REFEREED ARTICLE

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Development of a Profitability Analysis Prototype with Multidimensional Benchmarks for Dairy Herds

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ABSTRACT

The prototype of an information visualisation tool was developed using combined information from the Québec and Atlantic Provinces Dairy Production Centre of Expertise (Valacta Inc.) and the Quebec Animal Health Records (DSAHR Inc.), with the objective of presenting cumulative lifetime-profit results, and the factors that affect them, thereby facilitating the process of analysing and comparing results at the dairy-herd and individual-cow levels.

The information visualisation prototype created benchmarking curves with the possibility to evaluate current profitability at the herd and individual-cow level, and also to monitor the effect of historical decisions and events on the future components of profit. The user is presented with a herd analysis that compares its profit evolution to those of selected cohorts. These values are calculated from the accumulation of average daily profit estimates by herd or cohort. At the individual-cow level, lifetime profit curves are presents that include the effects of health and breeding-service costs among others. It is hoped that this prototype may demonstrate the value, to Dairy Herd Improvement agencies, of analysing and visualizing existing and potential profitability at the herd level, and lifetime analysis at the individual-cow level.

KEYWORDS: Profitability; management information system; information visualisation prototype; dairy cow

1. Introduction

Farm managers are challenged by multiple factors that affect herd profitability. Milk production and feed costs are among the most important components in the profit equation (Beck, 2011). Other factors such as rearing costs of heifers, animal health, and efficiency of reproduction also play an important role in lifetime profitability. Therefore, any producer, striving to succeed, needs not only to keep comprehensive records, but also have a clear understanding of how they relate to profit.

The proliferation of automation in the modern dairy herd for daily tasks means that large quantities of data are being, or can be, routinely collected. These large amounts of data are generated on-farm and off-farm, and their combination creates the “info-fog” (term coined by St-Onge, 2004). 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). However, the quantity of information that a user can practically examine and handle at a given time is limited, leading to the possibility of information overload, and the risk that these large, valuable datasets will not be exploited. This is especially true if computer applications are not available to provide an effective presentation and to permit interaction with the data (Chittaro, 2001). 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).

Frohlich (1997) proposed the development of visual and interactive tools as one possible solution to help with the processing of relevant information, since profitable decision-making depends on interpreting all of the inputs accurately. However, as critical as good quality data are, visual analysis involves posing questions, formulating hypotheses and discovering results (Eick, 2000). Information-visualisation methods explore, not only the space of successful designs and techniques, but also approach the application of accumulated knowledge in a principled manner (Heer *et al.*, 2005). According to Wright (1997) one of the advantages of information-visualisation systems is the ability to solve real-world problems.

However, in the dairy farming sector, data are collected by separate management and production software,

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and there is no real integration of the data. Therefore, the information reports and analyses offered are fragmented by subject (e.g. health, nutrition, production) and it is challenging to understand how management decisions from the past have an effect on current results. With enhanced computing capacity now available, it is possible to combine diverse data sources, create integrated reports, and, through the use of visualisation techniques, provide end-users with new perspectives of how operational and tactical decisions are affecting the management of their operations.

Working with production data, supplied by the Québec and Atlantic Provinces Dairy Production Centre of Expertise (Valacta Inc.) and the Quebec Animal Health Records (DSAHR Inc.), the objectives of this study were 1- to integrate health and production data at the individual and herd level into a relational database; 2- to compute lifetime values of different factors affecting profitability; and 3- to develop individual and herd profitability reports, integrated in a visualisation tool that could facilitate the process of understanding and monitoring different management components that affect profitability.

2. Materials and Methods

For the development of the profitability prototype, a total of 43 herds and 7,850 animals with matched data from Valacta and DSAHR, belonging to cohorts (year when the animal calved for the first time) from 2005 to 2013 inclusive were selected.

2.1 Data editing and integration of datasets

To start the process eleven flat files that described different aspects of milk production (animal and herd identification, test-day production, lactation, body weight, body height, body condition score, equipment, feed, breeding information, auxiliary traits and pregnancy check files) were obtained from Valacta. The data covered the period from 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 events, etc.). Various edit checks were carried out to detect inconsistencies, following the methodology described by St-Onge *et al.* (2002). For the construction of an integrated lifetime dataset, health data were obtained from DSAHR. This dataset consisted of a collection of health records from previously selected and identified herds as described in Delgado *et al.* (2017).

The Valacta records included different qualitative characteristics on herds and animals (e.g. Region, Breed, etc.). These characteristics were considered of potential interest as benchmark tools. Currently available reports only provide herd managers with comparisons by region and by breed, whereas other characteristics such as Feeding Equipment, Milking System or Herd Size might also have potential as benchmarks of interest and are not considered. 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 Quebec Ministry of Agriculture. The selected breeds correspond to the top five dairy breeds in the Province.

