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Precision Agriculture in the Dairy Industry: The Case of the AfiMilk® System

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ABSTRACT

Although predictable output is desirable for most businesses, agriculture is behind other industries in the adoption of information technology. While precision agriculture provides a technological means for obtaining desirable goals such as product quality, labor cost, and product mix and market requirements, the dairy industry relies on semi-controlled environments. This paper describes the use of a current AgIS implemented by S.A.E. Afikim. We use the dairy industry to illustrate the role of AgIS in controlling the inputs and environmental parameters required to achieve the above mentioned business goals. Data was collected using open-end interviews with managers in the applied research and development, and marketing departments of S.A.E. Afikim (AfiMilk® system). Findings suggest that even though AfiMilk® utilizes current information technology and supports precision agriculture concepts, it is still a transactional system with some management support capabilities. At present, the AfiMilk® system partially supports loop-back capabilities, and strategic and long-term executive decision-making.

Keywords

Agricultural Information Systems, Dairy Farms, Precision Agriculture, Six Sigma, Total Quality Management

INTRODUCTION

Predictable output is desirable for most businesses. Stability can be measured by performance in the quantity or quality produced. For example, companies invest in Total Quality Management (TQM) to minimize variance in product quality (Hendricks and Singhal, 1997). Predictable outputs can help a company plan their manufacturing, marketing, communications, sales, and distribution (Zairi, 1997).

Predictable manufacturing depends on two elements (Zairi, 1997) –

- A stable inflow of inputs such as raw material, labor, and energy use. Inflow is expected to be consistent in quality, quantity, and price.
- A stable and predictable production process.

For most industries, the latter is relatively easy. In today's automated manufacturing environment, a stable and predictable production process is accomplished by using robotics and shop-floor control systems (Grigori et al., 2001). Companies attempt to control their inputs by engaging in Just-in-Time (JIT), alliances, and integrative production. Inter Organizational Systems (IOS) such as electronic data interchange (EDI), supply chain management (SCM), Web auctions, and automated purchasing agents are often used to improve procurement of goods (Lauden and Lauden, 2009). Controlling inputs is more difficult particularly for industries that rely extensively on natural resources (e.g., food processing, energy producers).

Various industries have adopted different levels of sophistication and automation in their production and distribution. For example, the automobile industry is highly automated (Gorlach and Wessel, 2008). The hi-tech industry, particularly the hardware and networking components, are also highly automated (Marino and Dominguez, 1997). Two industries that are on the other side of the spectrum and are well known as technically inferior are traditional and industrial agriculture (IA). In the past 10,000 years, agricultural development went through six stages[1] . The sixth and current revolution is the availability of computers, software, satellite technologies, and sensors networks. Technology enables what is referred to as precision agriculture (PA). PA technology makes it possible to obtain effective data in real time (Zhang et al., 2002). Thus, technology such as the internet can be used by farm managers in other industries[2]. That is, PA should be driven by factors such as financial, economic, food safety and uneven access of staple foods. However, despite the availability of the necessary

[1] http://en.wikipedia.org/wiki/Agricultural_revolution [Last accessed 01/03/2010]
[2] http://www.answers.com/topic/high-technology-farming [Last accessed 01/03/2010]

components (hardware, networks, software), Agricultural Information Systems (AgIS) are few and the ones that do exist are relatively crude in today's standards (Banhazi and Black, 2009).

The goal of this paper is to examine a leading global AgIS – AfiMilk® and answer the following research questions –

- To what extent does AfiMilk® support decision-making on the farm?
- To what extent does AfiMilk® support the applicability of the five Six Sigma phases?

The next section will define precision agriculture (PA) in the context of Six Sigma and describe the use of information technology (IT) in agriculture, followed by a brief description of the dairy industry and milk production cycle, and the case of the AfiMilk® system. We conclude with a comparative analysis and conclusions.

PRECISION AGRICULTURE

Six Sigma and Total Quality Management

Six Sigma is a business management strategy developed by Motorola in 1981 (Tenant, 2001), and was inspired by prior quality improvement methodologies such as TQM, and Zero Defects. Six Sigma is focused on improving the quality of process outputs for manufacturing. Six Sigma also identifies and removes the cause of defect or error and minimizes variability in manufacturing (Snee, 1999). A defect is considered a process output that does not meet customer satisfaction or regulatory specifications (Antony, 2008). These business processes include methods for quality. For example, financial issues such as cost reductions and profit increase, or process issues such as cycle and delivery time are analyzed in order to identify deviations from preset standards. The following distinguishes Six Sigma from other quality improvement methodologies (Antony, 2008).

