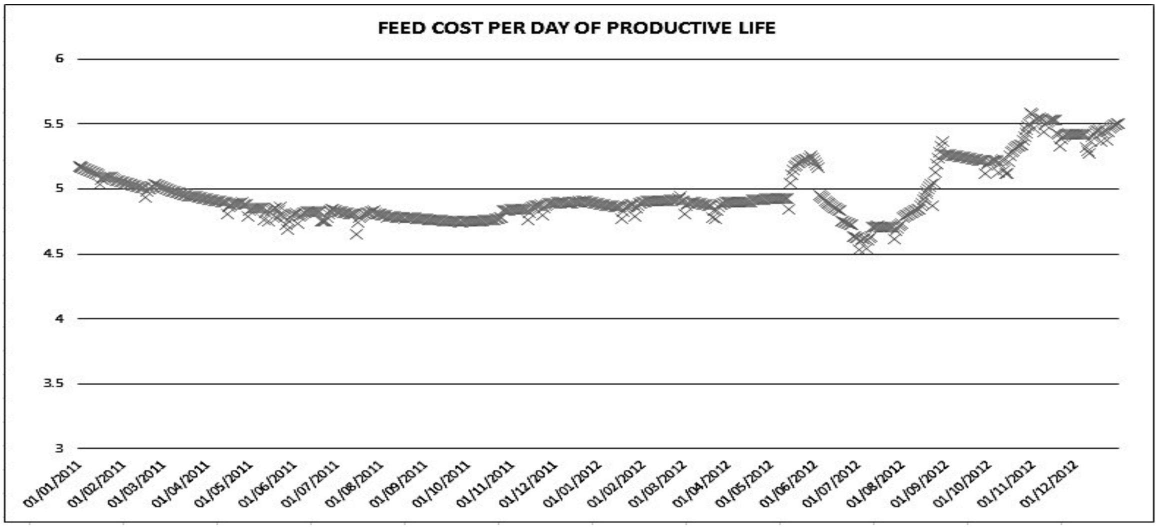


Figure 4.5 Average feed cost by day of productive life for animals in production for a selected period of time

This figure presents the average cost of the feed supply for the herd. Each point represented with an X represents the average feed cost for the animals by day of productive life in production at that specific moment. The X axis represents the dates in chronological order and the Y axis represents the cost in $.

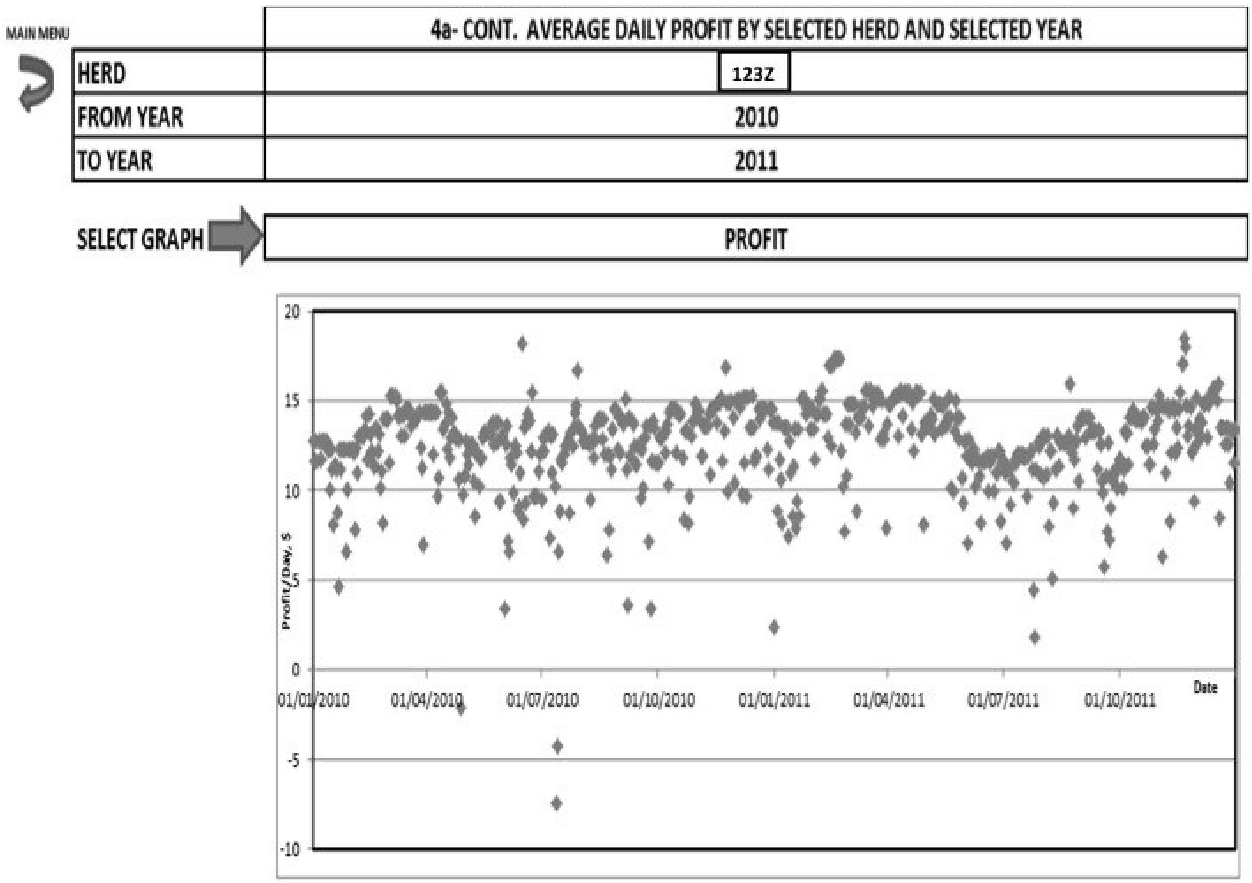


An example of the means of cumulative profit per day for a selected herd and period of time is presented in Figure 4.6 Visualizing profit results per day gives the user an idea of the dispersion of the data (e.g. herd day average profit), potentially identifying developing trends in the data. As be observed in the graph in Figure 4.6, for example, during the second half of 2011, the trend in the daily profit results was lower compared to the results in the first half of 2011 or the last part of the same year. The visualization of depressed profit by day in the second half of 2011 identifies a potential problem requiring management attention.

These variables calculated per day give the decision maker information on the average amount of money spent or obtained per day for the animals in production at a specific moment in time (dates) helping the user to keep control of cash flow and identify issues that require management attention and/or analysis.

Figure 4.6 Average profit per day for animals in the herd for a selected period of time

This figure shows a scatter plot of the average daily profit of the animals in the herd for a selected period of time. Each diamond represents the mean profit on a specific day.



4.4.5 Individual Cow Dimension

The herd-manager would be interested in obtaining information about the animals in the herd. A third dimension of the prototype that permits analyses of individual animals was developed. So it has been shown overall impacts that affect the profitability at the herd level and factors that may have caused changes in profitability (e.g. increased health cost). However an important part of management is to make operational and tactical decisions, including analyses of individual animals. To select the animals the end-user is presented with a table with a list of animals from the selected herd and cohort (Table 4.5). It is also possible to display animals from a different cohort. From Table 4.5 animal 1015 (highlighted) was selected to visualize its performance.

Table 4.5 List of animals from the selected herd and cohort-year from the visualization tool prototype

ANIMAL	PARITY	AGE IN DAYS	CUMULATIVE DIM	CUMULATIVE PROFIT	FEED COST	MILK VALUE	HEALTH COST	INSEM. COST
1001	1	1,078	115	-2,364	685	2,323	225	140
1002	1	1,688	334	-1,936	1,746	5,538	1,468	630
1003	2	1,234	344	126	1,893	5,798	225	280
1004	2	1,511	732	6,621	4,361	15,955	1,691	280
1005	2	1,505	658	6,731	4,152	14,511	236	210
1013	3	1,634	809	9,194	5,321	18,885	998	280
1014	3	2,136	1,226	12,258	7,435	26,208	2,539	700
1015	3	1,972	1,142	12,368	6,880	24,329	1,220	770
1016	3	1,970	1,129	12,971	6,977	24,245	576	630
1018	4	1,946	1,058	9,027	6,414	20,470	1,286	560

With the selected animal the end-user is offered three individual curves that summarize the revenues and costs of the animal. The first curve (Figure 4.7) shows the costs caused by the different recorded health issues and breeding-services. For the selected animal the cumulative health cost was $1,220 by 1972 days of life. This cost is explained by an episode of displaced abomasum, then a milk fever episode and finally a retained placenta problem. Breeding-services total cost was $770 for eleven services. The observed animal had three calvings, therefore in theory only three breeding-services should have been required, however there were extra eight inseminations with a total cost of $560. The combined costs of the health problems and the extra inseminations totalled $1,780.

Figure 4.7 Extra costs cumulative curves for an individual cow

This graph shows the different events in the lifetime of a dairy cow and their cost impacts. The gray bars represent the different insemination services and the age of the animal when they occurred (x axis). The cost of these inseminations is accumulated in the CUMUL SERVS COST curve. The white bars represent the health events and the numbers in the bars correspond to the codes of these health events. The cost of the health events is cumulated and is represented by the CUMUL SERVS COST curve. The total of the additional costs is represented by the CUMUL EXTRA COST curve.