2.2 Data transformation

Table 1 presents the different events, of an animal's productive life, that were selected and integrated from the different datasets. These events were integrated and ordered as series of chronological ''event-dates'' for each cow, starting from the first recorded event (birth record) to the last event recorded in the datasets (removal or culling). The Valacta test-day[5] dataset records individual milk values, as well as (for those producers availing of nutritional advice), costs for the calculated feed ration between test-day periods. Milk revenues and feed costs were consequently accumulated on a lifetime basis for every individual cow.

Costs of rearing the heifer to the moment of first calving, health events, and breeding (insemination) costs were calculated following the methodology described in Delgado *et al*. (2017). No indirect costs for effect on milk production or delayed/reduced conception rates were included since these are already accounted for in the individual production records; discarded milk was accounted for explicitly depending on the nature of the event, and the nature of the treatment (Kossaibati and Esslemont, 1997; Guard, 2008; Ruegg, 2011). Different sources (Booth *et al*., 2004; Guard, 2008 and Lefebvre *et al*., 2009) were consulted in order to estimate realistic provincial costs. The costs of the different health and breeding services, recorded in the health and reproduction datasets, were accumulated on a lifetime basis. To estimate the profit on any given date, and for visualisation purposes, it was important to interpolate the cumulative values for every single event-date. Lifetime values could, therefore, be estimated by accumulating all event-date values from the datasets over the life of the animal. Cumulative Lifetime Profit (**CLP**) accumulates, on a lifetime basis, the revenues obtained from milk value, and deducts the heifer rearing costs, lifetime cumulative feed, health and reproductive costs. This formula was originally implemented in the 1980s to compare genetic lines in experimental herds (VanRaden and Cole, 2014). The second formula is cumulative lifetime profit adjusted for the opportunity cost of the postponed replacement (**CLPOC**). This is the cumulative lifetime profit of the dairy cow minus the regressed average cumulative lifetime profitability of the herd. This formula was adapted by Kulak *et al.* (1997) and Mulder and Jansen (2001), from the concept originally proposed by Van Arendonk (1991).

Different procedures were required to transform the data and create variables that allowed suitable visualisation points at the different hierarchy levels, including individual cow levels, mean herd-level values, and different category-group levels. For instance, the event coded as ''INT'' or interpolation (Table 1) was inserted on the day before the recording of any health or insemination event in order to calculate the impact of those events on cumulative profit, as detailed in Table 2.

In order to obtain the herd values and the comparative benchmarks, cumulative means of the different values, and their standard deviations, were calculated by day of lifetime. All values were interpolated for each 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 presented in Table 3 (Breed, Region,

[5] A test day is a specific date on which an agent of the milk-recording agency (Valacta) takes measures and samples from individual cows. These events typically occur once per month, yielding up to 10 points of sampling throughout a lactation.

Table 1: List of Event Codes for the lifetime dataset and the different source datasets

Event code	Variable	Source	Observations
S	Lactation Start Date	Lactation	
E	Lactation End Date	Lactation	To include the final cumulative milk value 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	Insemination	Breeding	
H	Health event	DSAHR or Valacta	
DM	Discarded milk		If recorded a health event that requires DM. (14 days after H date)

Herd Size etc.), 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. All economic indicators were converted to 2012 constant Canadian dollars. 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).

With the lifetime integrated dataset constructed, and the qualitative benchmarks defined and stored in datasets (Table 3), a relational database was developed as a repository of information to develop different hierarchical analyses for decision support. To facilitate complex analyses and visualisations, the data were modelled, using three main hierarchical categories – animal, herd, and category-group (benchmarks) – that allowed for the visualisation of information from different perspectives. In order to select time variables, the information was modelled in days of life, parity cycles and calendar dates to facilitate navigation.

2.3 Development of the visualisation interface

Microsoft® Excel® software 2010 was chosen to develop the visualisation interface because its wide use, as well as its ease of connection to the database with the Open Database Connectivity (ODBC) system. For the design of the prototype, Microsoft® Excel® is a powerful tool for data visualisation (Evergreen and Metzner, 2013) and is commonly used for data reporting and analysis in businesses (Clark and Heckenbach, 2005). It is also simple to modify the graphs and queries as the protoype was developed iteratively. To allow users to select and display the different graphs in an organized manner, different codes were programmed in Visual Basic and embedded in the different modules (see Table 4).

The design of all graphs followed the Evergreen and Metzner (2013), the goal was 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 for the graphs, as presented by Tufte and Graves-Morris (1983).

The end-user selects the subsets of information to visualise directly from the interface with the help of ribbon lists. 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). Queries can be posed to obtain reports at the category, herd or individual level and the reports are presented in the form of descriptive tables and performance visualisation curves. If selected, benchmarks are also included.

2.4 Target users

The operation of the interactive system was kept simple, so as to avoid distractions to the user from the goal (Johnson, 2013) which, in this case, was profitability analysis; the interface and output information were improved through iterations of demonstrations to potential users (veterinarians and milk-recording advisors). Their feedback and comments were useful in ensuring that the interactive systems would not distract users from the goal, and the graphs presented were useful for them. Their input and ideas were incorporated into the design of the ultimate prototype.

