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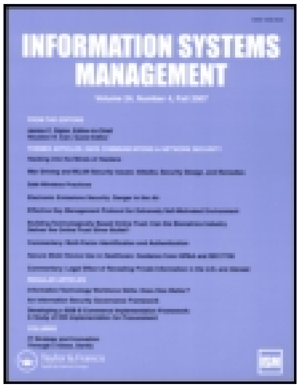


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# Using a Dairy Management Information System to Facilitate Precision Agriculture: The Case of the AfiMilk® System

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**Agriculture is behind in the adoption of information technology. Precision agriculture provides means for obtaining desirable business goals like product quality, reduced labor cost, and balanced product mix. This study describes the use of a dairy management information system implemented by S.A.E. Afikim to illustrate the applicability of systems in precision agriculture. Findings suggest that the adoption of Six Sigma-based dairy management information system supports four of five propositions: reduced product defect, optimal product mix, quality, and efficiencies.**

**Keywords** agricultural information systems; dairy management information systems; emerging technologies; precision agriculture; precision livestock farming; six sigma

## INTRODUCTION

Predictable output (PO) is desirable for most businesses since it reduces perceived financial risk (Baker, 1973). Supply chain outputs can be measured by performance in the quantity or quality produced (Beamon, 1999). For example, companies invest in Total Quality Management (TQM) to minimize variance in product quality (Hendricks & Singhal, 1997). In addition, a PO can benefit a company's manufacturing, marketing, communications, sales, and distribution processes (Zairi, 1997).

Predictable manufacturing depends on two essentials (Zairi, 1997):

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

For most industries, the latter is relatively easy. A stable and predictable production process in a modern automated manufacturing environment is often accomplished by using robotics and shop-floor control systems (Grigori, Casati, Dayal, & Shan, 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 provide the infrastructure used to improve the procurement of goods (Premkumar, 2000). Controlling inputs is more challenging for industries that rely on natural or perishable resources (e.g., food processing). Industries have adopted different levels of sophistication and automation in their production and distribution processes. The automobile industry (Gorlach & Wessel, 2008) and the hardware and networking components of the hi-tech industry (Marino & Dominguez, 1997) are highly automated. In contrast, the agriculture industry is well known to be technically inferior (Thomas & Callahan, 2002).

Agricultural development has progressed through six phases (*Agricultural Revolution*, 2010). The sixth and current phase is the availability of computers, software, satellite technologies, and sensor networks (Wang, Zhang, & Wang, 2006). Technology enables what is referred to as precision agriculture (PA) (Wang et al., 2006). Specifically, precision livestock farming (PLF), as a relatively new discipline (Banhazi et al., 2007; Mertens, Decuypere, De Baerdemaeker, & De Ketelaere, 2011), was introduced to ensure that every process in a livestock activity is controlled and optimized within narrow limits (Banhazi & Black, 2009). PA technology makes it possible to obtain effective data in real time (Zhang, Wang, & Wang, 2002). That is, PA should be driven by factors such as financial, economic (Zilberman, Khanna, & Lipper, 1997), food safety (Levidow & Bijman 2002), and uneven access to staple foods or food insecurity (Cassman, 1999). Ideally, PA should utilize the same processes and controls (e.g., TQM) that manufacturing does to achieve minimal output variability. However, despite the availability of the necessary components (i.e., hardware, networks,

Ron Berger and Anat Hovav independently developed this case study solely as the basis for journal research. It is not intended to serve as endorsements, sources of primary data, or illustrations of either effective or ineffective software of the vendor.

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and software), agricultural information systems (AgIS) are rare (Wang et al., 2006) and relatively rudimentary in today's standards (Banhazi & Black, 2009).

Since the availability of PA from the 1990s, the adoption and spread has been moderate (Daberkow & McBride, 2000). A national survey with 8,400 U.S. farms found that 70% of farm managers were unaware of PA technology (Daberkow & McBride, 2000). Findings also suggest that 25% were aware of PA technology, but had not yet adopted it, and that the adoption of PA technology is significantly lower compared to other types of agricultural technologies such as genetically modified products (Daberkow & McBride, 2003). Similarly, studies in New Zealand indicated that dairy farms have not adopted or have been slow to adopt new technologies that would benefit their milk production (Crawford, Gray, Parker, & Edwards, 1989; Deane, 1993; Edwards & Parker, 1994; Stantiall & Parker, 1997). In general, research has shown that farmers exhibit a low rate of information management software adoption (Alvarez & Nuthall, 2006; Morris, Loverideg, & Fairweather, 1995). As discussed later, most dairy farms around the world are small and most often family operated (EPA, 2007).

Ideally, dairy farms should be managed "like a business." However, most farms are small- and medium-sized enterprises (SMEs) and are operated by farming experts rather than business managers. It is our contention that most dairy farm managers lack the business knowledge and expertise to apply "business best practices." Rather, managers use intuition, experience, and gut feelings to support their decisions in operational processes. This is also apparent by the preference to implement technical solutions over business solutions (i.e., farming technology versus decision-making systems).