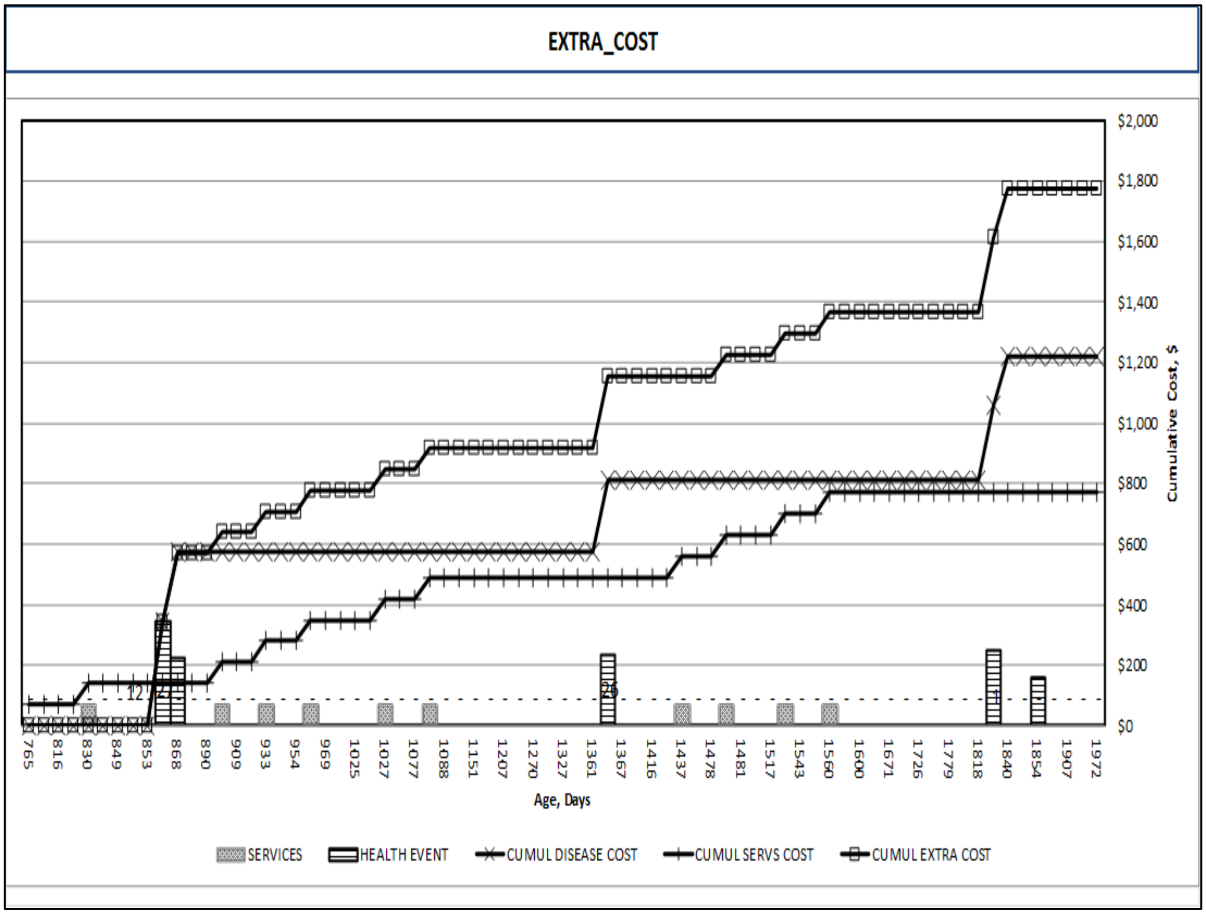
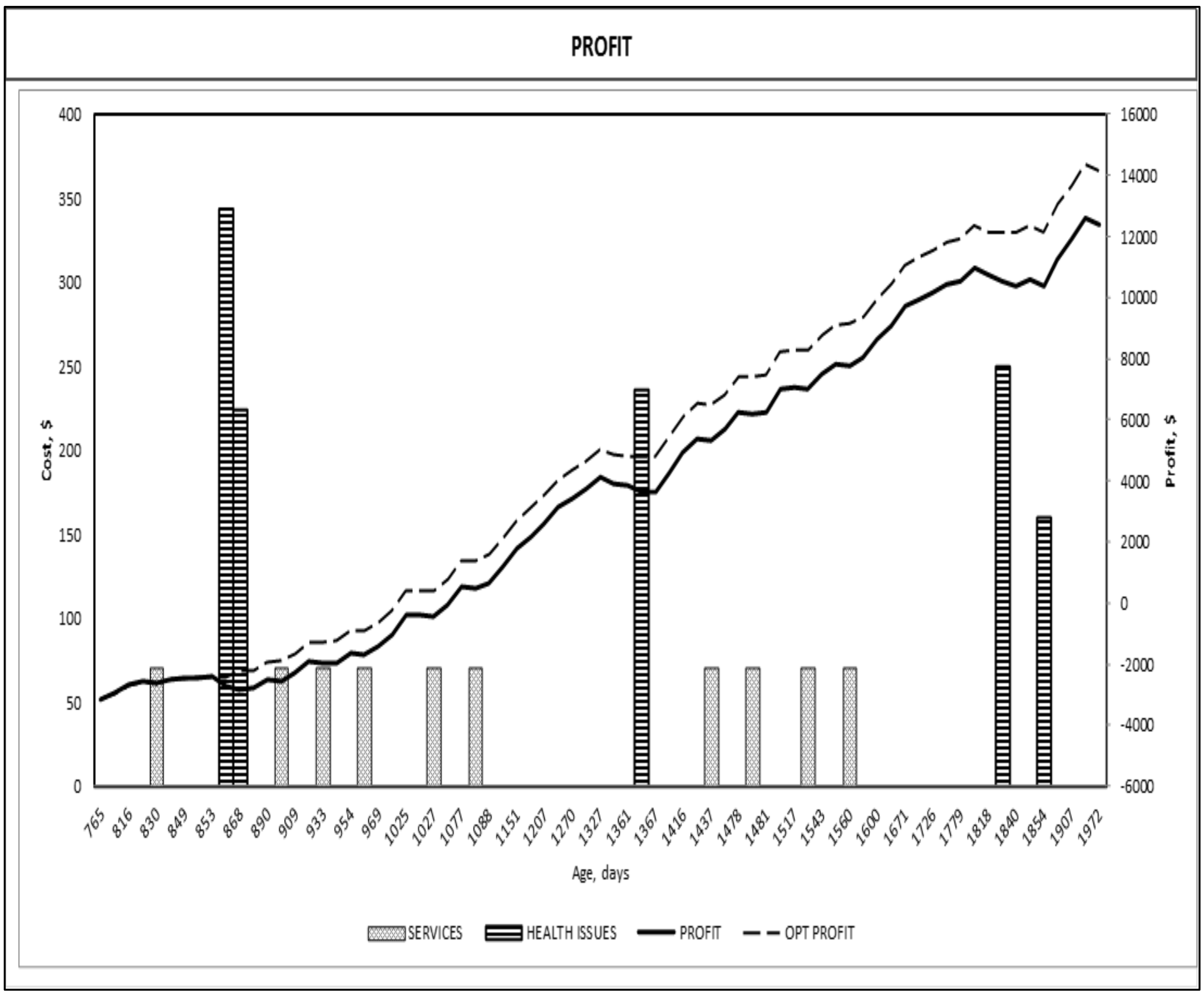


Figure 4.8 presents the Cumulative Lifetime Profit (**LTP**) for animal 1015. The Cumulative Lifetime Profit (LTP) of this animal was $12,368 (Table 4.5). The dotted line in Figure 4.8 represents the profitability without the avoidable costs (i.e., the cumulative profit we would have expected without the deductions caused by the health costs and the extra breeding-services). As an example, the line assumes no health problems and only one breeding per conception. The more health events and the more additional breedings that occur in the lifetime of the animal, the wider the gap between the curves. Figure 4.8 also shows the extra breeding-services cost and the

extra Health cost on a secondary vertical axis (left). For the selected animal as a consequence of the extra costs a potential profit of $1,780 was not achieved, or in other words 12.5% of the potential profit was foregone because of the costs caused by health problems and extra breeding services.

Figure 4.8 Cumulative Lifetime Profit and cumulative profit without avoidable losses for an individual cow

The curves in this figure represent the cumulative lifetime profit, interpolated by day of life (black), and the cumulative profit without the avoidable cost (dashed). The moment when the avoidable costs (extra services and health events) were incurred is represented by the vertical bars and their respective costs are illustrated by the Y-axis located on the left. The right Y-axis shows the values for the cumulative profits.



The Prototype allows the end-user to compare all the different components of profitability. Visualization curves of milk volume and components, revenues and variables costs were also developed. Figure 4.9 presents the cumulative breeding-service cost for the selected animal along with the relevant benchmarks. As can be observed, the cumulative cost of breeding-services for this individual was above the herd mean cost and the mean cost for the region. The cumulative breeding-service cost was comparable to the curve for those animals with a cumulative breeding-service cost in the top 10% in the herd (upper dashed line). The average cost for the herd can also be compared with the average for the region (twelve herds were included in the database for Central Québec). In this case they have a very similar performance.

The Cumulative Health cost curve for the same animal is shown in Figure 4.10. As observed in the graph, this cost was above the mean Health cost of the region and very similar to the mean cost of the herd. In this case the Infovis tool is not only useful to visualize the animal results, but also shows the herd-manager a comprehensive and multidimensional view of the profitability results at the animal, herd and Category-group levels.

Figure 4.9 Cumulative breeding-services cost for a selected animal with herd and Category-group benchmark curves

This figure shows the cumulative cost curve caused by breeding services during the lifetime of the animal (curve with stars). The black curve represents the mean cumulative cost for the herd by day of lifetime (X axis) and the dashed curves are the 10 and 90 percentiles of the distribution. The gray curve is the benchmark for the herds from the region.

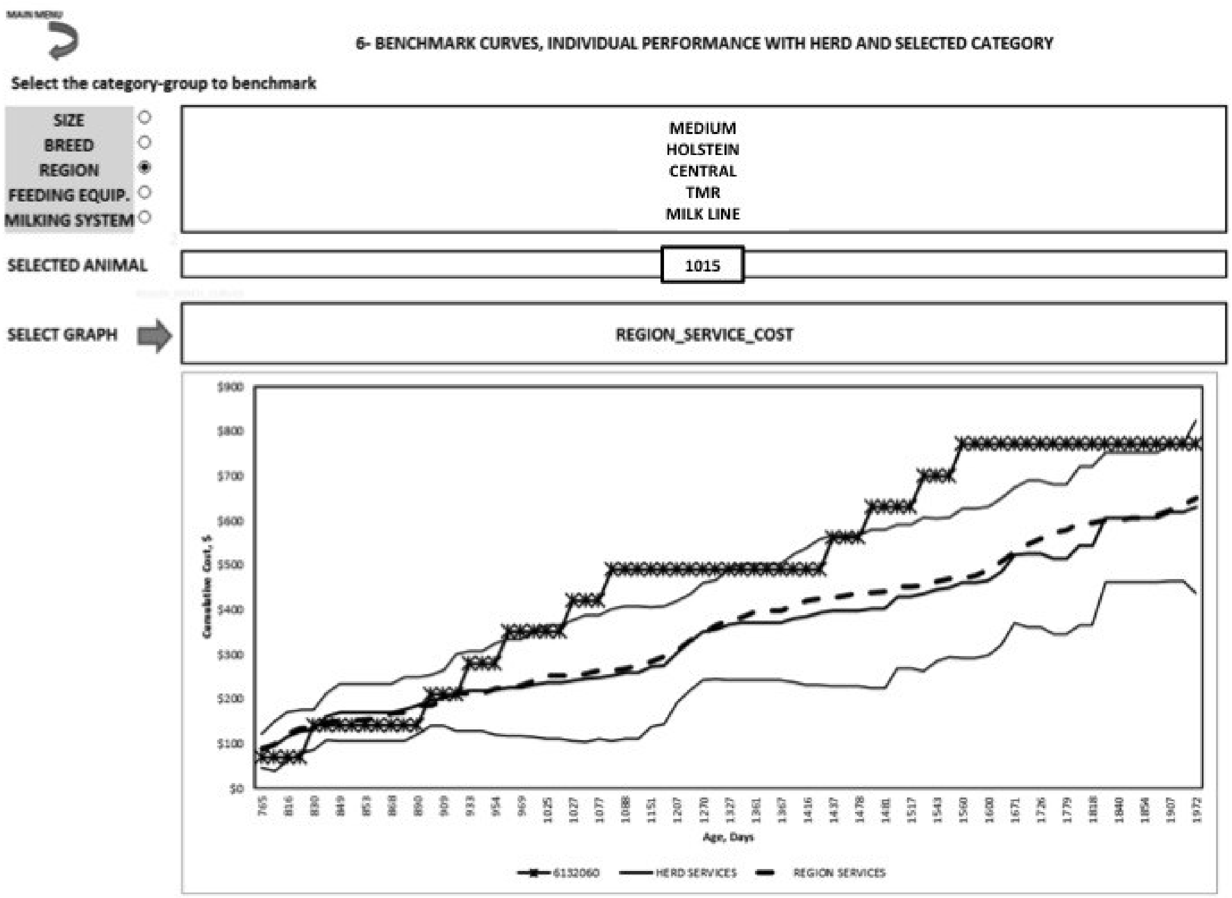


Figure 4.10 Cumulative health costs for a selected animal with category-group and herd benchmark curves