3. Results

3.1 Description of the information visualisation prototype

The user has the possibility to filter the information using seven different categories (see Table 3), and Table 4 presents the thirteen different profitability-related variables that can be selected in the interface for visualisation. Milk volume and its components were also included for visualisation following the suggestion of the Valacta advisors, based on their interest by producers.

3.2 Herd dimension

At the herd level, it is possible to visualize overall performance, and filter it to any selected benchmark listed in Table 3. The end-user can also select a group of animals from the herd for analysis (e.g., cohort year or parity). This selection allows for the monitoring, over time, of profitability and other variables for different subsets of the herd (e.g., animals that calved for the first time in the same quota year). This analysis is further facilitated by the use of graphics.

An example of the use of cohort analysis is presented in Figure 1, where two cohorts from year 2008 and 2010 were selected. The figure shows the mean CLP for the two year cohorts and the mean and distribution curves (10 and 90 percentiles) for the selected Category-group (Central region of the Province). The CLP for animals of

Table 2: Fragment of lifetime events, costs, revenues and profit for a cow in her third lactation presenting the different event dates and the ''INT'' event date to facilitate visualisation quality

Event date	Event code	Health code	Age (days)	Cumulative feed cost	Health cost	Discarded milk	Service cost	Cumulative milk value	Cumulative profit	Profit w/o 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
20/10/2010	TD		1,954	5,992				25,443	14,452	15,806
01/11/2010	INT		1,966	6,046				25,661	14,616	15,970
02/11/2010	I		1,967	6,050			70	25,679	14,560	15,984
05/11/2010	I		1,970	6,064			70	25,733	14,530	16,024
24/11/2010	TD		1,989	6,150				26,078	14,789	16,283
05/01/2011	TD		2,031	6,324				26,746	15,283	16,777
08/02/2011	TD		2,065	6,460				27,189	15,590	17,084

Table 3: Variables for selection of the data for visualisation and benchmarking included in the Prototype

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

Table 4: Variables presented in the form of lifetime cumulative curves and included in the prototype for visualisation purposes

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

Table 5: List of animals from a selected herd and cohort-year from the visualisation prototype

Animal	Parity	Age in days	Cumulative days in milk	Cumulative profit	Feed cost	Milk value	Health cost	Insemination 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

the 2008 cohort of this herd closely follow the top 10% of animals in the Central region of the Province, while the performance for the 2010 cohort was closer to the average profitability of the region. This illustrates an instance where the herd manager should be interested in understanding why the profit to 1,900 days of the latest cohort ($11,000) was inferior to the same age of the 2008 cohort ($14,000). Visualisation will not provide the end-users with the final answers to their management questions; it will, however, show the results of profit and profit-related variables in a way that will help them to understand and explore factors that affect profitability. Figure 2 further shows an important difference between both cohorts, relating to health costs: while the 2008 cohort health costs tracked the mean curve for the region, the 2010 cohort health costs were among the highest (top 10%) in the region. These two comparisons alone should prompt the herd manager to pay attention to the health issues of the 2010 cohort, to, perhaps, explore factors at the individual cow level in that cohort, and to take corrective measures regarding the causes. As a result of the testing of the prototype by the specialists (veterinarians and milk-recording experts), a module that visualizes profitability performance by year of production and other profit related indicators such as feed cost per cow per years were incorporated into the prototype.

3.3 Individual cow dimension

An important part of management involves making operational and tactical decisions concerning individual animals. With this in mind, a second dimension of the