- Places a clear focus on achieving measurable and quantifiable financial returns.
- Integrates human elements such as cultural change and customer focus, and process elements such as process management and statistical analysis.
- Utilizes tools and techniques in a sequential and disciplined format for problem solving in business processes.
- Emphasizes decision-making based on facts, data and measurements rather than assumptions.
- Utilizes statistical tools and techniques for reducing defect through process variability reduction methods.

The primary goals of Six Sigma are to achieve stable and predictable process results. Six Sigma measures, analyzes, improves and controls manufacturing and business processes, and sustains quality improvement. De Mast (2003) provides five phases in his "Six Sigma breakthrough Cookbook" based on activities for project improvement. While Six Sigma has been incorporated into manufacturing processes, it has not been used in PA. However, Banhazi and Black (2009) developed an initial framework for the use of TQM in precision livestock farming. Table 1 compares the two approaches.

Six Sigma	De Mast (2003)	Banhazi and Black (2009)
Measure	Operationalize	Integration of automated data measurement and acquisition systems
Analyze	Exploration Elaboration	Establishment of protocols for data-integration and automated data analysis
Improve	Confirmation	Transfer of the results from data analysis as inputs into automated decision-making processes
Control	Conclusion	Activate automated or standard operating procedures (SOP) control systems
		Procedures to monitor the outcome of control actions and documentation for quality assurance (QA) purposes

Table 1. Six Sigma comparison

The above comparative table indicates that general principles of Six Sigma (and other TQM methods) are applicable to PA. Predictable outputs (PO) can more effectively help a company plan their marketing, sales, and distribution regardless of the industry involved. For industries that produce perishable goods, PO is even more important since the product cannot be restocked, recycled, or diverted to discount stores. Industries that rely on natural resources for their production are likely to face higher variations in their inputs and thus have to account for these variations in their processing (Meade and Sarkis, 1999). Thus, agriculture, which heavily relies on natural resources, would benefit from the ability to control production. However, the literature suggests that the use of IT in agriculture is minimal (Thomas and Callahan, 2002).

IT Use in Agriculture

The manufacturing and service industries have implemented all four types of Information Systems (IS) – Transaction Processing Systems (TPS), Management Information Systems (MIS), Decision Support Systems (DSS), and Executive Support Systems (ESS) Yet, agriculture is rarely taking advantage of the IT tools available today (Thomas and Callahan, 2002). Schmidt et al., (1994) study showed that during the 1980s and 1990s farmers were not taking advantage of IT while Blezinger (2001) found that many cattle operations were not utilizing IT.

Despite the limited adoption of IT in agriculture, dairy management systems have been developed and implemented in large dairy farms in the past two decades (Devir et al., 1993). The following section describes one of the more advanced contemporary dairy management systems. We intend to show that although the AfiMilk® system utilizes many of the current technologies, it is still a TPS with MIS capabilities, and only partially supports strategic and long-term executive decision-making as suggested by Thomas and Callahan (2002) and Banhazi and Black (2009).

THE MILK/DAIRY INDUSTRY

Similar to other types of manufacturing, dairy farmers are concerned with the following –

- *Product quality* – Although milk standards vary by country, farmers need to ensure that their product is free of contaminants, white blood cells, bacteria or drugs. According to USDA regulations, "a plant shall reject specific milk from a producer if the milk fails to meet the requirements for appearance and odor (§ 58.133(a)), if it is classified No. 4 for sediment content (§ 58.134), or if it tests positive for drug residue (§ 58.133(c))[3]."
- *Labor cost* – Agriculture is a labor-intensive industry relative to manufacturing (Roe and Diao 1994[4]). Unlike other industries, perishable goods should be produced close to their markets since their distribution over long distance is complex (e.g., short shelf life, refrigerated containers). Labor cost is especially a concern for developed regions (e.g., USA and Western Europe).
- *Product mix and market requirements* – Market requirements change over time. Managers need to adapt their product mix to consumer taste and market adjustments. These changes can be seasonal, generational, or abrupt. For example, milk and cheese consumption for Korea was minimal. With the increase of travel and exposure to western culture, the younger generation favors milk in comparison to the older generation. Conversely, the melamine scare of 2008[5] was an unexpected event that caused global change in the dairy industry. Countries like Taiwan used mostly milk powder imported from China. After the Melamine scare, the Taiwanese consumer demanded fresh milk. This abrupt increase in fresh milk could not be planned or anticipated.

Dairy Farm Supply Chain

The traditional cow production cycle is said to begin with calving (Figure 1). However, from a manufacturing perspective cow pregnancy is the key to an optimal cycle. A cow may get pregnant on the first try, resulting in calving and lactation. If the farmer misses a heat period, 20 production days are lost until the next insemination window. Ideally, the farmer wants to reduce wait time to achieve an optimal average of days in milk (DIM) of their herds (approximately 180 DIM).