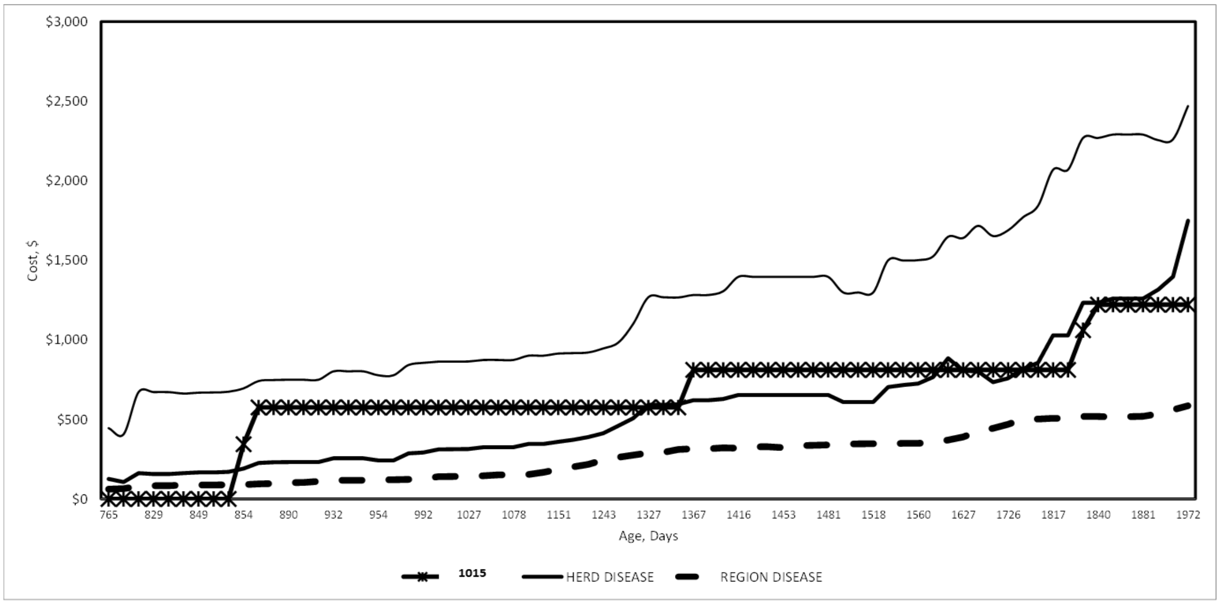
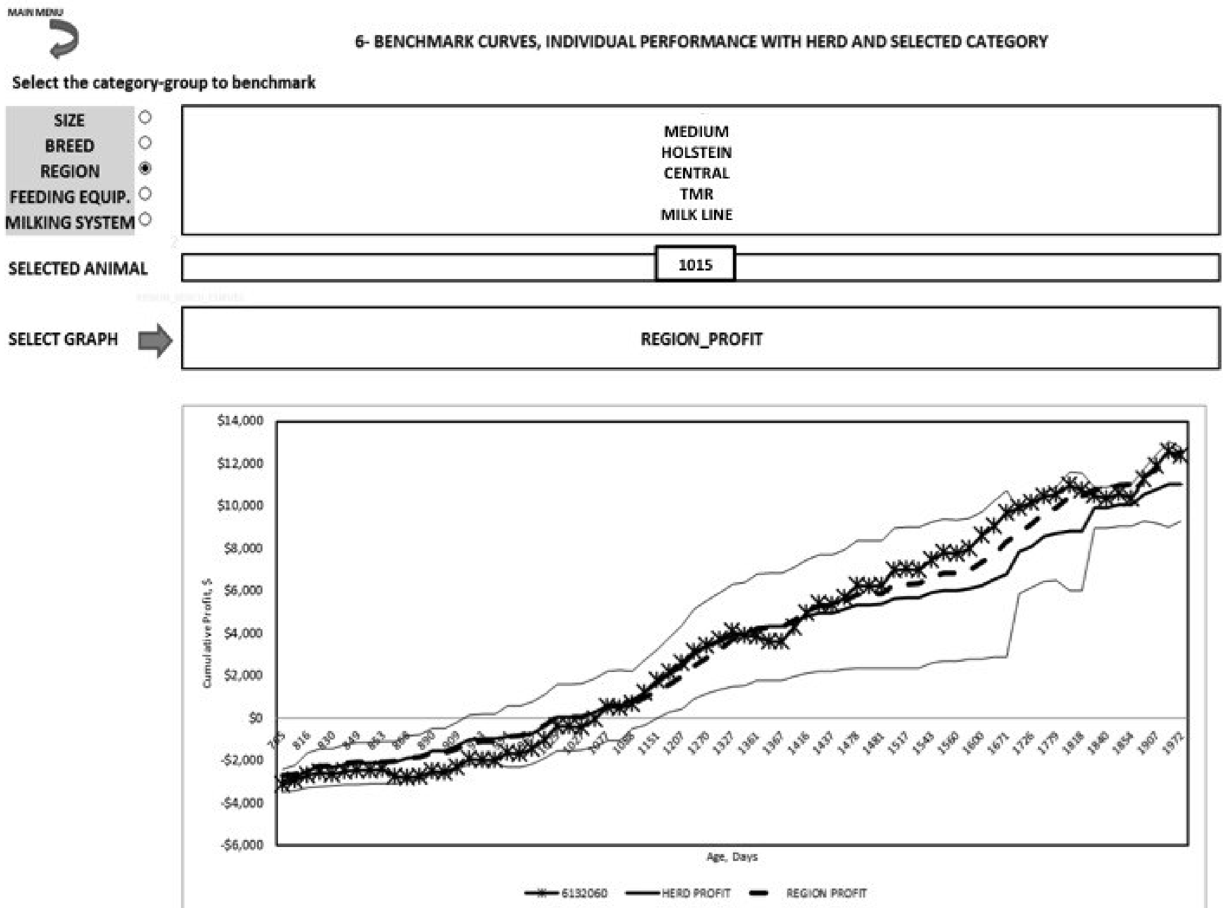


Figure 4.11 presents the Cumulative Lifetime Profit (LTP) curves displayed in the prototype. It can be observed from Figure 4.11 that the LTP curve for this animal initially was less than the herd mean and the region mean, however by the beginning of the second lactation the LTP was similar to the mean and by the beginning of the third lactation cycle was above the mean. It is important to consider that these comparisons are only show the Cumulative Profit of the animal across her lifetime. There is no measurement of the marginal contribution of the animal to the herd. Therefore it was important to introduce visualization of the Opportunity Cost of Postponed Replacement.

Figure 4.11. Cumulative Lifetime Profit curve for a selected animal with benchmark curves



The concept and use of lifetime profit adjusted for the regressed opportunity cost of the postponed replacement (**LTPOC**) has been discussed in the literature of the analysis of profitability of dairy herds (Van Arendonk, 1991, De Haan *et al.*, 1992, Kulak *et al.*, 1997) however no references were found about its visualization in dairy cows. Herd managers often have to face the decision about keeping or culling an animal. The use of both the cumulative lifetime profitability curve and the LTPOC curve might help herd managers to assess the results of an animal to optimize the stay-culling decision. When there is the need to make a decision about replacing an animal in the herd, the prototype helps the herd-manager to visualize and compare the performance among animals from the same herd.

To facilitate the comparison process the visualization tool provides the end-user a list of animals in the herd including profit per day and LTP for animals from the same cohort of the initially selected animal. Profit per day of life was assigned a ranking score by classes. The animals were grouped in five classes from 0 to 4 (0 for the animals with the lowest 20% profit per day and 4 for the top 20%). These classes allow the end-user to facilitate the comparison of animals with similar performances in profit per day of life as well make decisions about stayability, however in future versions it could also be possible to rank the individual animals within the cohort (rank from 1 to n). This ranking was designed as a function of cumulative lifetime profit divided by the total age in days.

Figure 4.12 presents the LTP curve for the initially selected animal (1015) compared to the mean herd Cumulative Profit (black line) and to animal 1018 (Table 4). While animal 1015 was ranked in category 4 with a mean Profit per day of $5.74, animal 1018 was ranked in category 3 with a Profit per day of $4.46. When comparing both profit curves it can be observed that the second animal had a superior performance during a good part of its lifetime, however after day 1400 the Cumulative Profit started to decrease, probably due to a persistent cystic ovary problem and then a case of CM. Figure 4.13 compares LTP REG OC for animals 1015 and 1018. By comparing both curves the herd manager can make a decision about which animal should be removed first from the herd based on both components, Cumulative Profit and Profit OC.

Figure 4.12. Lifetime Cumulative Profit benchmark among two animals from the selected herd including herd curves of distribution (10 and 90 %)

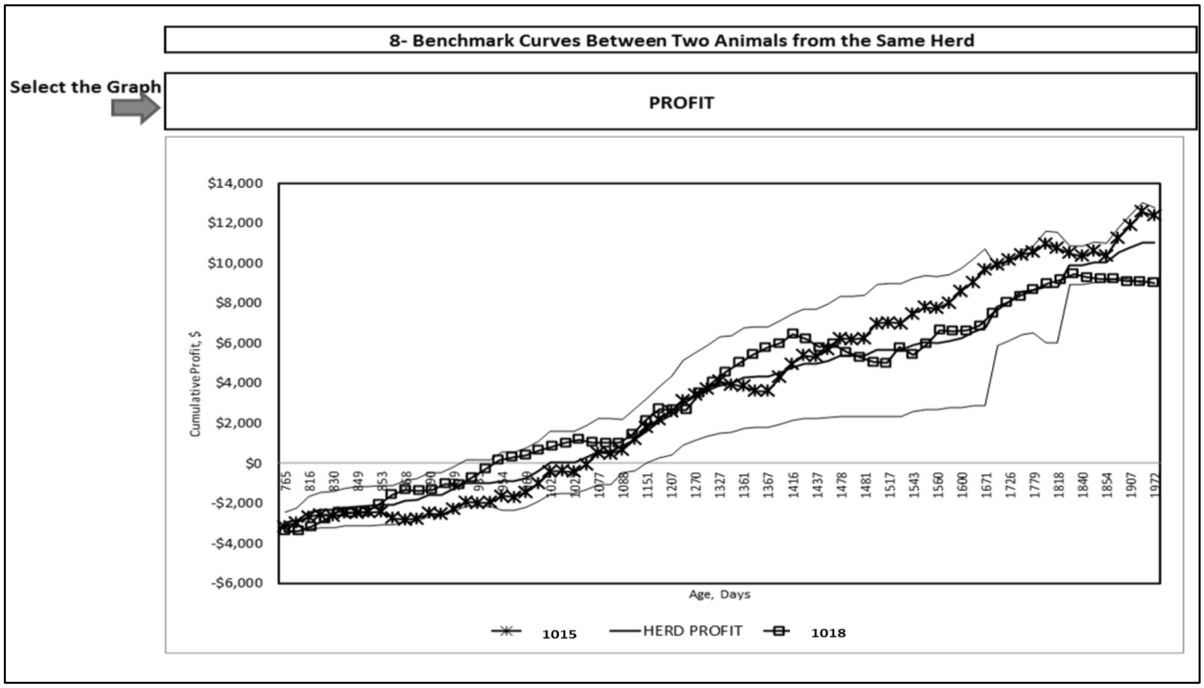
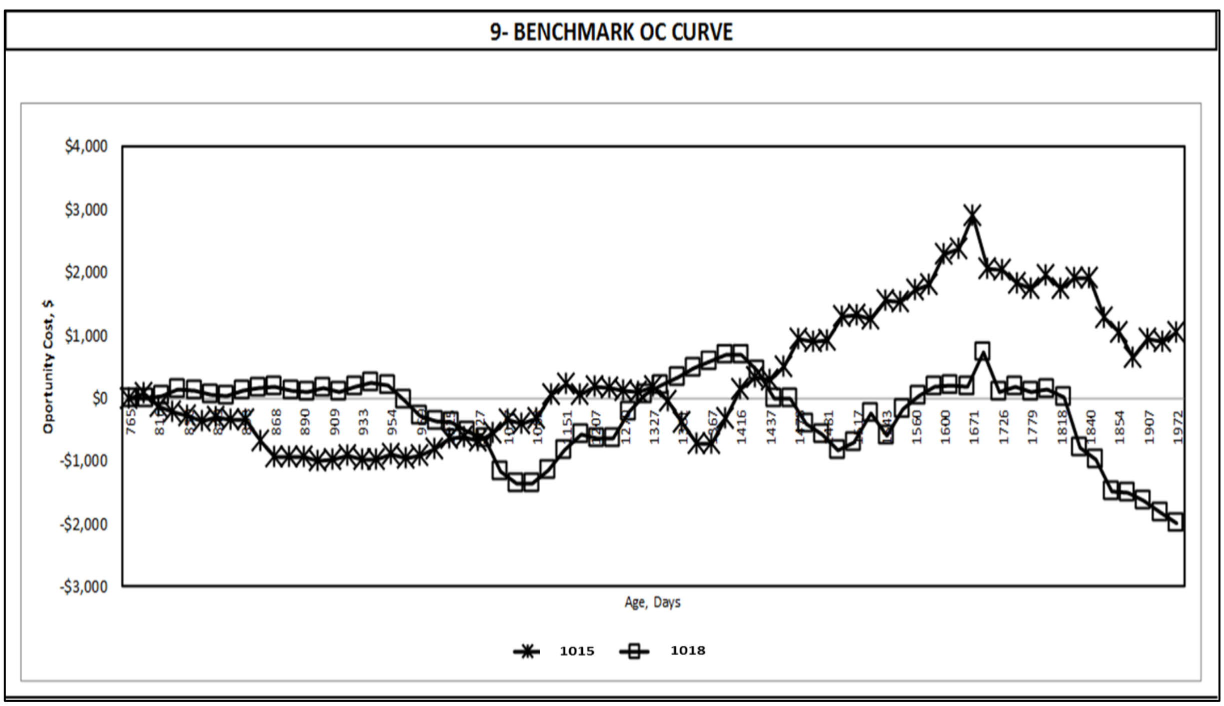


Figure 4.13. Comparison of the Cumulative Lifetime Profitability adjusted for the Regressed Opportunity Cost of the Postponed Replacement for two animals of the same herd and cohort-year



4.5 DISCUSSION

One of the main goals of this visualization prototype was to present benchmark reports. The prototype allows the end-user to select the main category-groups to be displayed as benchmarks at the herd and individual level with the help of filters and ribbon lists in the different dynamic graphs allowing the user to reach conclusions by comparing results in at herd and individual levels.