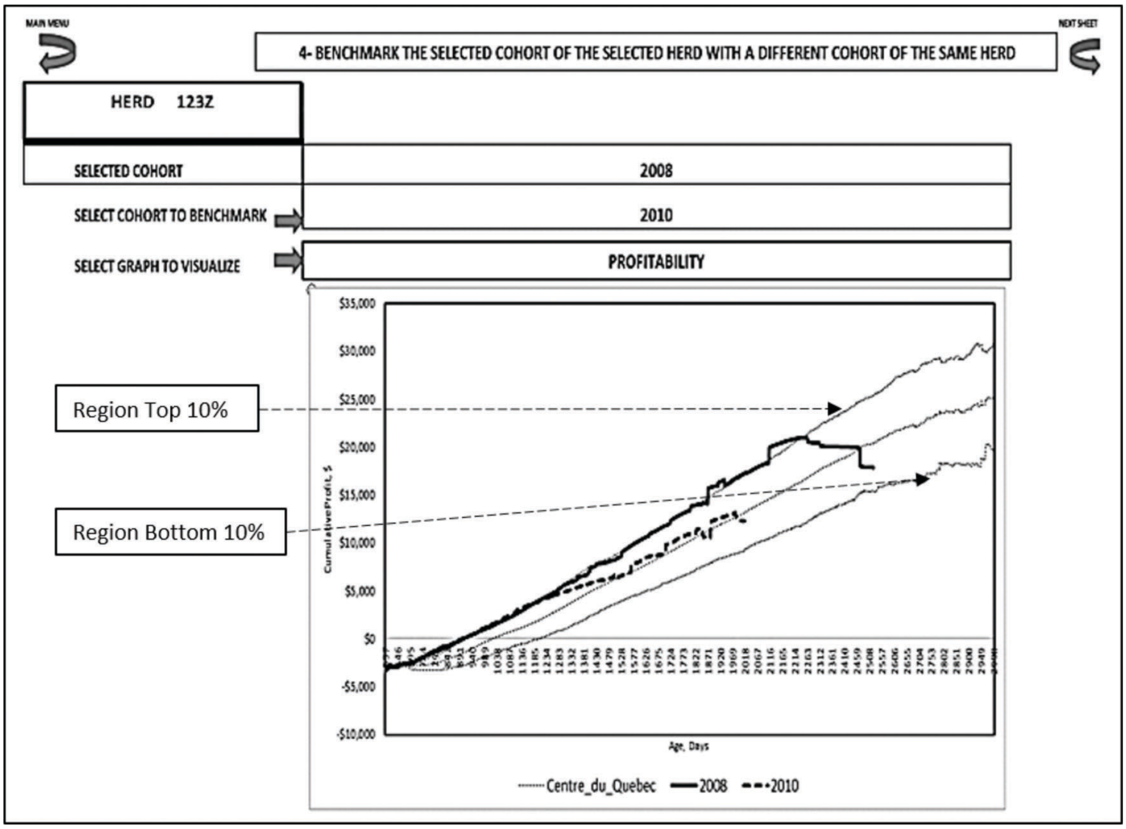

Figure 1: Profitability benchmarks between two year-cohorts of the same herd and category-group

prototype was developed, that permits such individual analyses. The monitoring and visualisation of the results of an individual cow can be presented by using information from an animal that is part of a herd, represented in the prototype. The user is presented with a table containing a list of animals from the selected herd and cohort (see Table 5 where the highlighted animal 1015 was selected to visualise her performance).

Figure 3 presents the evolution of CLP (continuous line), and the vertical bars represent the extra insemination and health costs that have occurred during the lifetime of the animal (secondary vertical axis). The dotted line in Figure 3 represents the cumulative profit that would have accrued without the deductions, caused by the health costs and the extra inseminations (avoidable losses). As can be observed, every health event and every additional breeding has an impact on the profitability of an animal, widening the gap between both curves (theoretical and actual) for the selected animal. In this particular case of animal 1015, a potential profit of $1,780 was not achieved because of the costs caused by health problems and extra inseminations. Going into further detail, Figure 4 allows the end-user to consult the medical history of the animal and find the direct costs of the recorded health events with one simple graph, thus saving time and avoiding the necessity to consult separate historic files. In this particular case (animal 1015), the animal registered a case of Displaced Abomasum during her first lactation, milk fever at the beginning of her second lactation, and finally a retained placenta problem during the third lactation. These cumulative direct costs can be visualised easily (Figure 4), and individual curves for Cumulative Breeding Cost, Health Cost, Feed Cost, Milk Production and CLP can be compared with herd and other benchmarks.

To facilitate the decision-making process, the prototype has incorporated a module that presents the end-user with various combined profit-related graphs that can help to monitor the performance of two animals and their performance within the herd. The visualisation prototype provides the list of animals in the herd including cumulative DIM and CLP information (Table 5). A second animal from Table 5 can be selected (animal 1018). By selecting this cow and repeating the process described for animal 1015 in Figures 3 and 4, the end-user can observe how a cystic ovary and clinical mastitis affected the performance of this second animal. In Figure 5, the end-user can monitor CLP performance of each of these selected cows with the average herd CLP and herd top and bottom 10% distribution curves. Although both animals (1015 and 1018) have presented various health and reproductive problems during their lifetime, the prototype may help the end-user to decide on keeping one animal over the other (or neither) through the use of comparison curves for CLP, health, reproduction, milk production, and milk components.

Finally, with the visualization curves of CLPOC (Figure 6), the end-user can compare the profitability performance of selected animal(s) to the profit obtained by an average animal in the herd (horizontal axis) at the same age. In this case the end-user can confirm that animal 1018 is under performing compared not only to animal 1015, but also to the expected average from that herd at the same age. This visualisation facilitates the process of decision making concerning the retention or culling of these animals.