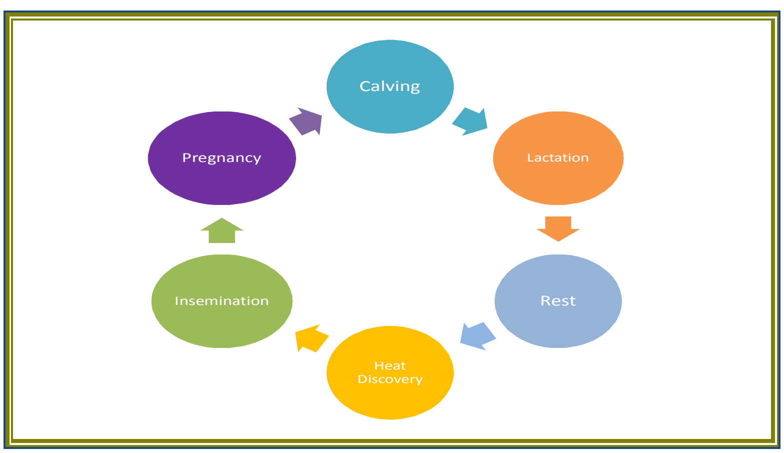

Figure 1. Traditional milk production cycle

[3] http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELDEV3004788 [Last accessed 01/03/2010]
[4] ageconsearch.umn.edu [Last accessed 01/03/2010]
[5] http://en.wikipedia.org/wiki/2008_Chinese_milk_scandal [Last accessed 01/03/2010]

Figure 2 illustrates the overall supply-chain of milk production. The inputs to milk production may vary in the types of feed, genetics of the bull used for insemination, and the environmental conditions surrounding the cow such as the weather, temperature, spacing, and barn bedding. The potential outputs and product mix are measured by yield and quality, and may vary in fat, protein, somatic cell count, color, and calcium.

Figure 2. Dairy Farm supply chain

The following sections describe the AfiMilk® system and their support of the above processes.

METHODOLOGY

For this study, we have selected a multiple case design with a single unit of analysis for each case (Yin 1994). This design can provide more compelling evidence by supplying multiple data points and rich descriptions. We selected AfiMilk® since it is considered a leading AgIS. Within the AfiMilk® company we –

- Conducted an interview with the applied research team head, marketing manager, and regional sales manager.
- Observed a demonstration of the system.
- Toured two facilities that use the system.
- Reviewed official marketing documentation.
- Reviewed academic studies conducted about the efficiency of the system in heat and contamination discovery.

The interviews followed a scripted set of open-ended questions. The questions are available from the first author. Follow-up questions were asked when clarifications were needed. The questions were phrased in such a way as to be "neutral" so that the interviewee would not be led to answer in a particular way. Each of the interviews took roughly two hours. One site visit and demo took an additional two hours, and the second site visit took approximately three hours. After the interviews, each of the authors coded their notes separately. The analysis results were compared for consistency. We found close to 90% inter-rater agreement. Inconsistencies were resolved by follow up e-mails with respective interviewees. The final paper was sent to each subject for his or her review and comments. If necessary, further e-mails were used to clarify answers.

THE AFIMILK® CASE

S.A.E. Afikim was founded in 1977 and was a pioneer in introducing electronics into the milking parlor. The first electronic milk meter was developed by the inventor and visionary Eli Peles who introduced a new philosophy of dairy farming. The brand name AfiMilk® consists of milk meters, individual cow identification, pedometers, milk analyzer, management and analysis software, and sorting, weighing and automatic individual feeding for the dairy farm. The AfiMilk® system works for a variety of dairy animals. However, the focus of this paper is on its application to milk production for cows.

Presently, the AfiMilk® family of products contains six main modules and four sub-modules (see Appendix A for details)**.** The modular structure of the AfiMilk® system enables dairy farm managers to adopt the system in stages. As of Feb 2010, AfiMilk® products are installed in over 50 countries and user interfaces have been translated to over 20 languages.

The main component of the AfiMilk® system, the AfiFarm™, and its four sub-components enable herd farmers to monitor milk production, yield and quality in real time. In addition, the system provides cow welfare support (e.g., quality of bedding, feeding, and weather stress), early disease detection, and cow quality management (e.g., individual cow productivity, cow life-cycle from birth to culling, heat management, and health management). The system also enables automated herd management, which is especially important for large or grazing farms.

ANALYSIS

The following sections describe the applicability of the AfiMilk® system in measuring, analyzing and improving product defects and mix, process efficiencies, and labor costs in the context of Six Sigma as defined by Banhazi and Black (2009).