The prototype presents the decision maker with options to select benchmarks related to the herd management characteristics allowing more specific comparisons. For instance, it might be of more interest to compare the herd profit performance or health costs with results obtained by herds in the same region rather than from the whole province. These specific comparisons will also give decision makers the opportunity to set realistic goals, based on specific criteria such as the region where the herd is located or the milking equipment in current use. So far the prototype only allows benchmarking one category at a time and not combined category groups, e.g., region and milking system. However, the concept could easily be extended to other groupings or combinations, e.g. organic milk producers, or the combination of region and milking system at the herd level.

The comparisons at a herd level were designed with two main purposes. The first one was to allow the decision-maker to monitor, through visualization curves, the longitudinal evolution of different components affecting profitability among the different cohorts in production. Comparisons among different cohorts allow the analysis of situations such as if the criteria for selecting the animals in one specific year were successful, or if, on the contrary, they need to be reviewed. From another viewpoint, if the analysis of the profitability results of the cohort of year

2011 are lower compared to the cohort of year 2009, the user can visualize these results with the prototype interface and can also drill down and observe different aspects such as breeding-service costs, milk production and milk costs, among others, that could help explain this result. It is expected that this tool will help the decision maker to identify the cause(s) of the difference in profitability or reassess if the strategic and tactical decisions made in the past were the right ones. The second purpose of the herd analysis was to allow monitoring the day-by-day or operational decisions. For instance, the prototype allows following the average daily cost of feed for a selected period of time. Therefore if changes in the costs are expected it is possible to assess the impact on cash flow.

In contrast to other profit reports that accumulate individual information by different lactation cycles (St-Onge, 2004, Giordano *et al.*, 2011), the profitability information visualization prototype presents the information accumulated by lifetime. The productive lifetime is considered as a full cycle where the animal should recover the cost of herself as a heifer at the moment of first calving and also return the expected profit. Another difference in the prototype is the inclusion of a more detailed cost analysis thanks to the use of the data provided by Québec DHI and the Provincial Animal Health File databases combined in a relational database which allowed the inclusion of costs of the different health events recorded and permitted a drill-down analysis presenting summarized health costs, but also detailed costs of some of the diseases recorded such as Clinical Mastitis and Reproductive Problems. As previously described, the impact of these health costs on profitability can be visualized, thereby encouraging herd managers to collect more inclusive data and also to focus their attention on health cost control.

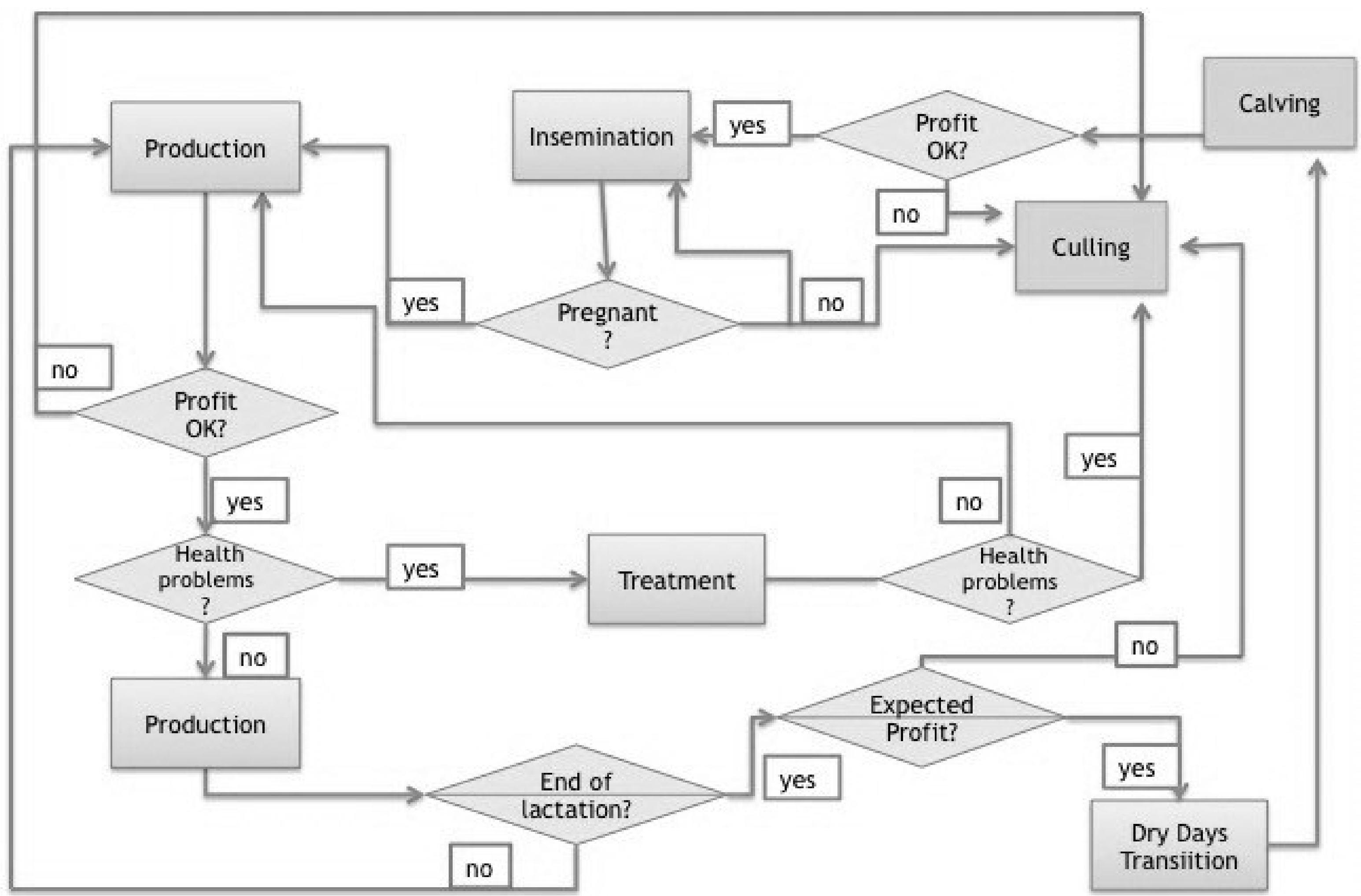
One limitation of the current prototype was the lack of real, herd-specific cost information for the eight recorded health events in the combined database. However the estimation of health and breeding-service costs was based on data collected in the province and gave us the opportunity to include these costs as part of the profitability formulae and to visualize the impacts they had on the cumulative lifetime profitability of the animal. The resulting graph that combined the interpolated cumulative lifetime profit by day of life with the cost of the different health and breeding services events during the lifetime of the animal (Figure 4.8) shows in a clear way the impact of these events on profitability and gives the decision-maker a very clear idea of what has happened with the animal during its lifetime. This is particularly important for animals with cycles longer than one lactation where the cumulative number of inseminations or health events over two or three years could end up being part of the forgotten files, given the immense amount of data and decisions a herd manager has to deal with on a daily basis. However, having the opportunity to observe all the information recorded for one animal in a visualization curve and benchmark it against other animals would be of potential benefit for more well-informed and better decisions. It is expected in the future that the actual health and breeding-services costs will be input by the herd-manager with the development of a pilot project of this prototype. This will provide a better analytical potential for the herd-manager and also better quality benchmarks.

The moment of removing a cow from the herd has been widely studied from different points of view (Salfer, 2002, Nordlund and Cook, 2004, Sewalem *et al.*, 2008). The prototype is intended to help decision makers monitor the evolution of the animals, not only with the aim of culling optimization purposes, but also to provide, in a visual way, information that otherwise would be not so obvious and sometimes difficult to detect, as discussed above. Diagram 4.3 identifies the different moments when the dairy producer could monitor factors affecting profitability in order to make decisions regarding an animal. For example, if the first breeding-service after calving failed should the animal be inseminated again? Or, if at the end of the lactation period, did the animal achieved its profitability goals?.

Different profitability formulae that show various aspects of the performance of the animal were included for visualization in the prototype. With LTP it is expected that the decision maker can observe if the selected animal is reaching the expected profit goal and compare the performance of the animal with other animals in the herd. It also allows the comparison of the individual results with any selected category-group.

The inclusion of the LTPOC formula defined by Van Arendonk (1991) and adapted by Mulder and Jansen (2001) as part of the visualization curves allows decision makers to monitor the marginal contribution of the animal to the overall herd profitability. This is important because it facilitates the understanding of the role the animal is playing within the overall profitability of the herd. It is not impossible that one animal might have negative results for a given period of time, for instance due to a long days dry period and yet still contribute positively to the long term profitability of the herd. However, if the contribution of the animal has been consistently below the negative line in the graph for LTPOC (Figure 4.13) for one complete lactation cycle and other related graphs (Figure 4.8) show above the mean costs for breeding-services or health events, this would give the decision maker reasons to flag the animal for culling with arguments better than just mere intuition.

Diagram 4.3 Diagram for the decision making process for an individual animal during a lactation cycle.



Profitability of dairy herds has been a topic approached by DSS. Cabrera (2012) designed a DSS using Linear Programming and Markov chain analysis models to estimate net present values of animals. This DSS was created with the objective to help decision makers to decide if an animal in production in their dairy herds should stay or be replaced. St-Onge (2004) developed an information visualization software named "Herd-Line" to help producers visualize the overall and specific values of the herd as well as individual phenotypic and genotypic performances. This software was developed with the objective of contributing to profitability analysis and the developed prototype allows the dynamic exploration of profit-related databases with the aid of an interactive visualization interface. The idea of St-Onge with this prototype was to allow users to quickly perceive patterns in data, navigate through data using interactive controls and rapidly modify their view.

The current prototype was developed using Microsoft technology that allows the integration of the databases with the designed interface in Excel. It is understood that for the next phases of this project the different ideas and concepts developed in this paper will have to be adapted to software with a larger capacity and also according to the standards and needs of the DHI. It is hoped for the next phase of this research to implement a pilot project with a selected number of herds from the province and, with monitoring by Québec DHI advisors, to evaluate the impact and the use of the information visualization methods on the decision making process regarding profitability.

An additional enhancement to the availability and usefulness of the information could be the provision of printed or online reports, such as for example, average profit for region Central Quebec for each day of life, and also the option to output these numbers into another software file (e.g., csv file) if the user wants to use the data further as part of a management system. For example the computed herd average profit measures might serve as the input data for a whole-farm business budgeting model.

4.6 CONCLUSIONS

The different profitability measures explored in this visualization prototype that have previously been used mostly in bio-economic and genetic analyses could also be used as potential tools for decision-making in dairy herd management on a regular basis.

The multi-level hierarchical approach developed in the visualization prototype allows different users with different interests from the dairy sector (policy makers, advisors, managers) to benefit from the prototype tool.

The herd analysis by year of cohort allows monitoring and benchmarking of the evolution of strategic and tactical decisions, such as genetic management improvement or health plans, and their impact on the profitability performance of those cohorts on a cumulative basis over time.

At the individual level the use of comparative visualization curves for profitability and profit related variables simplifies a long complicated process by showing in a simple set of graphs the evolution of profit and factors affecting it over the cumulative lifetime of the cow. Cumulated information allows monitoring and comparing the impact of different profitability components not only in the current but also in previous lactation cycles that otherwise would not be obvious facilitating the process of tactical decision-making.

Acknowledgements

The authors of this study would like to thank the Fonds de Recherche Nature et Technologies de Quebec (FRQNT), Novalait, the Ministère de l'Agriculture, des Pêcheries et de l' Alimentation du Québec (MAPAQ) and Agriculture and Agri-Food Canada for funding support (FRQNT project LT-163341), DHI Valacta, the Dossier Santé Animal (DSA) for providing the data, special thanks to the Hugh Blair Scholarship for financial support of Hector Delgado and also to Maxime Figarol and Camille Thoulon, masters students from the University Paul Sabatier in Toulouse France, for their input on the visualization of lifetime and daily measurements.