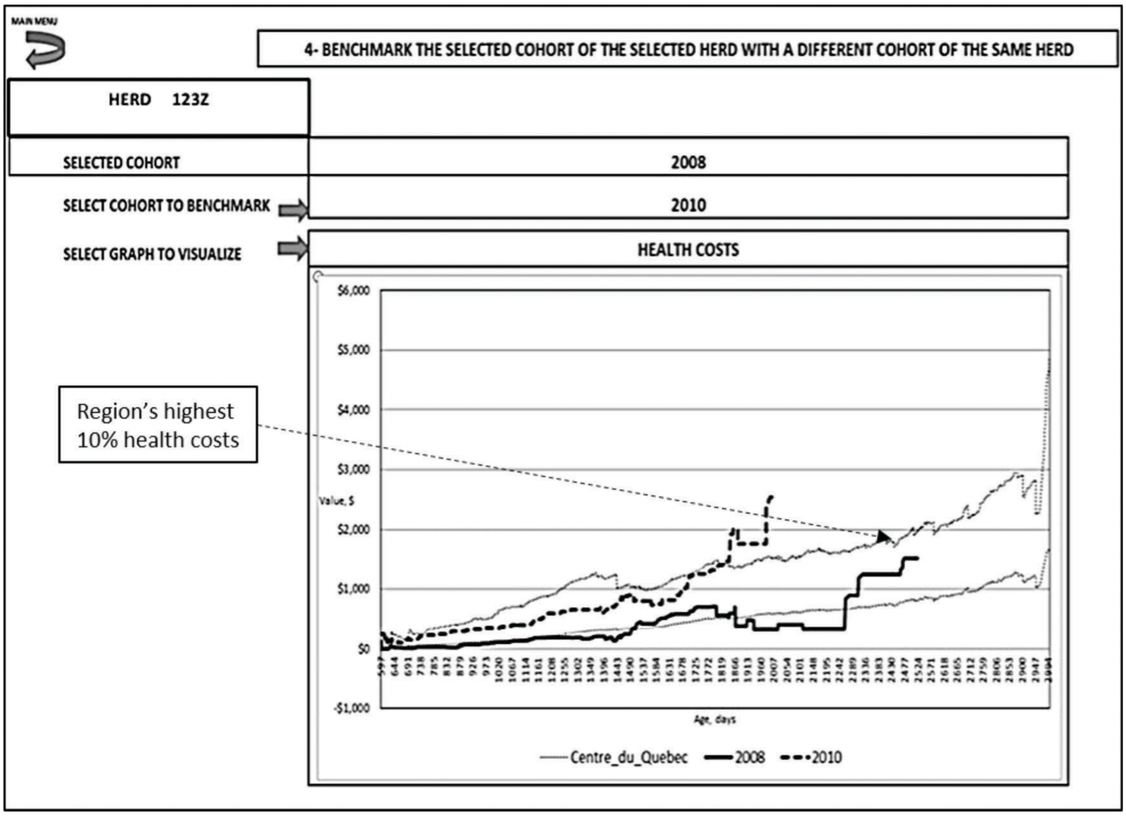

Figure 2: Comparison of cumulative health costs between two cohorts of the same herd with benchmarks by category-group

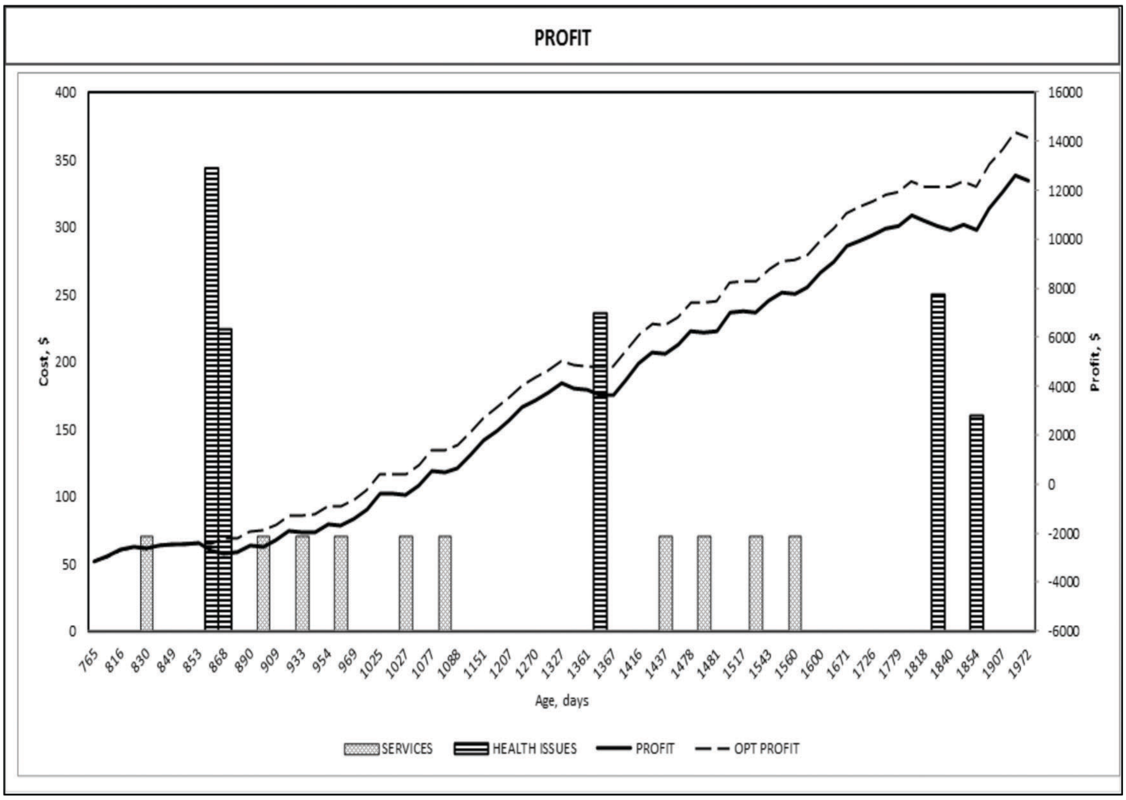

Figure 3: Cumulative Lifetime Profit and Cumulative Profit without Avoidable Losses for an individual cow. The curves in this figure represent the cumulative lifetime profit, interpolated by day of life (solid line), and the cumulative profit without avoidable cost (dashed line). The moment when the avoidable costs (extra services and health events) were incurred is represented by the vertical bars, and their respective costs are measured on the left Y-axis. The right Y-axis indicates cumulative profit