The Application of AfiMilk® to Product Defects

Much like in other industries, product defects and spoilage is a major issue for dairy farmers (Jakobsen and Narvhus, 1996, Champagne et al., 1994). For example, if a bottling manufacture has to dispose of caps that do not fit required standards (quality, measurements), a loss of material and time occurs. The earlier the deviation is discovered the lower the cost. Landesberg (1999) terms a large negative impact as a "hazard." A critical control point is the last point in which hazards can be prevented and averted (Banhazi and Black, 2009). For a dairy farm, a major hazard is the potential contamination of milk. A dairy farmer has to discard milk that does not fit local quality and health standards. An early critical control point would result in lower financial damage. For example, imagine a scenario where a farmer produced 10,000 liters of milk at a cost of $0.50 a liter. The last cow had elevated blood levels that caused milk contamination[6]. The following scenarios and resulting economic damage can occur.

- The contamination is discovered prior to the distribution and the milk is discarded. The farmer loses $5000.
- The contamination is discovered at the processing center, resulting in losses to the farmer and processing center. These losses include the cost of delivery and disposal of at least 10,000 liters of milk.
- The milk is processed and sent to the stores. The contamination is discovered after a few consumers become ill. The financial loss extends to the stores and the public. Research shows that food contamination can be detrimental to the financial health (market value) of a company (Salin and Hooker 2001).

Similar scenarios could take place with bacteria, and other foreign agents. The extent of the loss also depends on the severity of the spoilage, the spread of the product (how far was it distributed), regulations and liability. A critical control point (Banhazi and Black, 2009) would be the ability to detect contaminated milk before it is introduced to the main tank.

The AfiMilk® system measures the levels of blood and somatic cell count (SCC), fat, protein, and conductivity in the milk in real time, and alerts managers if the levels deviate from a preset criteria. The system prevents milk that does not meet health and quality standards from reaching the milking tank, thus reducing the inventory exposure to product defect (i.e. spoilage). Thus the AfiMilk® system supports automated measurements and data analysis for product defect management as defined by Banhazi and Black (2009).

The Application of AfiMilk® to Process Efficiencies

Similar to other industries, milk producers have to maximize their inputs and processing to gain competitive advantage. Operational efficiencies in herd management include –

- Managing the product (cow) life-cycle to optimize days in milking (DIM).
- Minimizing down time due to disease.
- Managing product mix.
- Herd management (HM)

Managing product life-cycle

Cow life-cycle management is similar to product management in manufacturing. A manufacturer is likely to have X% of units in finished goods, Y% in the production stages and Z% in row material. Similarly, a herd should have the proper mix of cows in various stages of production (e.g., pregnancy, lactation) depending on the farmer and market projected needs (Figure 1). The AfiMilk® system helps farm managers in achieving product life-cycle efficiencies. Mating time and estrus-level are key determinants of animal-farm productivity (Banhazi and Black, 2009). Similarly, heat discovery is a critical process in optimizing DIM and maximizing herd profitability. A delay in heat discovery can be equated to a delay in the receiving of incoming logistics. A shortage in one component could delay the entire production and fulfillment of orders. As shown in Figure 1 above, a delay in heat discovery and cow insemination may cause delayed pregnancy and calving, and ultimately reduces milk production and herd profitability.

Using the AfiMilk® heat detection system compared to manual detection increases the number of pregnancies by 12.6% with a p-value <0.005 (Gelb, Kislev and Voet, 1998). This variance increases with cow age, since it is more difficult to detect heat in older cows. The efficiency of visual observation is reported at 45%, while the use of pedometers resulted in 78-96% success rate (Lehrer et al., 1992, Pennington, 1986). In addition, using the system, managers can track the number of wasted days and optimize production.

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[6] Allowed levels of blood in the milk vary by country.

Minimizing down time

AfiMilk® also enables an early detection of disease (especially Mastitis). Manual detection of Mastitis results in an average of 4.4 days of diseases and a total loss of 65.1 Kg of milk while a computerized detection results in a 3.9 days of infection and only 44.8 Kg of milk loss per incident (Gelb, Kislev and Voet, 1998). Thus, a computer-based early detection of Mastitis reduces a cow's down time in days by 8.9% ($p<0.005$) and milk loss by 31% (Figure 3). In addition, the AfiMilk® system enables the early detection of metabolic disease using AfiLab™.