4.7 REFERENCES

Beck, T. 2008. How Does Cost Efficiency Affect Farm Profitability?. Accessed June 5, 2012. http://www.das.psu.edu/research-extension/dairy/capitalregion/news/df-200712-01

Cabrera, V. E. 2012. A simple formulation and solution to the replacement problem: A practical tool to assess the economic cow value, the value of a new pregnancy, and the cost of a pregnancy loss. J. Dairy Sci. 95:4683-4698.

Canada, S. 2014a. Farm Input Price Index (FIPI). Definitions, data sources and methods. Accessed Sept. 7, 2014. http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getInstanceList&SDDS=2305&InstaId=14940&SurvId=65019

Canada, S. 2014b. Prices and Price Indexes. Statistics by Subject. Accessed Sept. 7, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=3956&lang=eng&id=998&more=0&type=ARRAY&pageNum=1

Canada, S. 2014c. Statistics by subject, Livestock and acquaculture. Farm financial statistics. Accessed Oct. 10, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=920&id=2553&lang=eng&type=ARRAY&pageNum=1&more=0

Chi, E. H. 2000. A taxonomy of visualization techniques using the data state reference model. Pages 69-75 in Proc. Information Visualization, 2000. InfoVis 2000. IEEE Symposium on. IEEE.

Chittaro, L. 2001. Information visualization and its application to medicine. Artif. Intel. Med. 22:81-88.

Clark, K. and I. Heckenbach. 2005. Spreadsheet user-interfaced business data visualization and publishing system. Google Patents. http://www.google.com/patents/US20060112123

Cole, J. B., S. Newman, F. Foertter, I. Aguilar, and M. Coffey. 2012. Breeding and Genetics Symposium: really big data: processing and analysis of very large data sets. J. Anim. Sci. 90:723-733.

Cue, R. 2011. Profitability in Quebec dairy cattle, research proposal. McGill University, Montreal, Canada.

De Haan, M. H. A., B. G. Cassell, R. E. Pearson, and B. B. Smith. 1992. Relationships between net income, days of productive life, production, and linear type traits in grade and registered Holsteins. J. Dairy Sci. 75:3553-3561.

Eick, S. G. 2000. Visualizing multi-dimensional data. ACM SIGGRAPH computer graphics 34:61-67.

Elliott, A. C. and W. A. Woodward. 2010. SAS essentials a guide to mastering SAS for research. Jossey-Bass, San Francisco, CA.

Evergreen, S. M. C. 2013. Design Principles for Data Visualization in Evaluation. EV New Directions for Evaluation 2013:5-20.

Frohlich, D. 1997. Direct manipulation and other lessons. Handbook of Human-Computer Interaction:463-488.

Giordano, J. O., P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94:6216-6232.

Heer, J., S. K. Card, and J. A. Landay. 2005. Prefuse: a toolkit for interactive information visualization. Pages 421-430 in Proceedings of the SIGCHI conference on Human factors in computing systems. ACM.

Johnson, J. 2010. Designing with the mind in mind: Simple guide to understanding user interface design rules. Morgan Kaufmann.

Kulak, K. K., J. C. M. Dekkers, A. J. McAllister, and A. J. Lee. 1997. Lifetime profitability measures for dairy cows and their relationships to lifetime performance traits. Can. J. Anim. Sci. 77:609.

Nordlund, K. V. and N. B. Cook. 2004. Using herd records to monitor transition cow survival, productivity, and health. Vet. Clin. North Am. Food Anim. 20:627-649.

Ortiz, S. and V. P. Cid. 2010. Use cases of Impure, an information interface. VisWeek. http://de2010.cpsc.ucalgary.ca/uploads/Entries/Ortiz_2009_InfoVisDE_impure_final.pdf

Pietersma, D., R. Lacroix, and K. M. Wade. 1998. A Framework for the Development of Computerized Management and Control Systems for Use in Dairy Farming. J. Dairy Sci. 81:2962-2972.

Rahm, E. and H. H. Do. 2000. Data cleaning: Problems and current approaches. IEEE Bulletin on Data Engineering 23:4.

Roche, J. R., J. K. Kay, N. C. Friggens, M. W. Fisher, K. J. Stafford, and D. P. Berry. 2009. Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92:5769-5801.

Salfer, J. 2002. Improving profit through decreased culling. Reproduction 25:15.18-34.19.

Sewalem, A., F. Miglior, G. J. Kistemaker, P. Sullivan, and B. J. Van Doormaal. 2008. Relationship between reproduction traits and functional longevity in canadian dairy cattle. J. Dairy Sci. 91(4):1660-1668.

St-Onge, A. 2000. Economic values of traits for dairy cattle improvement estimated using field recorded data. Animal Science. MS Thesis. McGill University, Montreal, Canada.

St-Onge, A. 2004. The interpretation of dairy data using interactive visualization. Animal Science. PhD Thesis. McGill University, Montreal, Canada.

Statistics Canada. Prices, D. 1996. Your guide to the Consumer Price Index. Statistics Canada, Prices Division, Ottawa.

Stolte, C., D. Tang, and P. Hanrahan. 2002. Polaris: A system for query, analysis, and visualization of multidimensional relational databases. IEEE Transactions on Visualization and Computer Graphics 8:52-65.

Tufte, E. R. and P. R. Graves-Morris. 1983. The visual display of quantitative information. Vol. 2. Graphics press Cheshire, CT.

Van Arendonk, J. A. M. 1991. Use of Profit Equations to Determine Relative Economic Value of Dairy Cattle Herd Life and Production from Field Data. J. Dairy Sci. 74(3):1101-1107.

Ware, C. 2013. Information visualization: perception for design. Elsevier.

Wright, W. 1997. Business visualization applications. IEEE Computer Graphics and Applications, 17(4):66-70.

CHAPTER V

GENERAL DISCUSSION AND CONCLUSIONS

The main purpose of this study was to understand factors affecting and influencing lifetime cow and herd profitability based on an empirical approach in order to create a methodological framework with the help of information visualization methods to monitor profitability as a means of achieving constant improvement inside the dairy farm.

5.1 Construction of the integrated dataset

One of the most challenging tasks for the development of this project was the construction of the combined Québec DHI – Provincial health files dataset. The two sources use different formats for the key variables needed to match the data, therefore the first step was to understand these formats to normalize and match the key variables of the databases and match herds and cows (key variables from the Provincial health files were normalized to match them with the Québec DHI variables). The provincial animal health files only provided records for herds with a minimum of 90% of the animals matched. The final integrated database contains information for a total of 1,106 herds and 163,826 animals. The combined dataset will be an important source of information for future projects not only because of the of integration of health and production records in a single dataset but also due to the availability of the methodology used for the normalization and the matching of the data.

The combined dataset is an unmatched source of information, because with this resource it was possible to re-construct the lifetime of the animals based on different events recorded in the data sources, from the moment of first calving to the moment of culling. This collection of sequential events gave us the possibility to study the lifetime of the animals, cumulate lifetime events and their costs, such as the number of inseminations and health events, as well to evaluate the impact these events on profitability. Some gaps in the information for some animals were found due to different reasons such as incomplete feed data or because they were removed from a herd and appeared in a different herd some time later. The records for these animals were flagged and were kept in the database. However they were not included for the different analysis presented in this study but the information is still available for other studies.

The combined dataset contains information collected for herds for fourteen years (2000-2013 inclusive) providing a good number of cohorts of animals within herds for different retrospective analyses. The database was designed in a way that allows filtering information according to the required criteria because not all the 1,106 herds in the database meet the specific requirements for the different analyses, for instance in the first study (Chapter II) only 113 herds were selected from the database. Those were the herds with full information for clinical mastitis, reproductive problems and cumulative feed cost for the selected cohorts-years from 2000 to 2009. But different studies might require different criteria and the database can be adjusted to present the herds according to the requirements.

5.2 Use of profitability formulae

The construction of the lifetime cumulative values by event-date of those variables having an impact on profitability allows monitoring both changes in profit associated with these variables during the lactations cycle but also allows continuous monitoring during the complete productive lifetime cycle of the animal. he first cumulated variables were cumulative feed cost and cumulative milk value, both of which constitute a starting point for any profitability analysis as has been demonstrated by the important use of the ROFC formula (Bohmanova *et al.*, 2009). However with the integrated database it was possible to widen the study of profitability and observe how other recorded events affect it.

For the profitability formulae considered in this study, it was decided not to include fixed costs but to focus on the variable ones to have a better idea of the performance of an animal, the animal within the herd and the system, and no other administrative characteristics. However future developments of the prototype should include these types of fixed costs for a more complete scenario analysis.

The high correlation (P > 0.95) showed for the profitability formulae within groups (ROFC, LTP, LTPOC) presented in chapter II led us to select only one measure per Group of formulae. In this case we selected measures adjusted to net present value to the moment of birth and including the quota lease interest (Mulder and Jansen, 2001). However, depending on the interest of the end-user and the nature of the analysis, the profitability tool can be flexible concerning the variables to be included in the calculation of the formulae. For instance, the use of current or constant prices as well as the interest rate for the quota lease, among others, should be flexible options to be offered to the end-users in the profitability tool for the convenience of their own analysis, however reports presented at a higher level (region, breed) should be presented in a standard way with clear information about the methodology used.

For the analysis of profitability it was important to use LTPOC to help end-users understand the results of the animals compared to an average animal of their herd and to make decisions based on their marginal contributions. As a consequence, the time of removal from the herd could be optimized by constantly monitoring animals. For instance those animals with negative numbers for

LTPOC during a period of time could be flagged for culling. For example, when there is an animal with a series of repeated health events, the decision maker can visualize the impact of these events on the marginal contribution of the animal to the herd and based on that decide on keeping the animal or culling it.

Another aspect of profitability analyzed in this study was the significant differences in LTP among the different housing and milking systems groups due to different associated costs caused by health or reproduction events. The importance of the development of an information visualization tool is that it allows the monitoring of these significant differences in costs at the herd level using benchmarks related to their management system and it helps decision makers answer the difficult question posed in Chapter I, "Is my farm making money?"

5.3 Factors influencing profitability

All the statistical analyses used in this study had the objective of finding significant differences in factors affecting profitability at the cow and herd level in order to select and include these factors as control variables and benchmarks in the prototype tool. For instance, the cumulated extra costs (Chapter II) caused by health and additional insemination services, aside from having a significant effect on the final LTP and LTPOC result, when included in the visualization information tool allow the user to monitor how, with each new health or insemination event, the cumulative curves for the costs of these events grow and at the same time how the gap between the profit obtained and the profit without the avoidable losses widens (Figure 2.3).

Traits related to reproduction such as the age at first calving (AFC) showed a significant effect on profitability. What could be the strategy to optimize the age at first calving? Providing managers with combined tools to optimize AFC could be a solution. Pietersma *et al.* (2006) noted that

Québec heifers were large enough and heavy enough to be bred at 14 months and calve at 24 months and, based on this, Cue *et al.*, (2012) developed a formula to predict the optimal moment of first insemination based on the animal's body weight. The introduction of the formula is in the process of implementation by the provincial DHI and in combination with the visualization tool producers could monitor AFC in two ways, the first by optimizing the age of the first breeding service and the second by monitoring the effect of a late first calving on profitability.

The negative impact on profit caused by the excessive number of days dry as estimated by Plaizier *et al.* (1997) could also be monitored by the use of visualization methods. The use of LTPOC would help decision find reasons why the animals are not staying in the herd the required amount of time to provide the expected profit. For instance, animals with repeated breeding problems are expected to have longer number of dry days and higher cost in cumulative insemination services. This situation would be immediately reflected in the LTPOC (Chapter II). As presented in Chapter IV, with the visualization prototype the end-user could visualize the LTPOC curve for this animal and with the help of the different curves drill down on the different variables to find reasons to explain the profitability performance and take corrective measures.

To explain differences in health costs we obtained the means and distributions of the lifetime cumulative number of health events for CM, REPR and F&L. This study explored in a practical way the development of tools to help the producer to visualize the impact that different health events have on profitability at the cow and herd level. The differences found in profitability caused by health events and differences by management groups were similar to other studies reported in the literature (Steeneveld *et al.*, 2012, Gordon *et al.*, 2013). It is expected that in the future new health events could be included in the database as well as real herd costs. Although only three health events from the eight in the database were studied separately, different studies could follow these initial findings using the integrated database.

An important aspect that needs to be addressed in the future is raised by the differences obtained in the F&L problems differentiated by housing system (Chapter III). Is the higher number of F&L events in free-stall compared with Tie-stall because producers do not record all the cases? For this study all the herds selected independent of the housing systems had reported at least one case of F&L problems per year.