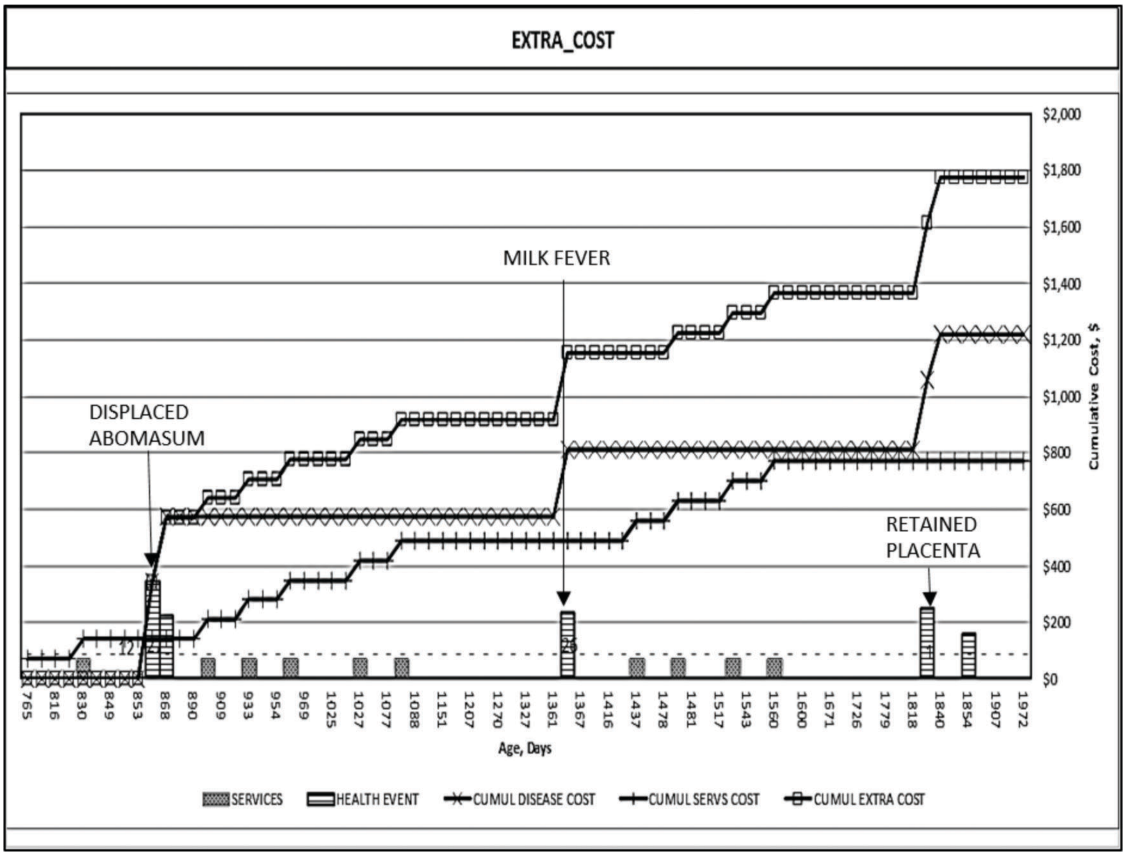

Figure 4: Extra costs cumulative curves for an individual cow. This graph shows the different events in the lifetime of a dairy cow and their cost impacts. The grey bars represent inseminations/services at the age of the animal they occurred (x axis). The cost of these inseminations is accumulated in the CUMUL SERVS COST curve. The white bars represent health events and the numbers in the bars correspond to the codes of these health events. The cost of the health events is accumulated and represented by the CUMUL SERVS COST curve. The total of the additional costs is represented by the CUMUL EXTRA COST curve