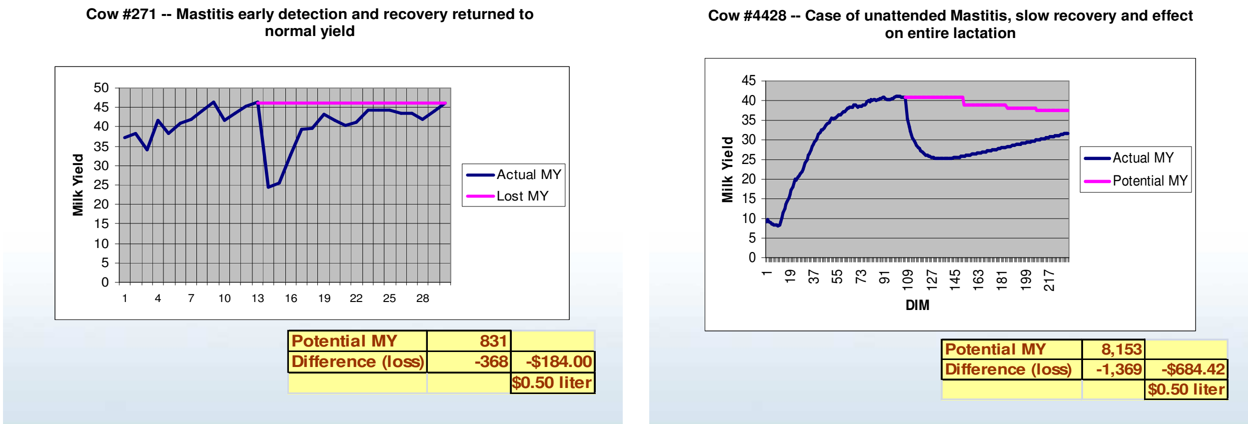

Figure 3. Early and late detection of disease total loss

Therefore, the AfiMilk® system supports automated measurements and data analysis for incoming logistics and process efficiencies to maximize productivity and facilitate industrialized precision agriculture (Banhazi and Black, 2009).

Managing product mix

Feeding strategy can influence product mix such as yield, fat, and protein (Maltz et.al., 1992). AfiMilk® enables farm managers to analyze the effectiveness of its feeding operations by comparing cost of feeding to yield (Figure 4). By measuring milk quantity and composition, the AfiMilk® system alerts the farmer of feeding problems and helps to create better-fitted rationing for the entire group or individual cow. In addition, AfiMilk® enables automated feeding adjustments for individual cows based on an algorithm developed by Maltz et.al. (1992). In addition, the AfiMilk® system enables an optimal utilization of the product mix. The system inspects the composition of the milk (i.e., fat, protein, lactose, blood, conductivity) for each cow in real time, and stops the milking process based on the composition of the milk. Therefore, the system supports automated feeding and production decision-making as defined by Banhazi and Black (2009).

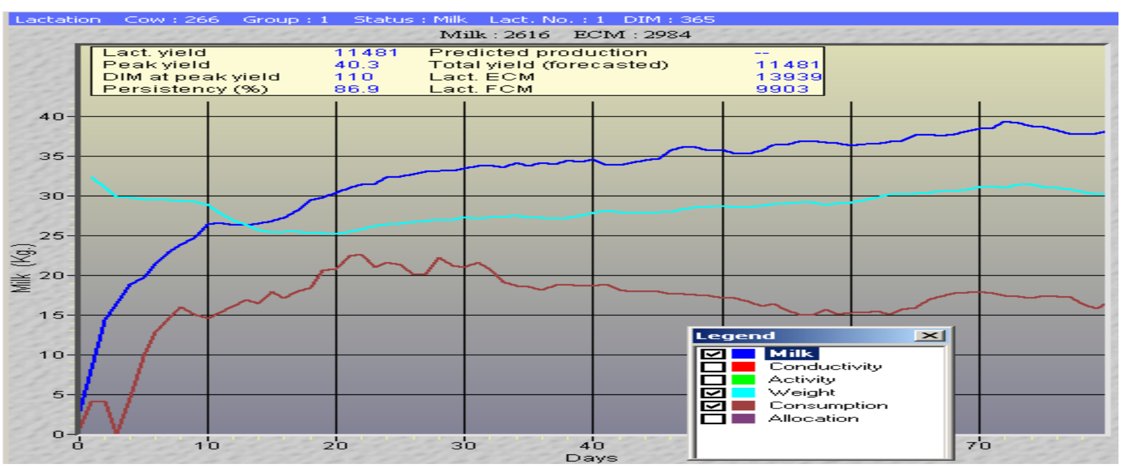

Figure 4. Feeding and Lactation

Herd management

HM in PA can be equated to assembly line efficiencies (i.e., shop-floor control). Regulations mandate a maximum number of cows per SQFT. Thus, managers have to optimize their herd composition to meet production requirements. AfiMilk® herd management capabilities provide a report of herd composition and structure. Managers are able to determine the current and projected composition of their herd, and plan future acquisitions and culling. The system also provides partial Decision Support (DSS) capabilities that enable the manager to analyze various potential compositions and their long-term impact on the farm's overall business strategy (e.g., marketing, sales). Presently, the software has some capabilities to support business planning such as the ability to predict milk yield of an individual cow based on her history. This information is used for herd, milk quota, and cull planning (Figure 5 – 6).