Another important aspect to be considered in the future is the case definition for the different health events. In this study we have obtained the health information from the provincial veterinary files and the provincial DHI, however big categories such as F&L problems or Reproduction problems include a group of other specific problems and therefore the costs included were generic and not specific. With the development of the visualization tool, it would be possible to be more specific and drill down into the nature of the health events and their respective costs however proper training in identifying health events and recording the data would be required.

5.4 Development of the Visualization Prototype

This initial information visualization prototype tool was developed by working with the information collected in the integrated database. The information from the database was filtered, sorted, transformed and aggregated to obtain different hierarchical levels (category-group, herd and animal). These hierarchies allow the end-user to visualize the data in different dimensions allowing functions such as drilling-down and slicing and dicing the information and all with multiple comparisons, e.g. at the herd level using benchmarks by category and at the animal level using benchmarks by herd and by category-group allowing monitoring of up to 13 different variables.

The development of the benchmarks is still a work in progress, but as was demonstrated in the study, the differences found among the management groups (Chapter III) merit the development of these benchmarks to include more time series of data from different systems. This would permit the improvement of the quality of the benchmarks, for example, by including more than the six herds classified as AMS that met the requirements in the study. In two or three more years, data for at least twelve AMS herds will meet the requirements.

When constructing the information visualization tool to understand the information stored in the relational database simplicity in the design of the graphs and the means to select the information was kept as a main principle (Evergreen, 2013) in order to prevent the user from distracting himself with additional information or technical issues. Also longitudinal series of time were enriched with other components to give users a better idea of the different effects of variables on profitability (Tufte and Graves-Morris, 1983) such as bars marking the different health events or breeding services during the life of an animal (Figure 4.7).

The prototype tool interface was divided into a series of spreadsheets in MS Excel. A spreadsheet includes various interactive graphs. In other words, in a given spreadsheet the user can filter and visualize different graphs (up to 13) that allow for comparisons of different factors within the same category. For instance, at the individual herd level the spreadsheet presents the user with benchmark comparisons for the results obtained by the herd for cumulative lifetime profit, cumulative milk value, cumulative feed cost, etc. Only one graph with the variable results and the respective benchmarks will be displayed at a time in the spreadsheet to avoid confusion. This design of the visualization prototype with embedded Visual Basic macros allows users to select the variables to be graphed from a drop down ribbon list and visualize only the information of their interest in an organized and efficient way.

The hierarchical design of the visualization prototype allows different users with different goals to benefit from the information. For instance, for a policy maker the main interest would be comparisons among regions or among milking systems (Category-group) while for a farm manager the Category-group would be of interest when selecting the benchmarks to compare the performance of the herd or the specific animal of interest.

One of the expectations of this project is that, in the future with the introduction of the visualization curves profitability report, herd managers will understand the impact that different events such as health problems or repeated services have on profitability. This report will encourage them to improve the quality of the collected data, for example more precise health event and cost recording. This improved data would also allow DHI to provide more specific and relevant benchmarks and therefore better assistance to producers.

The implementation of the final visualization tool should be done in different stages. During an initial pilot project for a selected number of farms DHI advisors, could use an updated version of the prototype and every time they visit the farm they could update the database with relevant information and provide the managers with printed or virtual reports. In a second stage end-users could access the database through a connected server where they could update the information and work on their own queries. An essential component would be a simple system to allow users to input data correctly which would require time and training. The benefit of a continuously updated database would be to be able to analyze difficult situations, for example, stayability at the individual level using relevant benchmarks.

With the development of this prototype we were interested in understanding how to integrate the different on-farm data in a relational database, how to construct cumulative lifetime variables related to profitability, how to explore and develop a methodology to visualize these variables and to lay the groundwork for a future benchmarking analysis tool visualization software for the dairy producer community. To accomplish these goals, different software was explored and tested. The current visualization prototype was developed using Microsoft technology that allows the integration of the databases with the designed interface in MS Excel. However, it is understood that for the next phases of this project the different ideas and concepts developed in this study will have to be adapted to software with bigger capacity and also according to the standards and needs of DHI.

Another aspect to consider in a future development is the implementation of more sophisticated filter queries for the criteria and benchmark selection. This would filter system would be more flexible in the selection by allowing ‘and’ ‘or’ query filters using embedded SQL codes. This would not represent a major technical problem.

5.5 REFERENCES

Bijl, R., S. R. Kooistra, and H. Hogeveen. 2007. The profitability of automatic milking on Dutch dairy farms. J. Dairy Sci. 90:239-248.

Bohmanova, J., F. Miglior, J. Jamrozik, B. J. Van Doormaal, K. J. Hand, and D. Lazenby. 2009. Genetic analysis of return over feed in Canadian Holsteins. Animal 4:173.

Cue, R., D. Pietersma, D. Lefebvre, R. Lacroix, K. Wade, D. Pellerin, A. de Passillé, and J. Rushen. 2012. Growth modeling of dairy heifers in Québec based on random regression. Can. J. Anim. Sci. 92:33-47.

Evergreen, S. M. C. 2013. Design Principles for Data Visualization in Evaluation. EV New Directions for Evaluation 2013:5-20.

Gordon, P. F., B. H. P. Van den Borne, M. Reist, S. Kohler, and M. G. Doherr. 2013. Questionnaire-based study to assess the association between management practices and mastitis within tie-stall and free-stall dairy housing systems in Switzerland. BMC veterinary research 9:200.

Mulder, H., & Jansen, G. 2001. Derivation of economic values using lifetime profitability of Canadian Holstein cows. Parity, 1 no. 3:1.

Pietersma, D., R. Lacroix, D. Lefebvre, R. Cue, and K. M. Wade. 2006. Trends in growth and age at first calving for Holstein and Ayrshire heifers in Quebec. Can. J. Anim. Sci. 86:325-336.

Plaizier, J. C. B., G. J. King, J. C. M. Dekkers, and K. Lissemore. 1997. Estimation of Economic Values of Indices for Reproductive Performance in Dairy Herds Using Computer Simulation. J. Dairy Sci. 80:2775-2783.

Steeneveld, W., L. W. Tauer, H. Hogeveen, and A. O. Lansink. 2012. Comparing technical efficiency of farms with an automatic milking system and a conventional milking system. J. Dairy Sci. 95:7391-7398.

Tufte, E. R. and P. R. Graves-Morris. 1983. The visual display of quantitative information. Vol. 2. Graphics press Cheshire, CT.

5.6 CONCLUSIONS

- The integrated dataset with information from Québec DHI and Provincial Health files was the main source of information for this study and will also be of use for future analyses on different topics related to production, health, management and genetics.
- This is the first empirical exploratory study using data from Québec dairy herds for the development of different benchmarks in the form of visualization curves designed to be included as part of a dairy herd management profitability tool. This tool is still is a work in progress, but offers a promising potential to help in the decision-making process.
- This study evaluated different profitability measures that had been used in different studies with different objectives, in order to assess their relevancy and usefulness as decision-making tools for herd managers.
- With the current information collected by Québec DHI, it is possible to create specific benchmarks, either as tables or as visualization curves, to help decision-makers understand current problems in their herds based on their results and compared with other herds with similar management characteristics. These more relevant benchmarks contribute to setting more realistic profitability goals based on the characteristics of the herd.

CHAPTER VI

6.1 REFERENCES

1. Agriculture and Agri-Food Canada. 2014. Slaughter reports. Statistcs and Market Information Service. Accessed Oct. 13, 2014. http://www.agr.gc.ca/redmeat-vianderouge/sla-aba_eng.htm

2. Atzori, A. S., L. O. Tedeschi, and A. Cannas. 2013. A multivariate and stochastic approach to identify key variables to rank dairy farms on profitability. J. Dairy Sci. 96:3378-3387.

3. Balaine, D. S., R. E. Pearson, and R. H. Miller. 1981. Profit Functions in Dairy Cattle and Effect of Measures of Effeciency and Prices. J. Dairy Sci. 64:87-95.

4. Beauregard, G. 2012. Élever une taure laitière coûte maintenant plus de 3000 dollars …! Octobre 2012 ed, Agri-Nouvelles. http://issuu.com/dominic.simard/docs/60914_agrinouv_oct12_appro_haute

5. Beck, T. 2008. How Does Cost Efficiency Affect Farm Profitability?. Accessed June 5 2012. http://www.das.psu.edu/research-extension/dairy/capitalregion/news/df-200712-01

6. Benson, G. A. 2008. Pasture-Based and Confinement Dairy Farming in the United States: An Assessment. Journal of International Farm Management 4:14-29.

7. Berry, D. P., B. L. Harris, A. M. Winkelman, and W. Montgomerie. 2005. Phenotypic associations between traits other than production and longevity in New Zealand dairy cattle. J. Dairy Sci. 88:2962-2974.

8. Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001. A comparison of free-stall barns used by modernized Wisconsin dairies. J. Dairy Sci. 84:528-541.

9. Bhowmik, B. 2010. Dynamic Programming–Its Principles, Applications, Strengths, and Limitations. International Journal of Engineering Science and Technology 2:4822-4826.

10. Bijl, R., S. R. Kooistra, and H. Hogeveen. 2007. The profitability of automatic milking on Dutch dairy farms. J. Dairy Sci. 90:239-248.

11. Bohmanova, J., F. Miglior, J. Jamrozik, B. J. Van Doormaal, K. J. Hand, and D. Lazenby. 2009. Genetic analysis of return over feed in Canadian Holsteins. Animal 4:173.

12. Bonneville-Hébert, A., E. Bouchard, D. Du Tremblay, and R. Lefebvre. 2011. Effect of reproductive disorders and parity on repeat breeder status and culling of dairy cows in Quebec. Canadian Journal of Veterinary Research 75:147.

13. Booth, C. J., L. D. Warnick, Y. T. Gröhn, D. O. Maizon, C. L. Guard, and D. Janssen. 2004. Effect of lameness on culling in dairy cows. J. Dairy Sci. 87:4115-4122.

14. Cabrera V.E. 2014. Economics of fertility in high-yielding dairy cows on confined TM systems Animal, 8 (Suppl. 1) (2014), pp. 211–221.

15. Cabrera, V. E. 2012a. DairyMGT: A Suite of Decision Support Systems in Dairy Farm Management. INTECH Open Access Publisher.

16. Cabrera, V. E. 2012b. A simple formulation and solution to the replacement problem: A practical tool to assess the economic cow value, the value of a new pregnancy, and the cost of a pregnancy loss. J. Dairy Sci. 95:4683-4698.

17. Cabrera, V. E., R. D. Shaver, and M. A. Wattiaux. 2009. Optimizing Income over Feed Supplement Costs. Page 116 in Proc. Four-State Dairy Nutrition and Management Conference.

18. Camps, M., K. Huijps, H. Barkema, and H. Hogeveen. 2009. Costs of mastitis in Canada. PhD Thesis. Open Access Version via Utrech University Repository.

19. Canada, G. o. 2013. Dairy Barns by Type in Canada. in Dairy Facts and Figures. Vol. 2014. http://www.dairyinfo.gc.ca

20. Canada, S. 2014a. Farm Input Price Index (FIPI). Definitions, data sources and methods. Accessed Sept. 7, 2014. http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getInstanceList&SDDS=2305&InstaId=14940&SurvId=65019

21. Canada, S. 2014b. Prices and Price Indexes. Statistics by Subject. Accessed Sept. 7, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=3956&lang=eng&id=998&more=0&type=ARRAY&pageNum=1

22. Canada, S. 2014c. Statistics by subject, Livestock and acquaculture. Farm financial statistics. Accessed Oct. 10, 2014. http://www5.statcan.gc.ca/subject-sujet/result-resultat?pid=920&id=2553&lang=eng&type=ARRAY&pageNum=1&more=0

23. Cha, E., Kristensen, A. R., Hertl, J. A., Schukken, Y. H., Tauer, L. W., Welcome, F. L., & Gröhn, Y. T. 2014. Optimal insemination and replacement decisions to minimize the cost of pathogen-specific clinical mastitis in dairy cows. J. Dairy Sci. 97:2101-2117.

24. Cha, E., D. Bar, J. A. Hertl, L. W. Tauer, G. Bennett, R. N. Gonzalez, Y. H. Schukken, F. L. Welcome, and Y. T. Grohn. 2011. The cost and management of different types of clinical mastitis in dairy cows estimated by dynamic programming. J. Dairy Sci. 94:4476-4487.