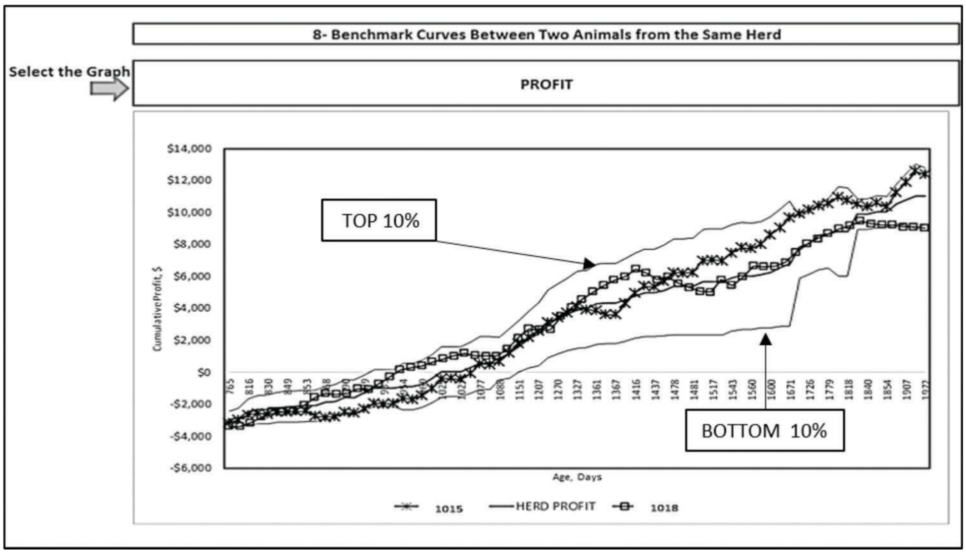

Figure 5: Lifetime Cumulative Profit benchmark between two animals from a selected herd including herd curves of distribution (10 and 90 %)

4. Discussion

Profitability of dairy herds has been a topic approached by management and decision-support systems: Cabrera (2012) developed a tool to estimate net present values of animals with the objective of helping decision makers to decide if an animal in production should stay or be replaced. St-Onge (2004) developed an information visualisation software named ‘‘Herd-Line’’ to help producers visualise the overall profile of the herd and specific performances of animals within the herd, through the use of individual phenotypic and genotypic performances.

This prototype presents the decision maker with options to select benchmarks, related to the herd-management

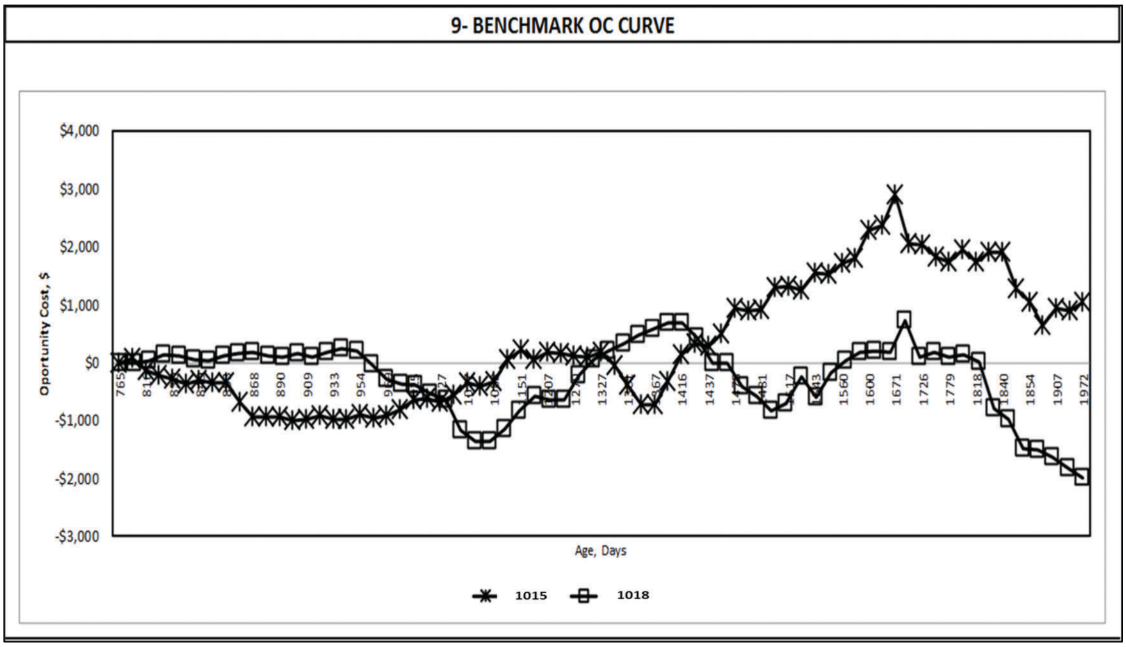

Figure 6: Comparison of the Cumulative Lifetime Profitability, adjusted for the Regressed Opportunity Cost of the Postponed Replacement for two animals in the same herd and cohort-year

characteristics, thus allowing more detailed comparisons. For instance, it might be of more interest to compare the herd profit performance or health costs with results obtained from herds in the same region rather than from the whole province. These specific comparisons can also provide decision makers with the opportunity to set realistic goals, based on specific criteria, such as the region where the herd is located, or the current milking system, or age profile of the herd. So far, this prototype only allows for benchmarking one category at a time; however, the concept could easily be extended to other groupings or combinations (e.g., organic milk producers, the combination of region and milking system, herd size and breed, etc.). Such additions are envisaged for future versions of the prototype, based substantially on the suggestions of the professionals that have tested (and will test) the prototype.