Milk Quota

Add Edit Delete Parameters

Index	Year	Update date	Quota	Quota % Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	2002	08/07/2002	5972780	8.56	8.06	9.28	9.08	9.29	8.47	8.32	7.62	7.19	7.69	7.84	8.60
2	2003	19/03/2003	5832311	8.56	8.06	9.28	9.08	9.29	8.40	8.32	7.62	7.19	7.69	7.84	8.67
3	2004	04/05/2004	8832000	8.56	8.06	9.28	9.08	9.29	8.40	8.32	7.62	7.19	7.69	7.84	8.67

Month	Quota %	Quota	Shipping %	Shipping	Deviation (%)	Deviation	Factor (%)
Jan	8.56	756019	69.97	529006	-30.03	-227013	0.00
Feb	8.06	711859	70.51	501913	-29.49	-209946	0.00
March	9.28	819610	83.56	684846	-16.44	-134764	0.00
First Quarter	25.90	2287488	75.01	1715765	-24.99	-571723	0.00
Apr	9.08	801946	89.00	713765	-11.00	-88181	0.00
May	9.29	820493	89.20	731857	-10.80	-88636	0.00
June	8.40	741888	99.56	738589	-0.44	-3299	0.00
Second Quarter	26.77	2364326	92.38	2184211	-7.62	-180115	0.00

Figure 5. Quota Management

Index	Cow	Gyn. status	Lact. no.	DIM	STD yield 305 DIM	Daily yield	Fat (%)	Protein (%)	SCC	Breed. no.	Priority factor	Select for culling	Date of planned exit	Exit reason	Planned event comment
1	5612	Do not Breed	1	329	19217	51.9	4.30	3.72	877	7	80	☐	--		Low Yield; Too Many Breeding
2	572	Do not Breed	1	842	17332	40.5	4.44	3.58	483	--	50	☐	--		Low Yield; High Level SCC;
3	343	Bred	5	95	17937	74.6	3.94	2.99	3382	1	50	☐	--		Low Yield; High Level SCC;
4	77	Bred	7	125	18054	81.4	3.53	3.18	1386	1	50	☐	--		Low Yield; High Level SCC;
5	5389	Pregnant	2	201	19081	69.7	2.42	3.05	3751	2	50	☐	--		Low Yield; High Level SCC;
6	115	Pregnant	6	352	19137	33.7	4.21	3.17	4233	2	50	☐	--		Low Yield; High Level SCC;
7	2120	Do not Breed	1	291	22375	60.7	3.11	3.61	1216	7	50	☐	--		Too Many Breedings; High Lev

Figure 6. Cull planning

Therefore, the system supports automated decision-making and standard operating procedures (SOP) to facilitated optimal production requirements as defined by Banhazi and Black (2009).

DISCUSSION

The core of precision agriculture, as in manufacturing, and the use of Six Sigma and TQM are to minimize the variation in production. The AfiMilk® system uses exception reporting to support these goals. As described above, farmers are able to detect changes in inputs, milking processes and cow health to minimize variation in milk yield and quality over time. Table 1 above introduced the five phases of Six Sigma implementation and their proposed adaptation to agricultural systems (Banhazi and Black, 2009). AfiMilk® support of these phases is partial and is summarized in Table 2. The following description of the AfiMilk® system and support to the five phases of Six Sigma include –

1. *Measure* – The AfiMilk® system measures every aspect, component and process of a dairy farm supply chain and milk production cycle in real time using sensors, tags, and proprietary hardware and software.
2. *Analyze* – AfiMilk® supplies users with automated analysis such as feed versus yield, milking efficiency, production by group, and cow health. AfiMilk® provides periodical analysis and monitoring reports called "Nir model" which are based on AfiFarm™ data. The "Nir Model" includes production, calving traits and disease, reproduction, lactation curves and abortion reports. The latter also includes a multi-factorial analysis that controls the effects of lactation number, trimester of pregnancy, sire and calendar months. The model provides loss in production and income information, and tactical and strategic recommendations. At present, the analysis is focused on the milk production cycle (Figure 1) and labor efficiency,[7] and partially supports strategic decision-making. The system does not provide economic, and labor cost/benefit analysis.

[7] Labor analysis is prepared using the milking efficiency module and data gathered by the milk meters (e.g., starting time, flow rate and quantity) to evaluate the milkers' work effectiveness in the parlor and to alert managers when inappropriate procedures are used.