25. Chi, E. H. 2000. A taxonomy of visualization techniques using the data state reference model. Pages 69-75 in Proc. Information Visualization, 2000. InfoVis 2000. IEEE Symposium.

26. Chittaro, L. 2001. Information visualization and its application to medicine. Artif. Intel. Med. 22:81-88.

27. Clark, K. and I. Heckenbach. 2005. Spreadsheet user-interfaced business data visualization and publishing system. Google Patents. http://www.google.com/patents/US20060112123

28. Cole, J. B., S. Newman, F. Foertter, I. Aguilar, and M. Coffey. 2012. Breeding and Genetics Symposium: really big data: processing and analysis of very large data sets. J. Anim. Sci. 90:723-733.

29. Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. J. Am. Vet. Med. Assoc. 223(9):1324-1328.

30. Cue, R., D. Pietersma, D. Lefebvre, R. Lacroix, K. Wade, D. Pellerin, A. de Passillé, and J. Rushen. 2012. Growth modeling of dairy heifers in Québec based on random regression. Can. J. An. Sci. 92:33-47.

31. Cue, R. 2011. Profitability in Quebec dairy cattle, research proposal. McGill University, Montreal, Canada.

32. Dale, J. M. 1998. Assessing and Improving Farm Profitability University of Maryland Cooperative Extension Fact Sheet 539.

33. De Haan, M. H. A., B. G. Cassell, R. E. Pearson, and B. B. Smith. 1992. Relationships between net income, days of productive life, production, and linear type traits in grade and registered Holsteins. J. Dairy Sci. 75:3553-3561.

34. Dechow, C. D., E. A. Smith, and R. C. Goodling. 2011. The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds. Anim. Welf. 20:145-158.

35. Dekkers. J.C.M. 1991 Estimation of economic values for dairy cattle breeding goals: bias due to sub-optimal management policies. Livest. Prod Sci. 29:131.

36. Dekkers. J.C.M. 1995. Genetic improvement of dairy cattle for profitability. In: Animal science research and development. Moving toward a new century: 307-327. Centre for Food and Animal Research, Agriculture and Agri-Food Canada, Ottawa, Canada.

37. Dekkers, J. C. M. and J. P. Gibson. 1998. Applying breeding objectives to dairy cattle improvement. J. Dairy Sci. 81:19-35.

38. Dekkers, J. C. M., J. H. Ten Hag, and A. Weersink. 1998. Economic aspects of persistency of lactation in dairy cattle. Livest. Prod. Sci. 53:237-252.

39. Deming, J. A., R. Bergeron, K. E. Leslie, and T. J. DeVries. 2013. Associations of housing, management, milking activity, and standing and lying behavior of dairy cows milked in automatic systems. J. Dairy Sci. 96:344-351.

40. Drackley, J. K. 1999. Biology of dairy cows during the transition period: the final frontier? J. Dairy Sci. 82:2259.

41. Eick, S. G. 2000. Visualizing multi-dimensional data. ACM SIGGRAPH computer graphics 34:61-67.

42. Elliott, A. C. and W. A. Woodward. 2010. SAS essentials a guide to mastering SAS for research. Jossey-Bass, San Francisco, CA.

43. Enevoldsen, C., J. T. Sørensen, I. Thysen, C. Guard, and Y. T. Gröhn. 1995. A diagnostic and prognostic tool for epidemiologic and economic analyses of dairy herd health management. J. Dairy Sci. 78:947-961.

44. Enting, H., D. Kooij, A. A. Dijkhuizen, R. B. M. Huirne, and E. N. Noordhuizen-Stassen. 1997. Economic losses due to clinical lameness in dairy cattle. Livest. Prod. Sci. 49:259-267.

45. Essl, A. 1998. Longevity in dairy cattle breeding: a review. Livest. Prod. Sci. 57:79-89.

46. Evergreen, S. M. C. 2013. Design Principles for Data Visualization in Evaluation. EV New Directions for Evaluation 2013:5-20.

47. Fekete, J.-D., J. J. Van Wijk, J. T. Stasko, and C. North. 2008. The value of information visualization. Pages 1-18 in Information visualization. Springer.

48. Fleischer, P., M. Metzner, M. Beyerbach, M. Hoedemaker, and W. Klee. 2001. The relationship between milk yield and the incidence of some diseases in dairy cows. J. Dairy Sci. 84(9):2025-2035.

49. Ford, S. A. and J. S. Shonkwiler. 1994. The effect of managerial ability on farm financial success. Agr. and Resour. Econ. Rev. 23:150-157.

50. FPBQ. 2014. Fédération des producteurs de bovins du Québec, Prices-Info. Page Market data updated by the Fédération des producteurs de bovins du Québec. Accessed Sep. 9, 2014. FPBQ. http://www.bovin.qc.ca/en/price-info/cull-cattle-and-bob-calves/daily.php

51. Freer, M., A. D. Moore, and J. R. Donnelly. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises—II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agric. Syst. 54:77-126.

52. Frohlich, D. 1997. Direct manipulation and other lessons. Handbook of Human-Computer Interaction:463-488.

53. Gandini, G., C. Maltecca, F. Pizzi, A. Bagnato, and R. Rizzi. 2007. Comparing local and commercial breeds on functional traits and profitability: the case of Reggiana dairy cattle. J. Dairy Sci. 90:2004-2011.

54. Gantner, V., S. Jovanovac, N. Raguz, D. SOLIC, and K. Kuterovac. 2010. Nonlinear vs. linear regression models in lactation curve prediction. Bulgarian Journal of Agricultural Science 16:794-800.

55. Geary, U., N. Lopez-Villalobos, N. Begley, F. McCoy, B. O'Brien, L. O'Grady, and L. Shalloo. 2012. Estimating the effect of mastitis on the profitability of Irish dairy farms. J. Dairy Sci. 95:3662-3673.

56. Giguère, M. 2011. Inséminer ou comment augmenter ses performances. in Élevage. Portal Agricole du Quebec, La Terre de chez nous. http://www.laterre.ca/elevage/inseminer-ou-comment-augmenter-ses-performances/

57. Giordano, J. O., Kalantari, A. S., Fricke, P. M., Wiltbank, M. C., & Cabrera, V. E. 2012. A daily herd Markov-chain model to study the reproductive and economic impact of reproductive programs combining timed artificial insemination and estrus detection. J. Dairy Sci. 95:5442-5460

58. Giordano, J. O., P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2011. An economic decision-making support system for selection of reproductive management programs on dairy farms. J. Dairy Sci. 94:6216-6232.

59. Gordon, P. F., B. H. P. Van den Borne, M. Reist, S. Kohler, and M. G. Doherr. 2013. Questionnaire-based study to assess the association between management practices and mastitis within tie-stall and free-stall dairy housing systems in Switzerland. BMC veterinary research 9:200.

60. Grant, R. J., J. L. Albright, and J. P. F. D'Mello. 2000. Feeding behaviour. Farm Animal Metabolism and Nutrition:365-382.

61. Groen, A. 1989. Cattle breeding goals and production circumstances. PhD Thesis. Wageningen Agricultural University, Wageningen, Netherlands.

62. Groen, A. F., T. Steine, J. J. Colleau, J. Pedersen, J. Pribyl, and N. Reinsch. 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49:1-21.

63. Grohn, Y. T. and P. J. Rajala-Schultz. 2000. Epidemiology of reproductive performance in dairy cows. Anim. Reprod. Sci. 60-61.

64. Guard, C. 2008. The costs of common diseases of dairy cattle (Proceedings). In Proceedings of the Central Veterinary Conference West, San Diego, Ca. Accessed Oct. 08 2013. http://veterinarycalendar.dvm360.com/avhc/Veterinary+Food+Animal/The-costs-of-common-diseases-of-dairy-cattle-Proce/ArticleStandard/Article/detail/586496

65. Hadley, G. L., C. A. Wolf, and S. B. Harsh. 2006. Dairy Cattle Culling Patterns, Explanations, and Implications. J. Dairy Sci. 89:2286-2296.

66. Haley, D. B., J. Rushen, and A. M. d. Passillé. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci. 80:257-263.

67. Hedeker, D. R., R. D. Gibbons, and J. M. Davis. 1991. Random regression models for multicenter clinical trials data. Psychopharmacology Bulletin.

68. Heer, J., S. K. Card, and J. A. Landay. 2005. Prefuse: a toolkit for interactive information visualization. Pages 421-430 in Proc. Proceedings of the SIGCHI conference on Human factors in computing systems. ACM.

69. Heikkilä, A. M., J. I. Nousiainen, and S. Pyörälä. 2012. Costs of clinical mastitis with special reference to premature culling. J. Dairy Sci. 95:139-150.

70. Huijps, K., T. J. G. M. Lam, and H. Hogeveen. 2008. Costs of mastitis: facts and perception. J Dairy Res 75:113-120.

71. Huijps, K. 2009. Economic decisions in mastitis management. Dissertation Faculty of Veterinary Medicine. Utrecht University, the Netherlands.

72. Jacobs, J. A. and J. M. Siegford. 2012. Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. J. Dairy Sci. 95:2227-2247.

73. Jagannatha, S., J. F. Keown, and L. D. Van Vleck. 1998. Estimation of relative economic value for herd life of dairy cattle from profile equations. J. Dairy Sci. 81:1702-1708.

74. Jalvingh, A. W. 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. Livest. Prod. Sci. 31:351-365.

75. Johnson, J. 2010. Designing with the mind in mind: Simple guide to understanding user interface design rules. Morgan Kaufmann.

76. Kalantari A.S., H. Mehrabani-Yeganeh, M. Moradi, A. H. Sanders and A. De Vries. 2010. Determining the optimum replacement policy for Holstein dairy herds in Iran. J. Dairy Sci. 93: 2262-2270.

77. Kelton, D. F., K. D. Lissemore, and R. E. Martin. 1998. Recommendations for recording and calculating the incidence of selected clinical diseases of dairy cattle. J. Dairy Sci. 81:2502-2509.

78. Kossaibati, M. A. and R. J. Esslemont. 1997. The costs of production diseases in dairy herds in England. Vet. J. 154:41-51.

79. Kristensen, E., S. Østergaard, M. A. Krogh, and C. Enevoldsen. 2008. Technical indicators of financial performance in the dairy herd. J. Dairy Sci. 91:620-631.

80. Kulak, K. K., J. C. M. Dekkers, A. J. McAllister, and A. J. Lee. 1997. Lifetime profitability measures for dairy cows and their relationships to lifetime performance traits. Can. J. Anim. Sci. 77:609.

81. Lam, H., E. Bertini, P. Isenberg, C. Plaisant, and S. Carpendale. 2012. Empirical studies in information visualization: Seven scenarios. IEEE Transactions on Visualization and Computer Graphics, 18:1520-1536.

82. Lang, B. 2011. The Cost of Raising Replacement Dairy Heifers. Factsheet - Ministry of Agriculture, Food and Rural Affairs, Ontario ORDER NO. 11-055.

83. Leblanc, S. 2010. Assessing the association of the level of milk production with reproductive performance in dairy cattle. J. Reprod. Dev. 56:1-7.

84. LeBlanc, S. J., K. D. Lissemore, D. F. Kelton, T. F. Duffield, and K. E. Leslie. 2006. Major advances in disease prevention in dairy cattle. J. Dairy Sci. 89:1267-1279.

85. Lefebvre, D. 2009. D'une lactation à l'autre: pour une transition réussie. In Proceedings of the Symposium sur les Bovins Laitiers,CPAQ.Drummondville.QC. Accessed Nov. 15, 2014. http://www.agrireseau.qc.ca/bovinslaitiers/documents/lefebvre_d_ar.pdf

86. Lehenbauer, T. W. and J. W. Oltjen. 1998. Dairy Cow Culling Strategies: Making Economical Culling Decisions. J. Dairy Sci. 81:264-271.

87. Leonard, F. C., J. O'Connell, and K. O'Farrell. 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Vet. Rec. 134:490-494.

88. Levallois, R. 1989. Analyse des résultats technico-économiques d'une entreprise laitière par un système expert. Canadian Journal of Agricultural Economics/Revue canadienne d'agroéconomie 37:681-694.

89. Levallois, R., Y. Allard, P. Carle, S. Gagnon, D. Pellerin, R. Roy, and A. Thériault. 1997. L'augmentation de la production par vache est-elle rentable. Pages 129-162 in Proceedings of the Sympsium sur les Bovins Laitiers, CPAQ,.Drummondville QC.