At a herd level, comparisons among different cohorts allow for the analysis of various scenarios (for example, were the criteria for selecting animals in a specific year deemed successful? Or why was the 2011 cohort more profitable than the 2009 cohort?). In the case of the latter example, the user can drill down and observe different aspects such as breeding-service costs, milk production and milk costs, among others, that could help answer the question, and set realistic goals for the future. It is expected that this prototype will help the decision maker to identify the cause(s) of the differences in profitability, or to reassess the strategic and tactical decisions, made in the past.

In contrast to other profit reports that accumulate individual information by different lactation cycles (St-Onge, 2004, Giordano *et al.*, 2011), the profitability information visualisation prototype presents the information, accumulated by lifetime. The productive lifetime is considered as a full cycle where the animal should recover her costs as a heifer at the moment of first calving and also return the expected profit. Currently this expected to happen only around the fourth lactation (Pellerin *et al.*, 2014). Another difference in the prototype, compared to previous reports, is the inclusion of a more-detailed cost analysis thanks to the integration of the data provided by Québec DHI (Valacta) and the provincial Animal Health Records (DSAHR) databases. This combined information in a relational database allowed the inclusion of costs of the recorded health events, and permitted a drill-down analysis documenting, not only summarized health costs, but also specific diseases such as clinical mastitis and reproductive problems. As previously described, the impact of these health costs on profitability can be visualised, thereby alerting herd managers to these costly management situations, and encouraging them to collect more extensive data for the future.

The inclusion of health and breeding events provided the opportunity to include these costs as part of the profit measures, and to visualise their impacts 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 3) shows, in a clear way, the impact of these events on profitability (obtained CLP versus CLP without avoidable losses). This gives the decision-maker a very clear idea of what has happened with an animal during its lifetime. Having the opportunity to observe all the information recorded for one animal in a visualisation curve, and to benchmark it against other animals, offers the benefit for more well-informed decisions. The act of removing a cow from the herd has been widely studied from different points of view (Nordlund and Cook, 2004, Sewalem *et al.*, 2008). This prototype is intended to help decision makers monitor the evolution of an animal, not only with the aim of optimising culling decisions, but also in providing visual information that might otherwise not be so obvious or difficult to detect.

Different profitability formulae that show various aspects of the performance of the animal were included for visualisation in the prototype. With CLP formula (VanRaden and Cole, 2014), it is expected that the decision maker can determine if a selected animal is reaching the expected profit goal and compare her performance with other animals in the herd. It also allows the comparison of the individual results with any selected category-group (Figure 5). The inclusion of the CLPOC formula, defined by Van Arendonk (1991) and adapted by Kulak *et al.* (1997) and Mulder and Jansen (2001), as part of the visualisation curves, allows decision makers to monitor the marginal contribution of an animal to the overall herd profitability. This is important because it facilitates the understanding of the role an animal is playing within the overall profitability of the herd. It is not impossible for an individual animal to have negative results for a given period of time (e.g., a lengthy dry period yet still contributes positively to the long-term profitability of the herd. However, if the contribution of an animal has been consistently below the performance of the average individual in the herd – as illustrated in shown in 6 – this would give the decision maker concrete reasons to flag the animal for culling. An additional use of the information presented in this prototype could be the provision of online reports by category, or the export of data (e.g., a csv file) for incorporation into other management systems (e.g., accounting software).

The integration and visualisation features were appreciated by the experts who explored the prototype. Both groups found the lifetime concept useful as well as the possibility to visualize and compare results in an intuitive and fast manner. New versions of the prototype will include modifications in the scales such as age of life expressed in months and not in days. Another concern revolves around the recording system at the herd level: herds included in the design of this porotype were carefully selected following the criteria proposed by Delgado *et al.* (2017), but it is likely the case that, not all the farms keep such good health records – a situation that could not only affect the herd results, but also the benchmark comparisons. Another limitation was the lack of individual herd-specific cost information for the recorded health events in the combined database; this necessitated the use of average values from the literature and previous surveys it is expected in the future to develop a user-version that could ask the user for the actual costs (e.g. specific vet costs, actual drug costs).

The current tool was developed using Microsoft technology that allows the integration of an Access database with the designed interface of Excel. It should be understood that this project was concerned with the production of a working prototype, and that any future large-scale development would require software and systems with a larger capacity. The next phase of this research is to implement a pilot project with a selected number of herds in the Province of Quebec and, through collaboration with Valacta advisors, evaluate the impact of this prototype on decision-making processes regarding profitability.

5. Conclusions

The different profitability measures, explored in this visualisation tool, have previously been used mostly in bio-economic and genetic analyses. This study demonstrates their use as potential tools for decision-making in dairy herd management. In addition, the multi-level hierarchical approach allows different users with different interests and goals, to benefit from the prototype.

Herd analysis by year of cohort allows for the 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 visualisation curves for profitability and profit-related variables simplifies the process of examining (and benchmarking) the cumulative lifetime of an individual animal. Accumulated information allows for the monitoring and comparison of the impact of different profitability components, not only in the current, but also in historical lactation cycles, thus facilitating the process of future tactical decision-making.

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