3. *Improve* – AfiMilk® partially provides automated decision-making capabilities. Generally, the system produces exception reports that are used by managers for operational and strategic decisions. There are two exceptions: AfiLab™ automatically diverts contaminated milk from the milking tank. AfiSort™ provides an automated herd management and cow control option.
4. *Control* – AfiMilk® automates two core processes: heat discovery and product defect detection. These two processes have the largest impact on milk production and thus should be automated first. The system also supports automated control of technical problems and failures of the sensors and equipment, but does not include automatic recalibration.
5. *Loop-back* – Banhazi and Black (2009) added a fifth phase in which the system monitors outcomes and uses it to determine the effectiveness of actions taken. We termed this phase loop-back. At present, the AfiMilk® system partially supports loop-back capabilities for individual cow feeding adjustment based on milk yield.

Six Sigma	Banhazi and Black (2009)	AfiMilk®	Support of Six Sigma	Comments
Measure	Integration of automated data measurement and acquisition systems	AfiTag™, AfiLab™, AfiLite™, AfiWeight™ collect information as described in appendix A	Very high	
Analyze	Establishment of protocols for data-integration and automated data analysis	AfiMilk® central system, AfiAct™, and AfiFarm™ analyze data based on veterinarian research and produces exception reports	High	Lack economic (labor) analysis and partial strategic implications
Improve	Transfer of the results from data analysis as inputs into automated decision-making processes	AfiSort™ provides automated herd management, AfiLab™ automatically prevents contaminated milk from entering the milking tank	Medium/High	
Control	Activate automated or SOP control systems	Exception reports and manual control. Heat control and Mastitis control	Medium	Partial DSS capabilities
Loop-back	Procedures to monitor the outcome of control actions and documentation for QA	Automated feeding adjustments for individual cows	Low	Partial loop-back

Table 2. Application of the AfiMilk® system to Six Sigma

As mention above, an effective system would enable a company to plan for market and strategic needs (i.e. ESS). Current business trends allow managers to respond to market demands in a relatively short time. An expert system can forecast expected market demands and potential production shortage. Farm managers can use the system to select high yielding cows for extended lactation (Arbel, 2001) to meet these forecasted demands[8]. Although the AfiMilk® system collects information for each of the phases in Figure 2, it provides only partial loop-back from markets to logistics and production. For example, one can assume that feed strategy, environmental conditions and the genetics of the bull, have an effect on the yield and quality of the milk. A farm might be interested in producing X tons of low fat, high protein milk. An ESS should provide a manager with the optimal conditions necessary to achieve that goal.

In addition, although traditionally farmers look at calving as the beginning of the milk production process, manufacturing's "best practices" suggest that heat detection and insemination should be regarded as the driving processes of milk production. Thus, from a PA perspective the milk production life-cycle should begin at heat detection.

STUDY LIMITATIONS AND FUTURE RESEARCH

AgIS research is in its nascent stage. This exploratory study aims to describe an advance AgIS in business terms and analyze its effectiveness in the context of Six Sigma and PA. However, the analysis described above is subjective and is based on the authors' view of the current state of affairs in the dairy industry. Although we followed traditional case study methodology with an inter-rater of 90%, the discussion, conclusions and the system's applicability to the traditional Six Sigma process are based on subjective analysis. Future research should develop objective measures to the study of PA. Given the generally low utilization of AgIS, future research should also investigate the political, economic, social and technical drivers and inhibitors for the adoption of such systems.

[8] Extended lactation also enables the farmer to manipulate the fat and protein content of the produced milk (Arbel 2001).

Although the AfiMilk® system is implemented in various dairy farms around the world, the relations between the level of utilization of the various modules, farm size, farmer's education, environmental conditions, and the economic benefits of the system are unclear. Although, it is shown that the AfiMilk® system can improve some processes, it is unclear what the overall system's impact on agency and transaction costs, labor needs, and productivity across cultures. Future research could use the AfiMilk® system as a benchmark for the study of the economic, labor and management effectiveness of AgIS. In addition, PA attempts to reduce variation in agricultural production. Extending systems such as AfiMilk® to include decision and executive support components could improve decision-making on the farm and increase uniformity. Future research could study the effectiveness of such components on PA and production variability.

Traditional dairy farm management is labor intensive. A manual farm requires milking, herdsmen, and non-skilled laborers for cleaning, feeding and general cow maintenance. The automation of functions such as disease and heat detection could reduce the labor force of a farm. In addition, herding activities such as moving, directing and selecting cows to their respective pens are labor intensive. AfiTag™ and AfiSort™ automate many of these activities, reducing manual labor and potential human error. Future research could develop models to quantify the labor-related economic value for these systems.

Finally, food safety is a major concern mostly in developed countries while the shortage of staple foods is mostly a concern in developing countries. One way to alleviate food safety and shortage issues is to encourage the adoption of AgIS that can monitor product yield and quality throughout the food supply chain. Due to the increasing global nature of agriculture, such encouragement might require national and international policies, treaties and agreements. In addition, governments in developing countries might consider establishing test-beds, training and education facilities, and information centers that can help farmers in the adoption process. Future research could examine the effectiveness of AgIS on food safety and shortage.