90. Littleton, A. C. 1928. What is profit? The Accounting Review 3:278-288.

91. Mackinlay, J. 1986. Automating the design of graphical presentations of relational information. ACM Transactions on Graphics (TOG) 5:110-141.

92. Mahnani, A., Sadeghi-Sefidmazgi, A., & Cabrera, V. E. 2015. Consequences and economics of metritis in Iranian Holstein dairy farms. J. Dairy Sci. 98:6048-6057.

93. Mainland, D. D. 1994. A decision support system for dairy producers and advisors. Agricultural Systems 45:217-231.

94. McKean, E. 2005. The new Oxford American dictionary. Oxford University Press, New York, N.Y.

95. McLaren, C. J., K. D. Lissemore, T. F. Duffield, K. E. Leslie, D. F. Kelton, and B. Grexton. 2006. The relationship between herd level disease incidence and a return over feed index in Ontario dairy herds. Can. Vet. J. 47:767.

96. Mulder, H., & Jansen, G. 2001. Derivation of economic values using lifetime profitability of Canadian Holstein cows. Parity, 1 no. 3:1.

97. Murray, B. 2013. Finding the Tools to Achieve Longevity in Canadian Dairy Cows. WCDS Advances in Dairy Technology 25:15-28.

98. Nordlund, K. V. and N. B. Cook. 2004. Using herd records to monitor transition cow survival, productivity, and health. Vet. Clin. North Am. Food Anim. 20:627-650.

99. Olde Riekerink, R. G. M., H. W. Barkema, D. F. Kelton, and D. T. Scholl. 2008. Incidence rate of clinical mastitis on Canadian dairy farms. J. Dairy Sci. 91:1366-1377.

100. Oltenacu, P. A., and D. M. Broom. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim. Welf. 19:39–49.

101. Ortiz, S. and V. P. Cid. 2010. Use cases of Impure, an information interface. VisWeek. http://de2010.cpsc.ucalgary.ca/uploads/Entries/Ortiz_2009_InfoVisDE_impure_final.pdf

102. Parrott, L., R. Lacroix, and K. M. Wade. 2003. Design considerations for the implementation of multi-agent systems in the dairy industry. Comput. Electron. Agric. 38:79-98.

103. Perez-Cabal, M. A. and R. Alenda. 2003. Lifetime Profit as an Individual Trait and Prediction of its Breeding Values in Spanish Holstein Cows. J. Dairy Sci. 86:4115-4122.

104. Pietersma, D., R. Lacroix, and K. M. Wade. 1998. A Framework for the Development of Computerized Management and Control Systems for Use in Dairy Farming. J. Dairy Sci. 81:2962-2972.

105. Pietersma, D., R. Lacroix, D. Lefebvre, R. Cue, and K. M. Wade. 2006. Trends in growth and age at first calving for Holstein and Ayrshire heifers in Quebec. Can. J. Anim. Sci. 86:325-336.

106. Pietersma, D., R. Lacroix, D. Lefebvre, E. Block, and K. M. Wade. 2001. A Case-Acquisition and Decision-Support System for the Analysis of Group-Average Lactation Curves. J. Dairy Sci. 84:730-739.

107. Plaizier, J. C. B., G. J. King, J. C. M. Dekkers, and K. Lissemore. 1997. Estimation of Economic Values of Indices for Reproductive Performance in Dairy Herds Using Computer Simulation. J. Dairy Sci. 80:2775-2783.

108. Rahm, E. and H. H. Do. 2000. Data cleaning: Problems and current approaches. IEEE Bulletin on Data Engineering 23:4.

109. Ribeiro, A. C., A. J. McAllister, and S. A. Queiroz. 2008. Profitability measures of dairy cows. Revista Brasileira de Zootecnia 37:1607-1616.

110. Roche, J. R., J. K. Kay, N. C. Friggens, M. W. Fisher, K. J. Stafford, and D. P. Berry. 2009. Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92:5769-5801.

111. Rotz, C. A., C. U. Coiner, and K. J. Soder. 2003. Automatic milking systems, farm size, and milk production. J. Dairy Sci. 86:4167-4177.

112. Roy, R. 2011. Les temps c'est de l'argent … et bien plus! In Proceedings of Symposium sur le Bovin Laitiers, CPAQ, Drummondville, QC. http://www.agrireseau.qc.ca/bovinslaitiers/documents/Roy_Rene.pdf

113. Ruegg, P. L. 2011. Managing mastitis and producing quality milk. In: "Dairy Cattle Production Medicine" (Eds. C. Risco and P. Melendez), Wiley-Blackwell Publishing Ltd, Ames, Iowa, USA.

114. Salfer, J. 2002. Improving profit through decreased culling. Reproduction 25:15.18-34.19.

115. Schaeffer, L. R. and J. Jamrozik. 1996. Multiple-Trait Prediction of Lactation Yields for Dairy Cows. J. Dairy Sci. 79:2044-2055.

116. Schepers J.A., Dijkhuizen A. A. 1991. The economics of mastitis and mastitis control in dairy cattle: a critical analysis of estimates published since 1970. Prev. Vet. Med. 10 213–224.

117. Schroeder, J. 1996. Feeding for Milk Components and Profit. NDSU Extension Service, North Dakota State University of Agriculture and Applied Science. Accessed Sept. 07 2013. https://library.ndsu.edu/repository/bitstream/handle/10365/5400/as1118.pdf?sequence=1

118. Seegers, H., C. Fourichon, and F. Beaudeau. 2003. Production effects related to mastitis and mastitis economics in dairy cattle herds. Vet. Res. 34:475-491.

119. Sewalem, A., F. Miglior, G. J. Kistemaker, P. Sullivan, and B. J. Van Doormaal. 2008. Relationship between reproduction traits and functional longevity in canadian dairy cattle. J. Dairy Sci. 91:1660-1668.

120. Sewalem, A., F. Miglior, G. J. Kistemaker, and B. J. Van Doormaal. 2006. Analysis of the relationship between somatic cell score and functional longevity in Canadian dairy cattle. J. Dairy Sci. 89:3609-3614.

121. Shahinfar, S., Kalantari, A. S., Cabrera, V., & Weigel, K. 2014. Short communication: Prediction of retention pay-off using a machine learning algorithm. J. Dairy Sci. 97:2949-2952

122. Shearer, J. K. and S. R. Van Amstel. 2011. Lameness in dairy cattle. Dairy Production Medicine, (1st ed). Ed. Carlos A. Risco and Pedro Melendez Retamal. West Sussex, UK: Wiley- Blackwell, 233-253.

123. Sogstad, Å., T. Fjeldaas, O. Østerås, and K. Forshell. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Prev. Veterinary Med. 70:191-209.

124. Spahr, S. L. and E. Maltz. 1997. Herd management for robot milking. Comput. Electron. Agricu. 17:53-62.

125. St-Onge, A. 2004. The interpretation of dairy data using interactive visualization. Animal Science. PhD Thesis. McGill University, Montreal, Canada.

126. St-Onge, A., J. F. Hayes, and R. I. Cue. 2002. Economic values of traits for dairy cattle improvement estimated using field-recorded data. Can. J. Anim. Sci. 82:29-39.

127. St-Onge, A. 2000. Economic values of traits for dairy cattle improvement estimated using field recorded data. Animal Science. MS Thesis. McGill University, Montreal, Canada.

128. Statistics Canada. 1996. Your guide to the Consumer Price Index. Catalogue No. 62-557-XPB Journal Articles

129. Steeneveld, W., L. W. Tauer, H. Hogeveen, and A. O. Lansink. 2012. Comparing technical efficiency of farms with an automatic milking system and a conventional milking system. J. Dairy Sci. 95:7391-7398.

130. Stolte, C., D. Tang, and P. Hanrahan. 2002. Polaris: A system for query, analysis, and visualization of multidimensional relational databases. IEEE Transactions on Visualization and Computer Graphics 8:52-65.

131. Stott, A. W., M. P. Coffey, and S. Brotherstone. 2005. Including lameness and mastitis in a profit index for dairy cattle. Anim. Sci. 80:41-52.

132. Stott, A. and D. Elston. 1991. Interpretation of linear profit functions in the presence of correlated predictors, with application to decision support in a dairy enterprise. Agricultural Systems 37:87-98.

133. Svennersten-Sjaunja, K. M. and G. Pettersson. 2008. Pros and cons of automatic milking in Europe. J. Anim. Sci. 86:37-46.

134. Toker, D., C. Conati, B. Steichen, and G. Carenini. 2013. Individual user characteristics and information visualization: connecting the dots through eye tracking. Pages 295-304 in proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM.

135. Tucker, C. B., D. M. Weary, M. A. G. von Keyserlingk, and K. A. Beauchemin. 2009. Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. J. Dairy Sci. 92:2684-2690.

136. Tufte, E. R. and P. R. Graves-Morris. 1983. The visual display of quantitative information. Vol. 2. Graphics press Cheshire, CT.

137. Valacta. 2011. Évolution de laproduction laitière québécoise2010. in Le producteur de lait québécois. Vol. may 2011. Fédération des producteurs de lait du Québec (FPLQ), Longueuil, Quebec.

138. Valacta. 2014. Évolution de la production laitière québécoise 2013. Le producteur de lait québécois. Vol. Numéro spécial, mai 2014. Fédération des producteurs de lait du Québec (FPLQ)Longueuil,Québec.

139. Valde, J. P., D. W. Hird, M. C. Thurmond, and O. Osterås. 1996. Comparison of ketosis, clinical mastitis, somatic cell count, and reproductive performance between free stall and tie stall barns in Norwegian dairy herds with automatic feeding. Acta veterinaria scandinavica 38:181-192.

140. Van Arendonk, J. A. M. 1985. A model to estimate the performance, revenues and costs of dairy cows under different production and price situations. Agricultural Systems 16:157-189.

141. Van Arendonk, J. A. M. 1991. Use of Profit Equations to Determine Relative Economic Value of Dairy Cattle Herd Life and Production from Field Data. J. Dairy Sci. 74:1101-1107.

142. Van Doormaal, B. J. 2009. Health data recording in Canada. C. D. Network, ed. CDN, Canada. Accessed Sept. 21, 2014. http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC8QFjAA&url=http%3A%2F%2Fwww.cdn.ca%2Fdocument.php%3Fid%3D160&ei=mAi9VJ_xEOyTsQS20YHYBA&usg=AFQjCNHx_G0RKifTGME4xsf2agxs0tR1MQ&sig2=Hjq861clmZgix3xhCBJwmw&bvm=bv.83829542,d.cWc

143. VandeHaar, M. J. 2006. Alimentation, gestion et croissance des génisses laitieres de remplacement. in Proceedings 30 Symposium sur le bovin laitiere, Quebec.

144. VanRaden, P. 1997. Lactation yields and accuracies computed from test day yields and (co) variances by best prediction. J. Dairy Sci. 80:3015-3022.

145. Vargas, B., A. F. Groen, M. Herrero, and J. A. M. Van Arendonk. 2002. Economic values for production and functional traits in Holstein cattle of Costa Rica. Livest. Prod. Sci. 75(2):101-116.

146. Verstegen, J. A. A. M., R. B. M. Huirne, A. A. Dijkhuizen, and J. P. C. Kleijnen. 1995. Economic value of management information systems in agriculture: a review of evaluation approaches. Comput. Electron. Agric. 13:273-288.

147. Visscher, P. M. 1995. Genetic analyses of profit for Australian dairy cattle. Anim. Sci. (Pencaitland) 61:9-18.

148. Wagner-Storch, A. M. and R. W. Palmer. 2003. Feeding behavior, milking behavior, and milk yields of cows milked in a parlor versus an automatic milking system. J. Dairy Sci. 86:1494-1502.

149. Ware, C. 2013. Information visualization: perception for design. Elsevier.

150. Weigel, D. J., B. G. Cassell, and R. E. Pearson. 1995. Adjustment of a net income function for opportunity cost of postponed replacement on a lactation basis. J. Dairy Sci. 78(3):648-654.

151. Winsten, J. R., R. L. Parsons, and G. D. Hanson. 2000. A profitability analysis of dairy feeding systems in the northeast. Agr. and Resour. Econ. Rev. 29:220-228.

152. Wright, W. 1997. Business visualization applications. IEEE Computer Graphics and Applications, 17(4):66-70.