CONCLUSIONS

The agriculture industry is lagging in the adoption of information technology and systems. One of the more advanced systems in dairy management is AfiMilk®. This paper set out to examine the maturity level of the system (from TPS to ESS) and its applicability to the implementation of the five Six Sigma phases described above. AfiMilk® fully supports two of the Six Sigma steps, measuring and analysis. It partially supports the second two steps, improvement and control. The developers of the system chose to concentrate their efforts on four key processes – production, fertility, animal health and milk quality. Future iterations of the system could develop automated controls for other processes. The fifth Six Sigma phase, which we termed loop-back, is only partially supported by the AfiMilk® system. As such, we can classify AfiMilk® as containing transaction processing and management information systems components with partial decision support capabilities.

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APPENDIX A – DETAILS OF THE AFIMILK® SYSTEMS

The AfiMilk® system is composed of four sub-modules. Its main function is to collect detailed information about every cow, store and process the data, and present it in a user friendly format. The system consists of the following main components.

AfiLite™ is a milk meter that measures yield, conductivity[9], flow rate, and milking times. The module analyzes milking pattern and provides automated cluster removal to optimize yield and milking parlor optimization. AfiLite™ also helps prevent contaminated milk from entering the milk tank, alerts the farmer if a cow has mastitis and faulty milking equipment.

AfiLab™ is a real-time on-line milk analyzer. It collects data on individual cows in every milking session. *AfiLab*™ collects milk component information (e.g., fat content, protein and lactose) and measures blood and SCC quantity. The system provides real time analysis and alerts. A critical component of *AfiLab*™ is its ability to identify the presence of blood in the milk in real time, allowing the discontinuation of the milking and minimizing the contamination of "milk in the tank."

AfiTag™ and *Ideal*™ are sensor-based. The *AfiTag*™ is a transponder/pedometer that is attached to the cow's leg and measures its activities and rest behavior. At present, the data is downloaded at milking time. The data collected helps the farmer in "heat detection" and cow welfare. The system alerts the farmer if environmental conditions such as bedding, group density, weather stress and access to food and water are suboptimal. The *Ideal*™ system is used to ensure accurate identification of each cow.

In addition, the *AfiMilk*® system offers the following sub-modules for farm and herd management.

AfiFarm™ is HM software used with all modules. The system automates daily operational routine activities traditionally carried out by herdsmen. The *AfiFarm*™ system relies on data collected by AfiMilk®, *AfiWeigh*™ and *AfiAct*™. The system can be customized by the user to fit individual farming style, select reports, and daily activities. *AfiFarm*™ provides the farm manager with a list of daily activities based on the state of the herd on a given day. The activities are related to cow fertility (e.g., breeding list, open cows, dry-off schedule, calving schedule), cow health (e.g., cows suspected as having health problems, veterinary visits), equipment (e.g., efficiency of milking machines and milkers work, over milking, average milk curve, equipment malfunction), and production (e.g., milk production by group, day, session, deviation from the standard). *AfiFarm*™ enables the manager to plan the herd structure, quota management and yield optimization.

AfiAct™ uses the pedometers described above to monitor and detect cows in heat for optimal breeding and lactation. Due to the critical function of heat detection, *AfiAct*™ is often the first module installed by farmers. Other modules can be added as needed. *AfiAct*™ is also used by large grazing farms to identify cows in need regardless of their location.

AfiWeigh™ is a module that enables the automatic identification and weighing of cows without manual intervention. Tracking cows' weight is one way to detect potential metabolic disorders and other health problems. Thus, *AfiWeigh*™ enables early detection and treatment of unhealthy cows, which contributes to the overall welfare of the herd and reduced loss due to downtime of unhealthy cows. Tracking cow's weight also enables improved feeding management and the precision feeding of individual cows.

AfiSort™ is a computerized gate control that directs cow traffic. Farmers have to perform numerous checks, examinations and treatments daily. *AfiSort*™ tracks, selects and monitors the cows that need special attention and directs them to the proper location. For example, cows that are due for a veterinary check are selected and directed to a hospital/treatment pen. This is done automatically as cows move from the milking area back to their pen.

Afi2GO™ is a PDA type device used by the farmer while in the field. *Afi2GO*™ is a complementary accessory to the *AfiMilk*® system. The system includes RFID capabilities, enabling the herdsman a quick and accurate identification of cows. As of Feb 2010, the synchronization of data between the *Afi2GO*™ and the AfiMilk® systems is done off-line.

[9] Conductivity is measured as a screening test for mastitis (Fernando et.al. 1982) and is used for tracking udder health (Woolford, 1998).