The implementation of a dairy management information system (DMIS) in farms can be equated to the early implementations of ERP systems in the 1980s. Many of these implementations were driven by organizations' desires to adopt "best practices," gain operational efficiencies and remain competitive in a changing world (Bingi, Maneesh, & Jayanth, 1999). It is our contention that by implementing a DMIS, small herd-size farms can implicitly adopt the best practices inherent in the system without having explicit business knowledge and address PLF specific issues such as animal welfare and public perceptions of animal usage. As Six Sigma is used in a variety of industries as a best practices framework for operational efficiencies and Banhazi and Black (2009) championed its application as a potential best practices framework in livestock management, we chose a modified version of Six Sigma as our evaluation scheme.

The goal of this article is to evaluate a leading global DMIS, AfiMilk®**,** and answer the following research questions:

- To what extent does AfiMilk® implicitly support best practices on the farm?
- To what extent does AfiMilk® support the use of TQM/Six Sigma?

The next sections will define PA in the context of TQM and Six Sigma and describe the use of 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.

## SIX SIGMA AND TQM

Six Sigma is a business management process developed by Motorola in 1981 and was inspired by prior quality improvement methodologies such as TQM and Zero Defects (Tennant, 2001). Companies such as Allied Signal, IBM, and General Electric adopted Six Sigma for strategic and tactical operations and improved labor skills (Aboelmaged, 2010). Six Sigma has varied definitions and perspectives. From a statistical perspective, Six Sigma is a measurement that represents variation within normally distributed data (Chassin, 1998). Statistically, the goal of Six Sigma is 3.4 defects per million opportunities. The tolerance for Six Sigma is six standard deviation units or about 99.7% (Arnheiter & Maleyeff, 2005). A defect rate for a faulty part or customer billing may range from 35,000 to 50,000 per million opportunities, or 3.0–3.5 sigma (Conlin, 1998). A defect is considered a process output that does not meet customer satisfaction or regulatory specifications (Antony, 2008).

From a business perspective, Six Sigma allows companies to improve everyday business activities and to increase customer satisfaction (Andersson, Eriksson, & Torstensson, 2006). For example, Schroeder and colleagues (2008) define it as a way to control and improve a firm's operations, while Antony (2006) suggests that Six Sigma supports the early discovery of potential defects (i.e. preventive measures). In addition, it enables the identification and removal of the defect's source and minimizes variability in manufactured outputs (Snee, 1999). Finally, from a goal theory perspective, behavior may add a social and psychological component to Six Sigma (Linderman, Schroeder, Zaheer, & Choo, 2003). In this article, we refer to Andersson and colleagues' (2006) definition of Six Sigma.

Six Sigma differs from other quality improvement methodologies (Antony, 2008). Six Sigma

- Focuses on achieving measurable and quantifiable financial returns.
- Integrates human elements such as cultural change and customer focus.
- Includes 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.

De Mast (2003) proposed five phases for project quality improvement. In the first phase, operationalization, the analyst defines the problem and makes the concept measurable. The concept is defined and composed as units in a population. A measurement procedure and scale are defined for quality improvement of the project and the extent of the problem is evaluated. In the second phase, exploration, the analyst identifies potential issues that can influence a project. In the third phase, elaboration, the researcher identifies an order and explicitation or translation for potential issues by unmethodical measures such as identifying relevant classes, developing categories, searching for patterns in data, and creating analogies for these potential issues. In the fourth phase, confirmation, the analyst verifies the effects of the potential issues that can influence a project, thus insuring objectivity to the study. The second and fourth phases are the center of the five phase process. In the concluding fifth phase, the relationship between the influence and quality characteristics of the project is examined to define improved actions and update quality control.

In addition to manufacturing, Six Sigma has been applied in service industries. For example, in the health industry, deaths related to anesthesia in the 1970s and 1980s measured at 1 in 10,000–20,000 or 25–50 per million (Chassin, 1998; Ross & Tinker, 1994). Through improved monitoring, guidelines, and approach, the healthcare industry has reduced error of anesthesia deaths to 5 per million (Eichhorn, 1989; Lunn & Devlin; 1987; Orkin, 1993). Similarly, libraries have applied Six Sigma to improve their services (Kim, 2010).

While Six Sigma has been incorporated into manufacturing and service processes, it has not been applied in agriculture. Bewley (2009) suggested the use of technology to advance precision dairy farming while Banhazi and Black (2009) developed an initial framework for the use of TQM in PLF. Table 1 compares De Mast (2003), and Banhazi and Black (2009) approaches.

The comparative table suggests that general principles of Six Sigma (and other TQM methods) are applicable to PA. As mentioned above, the objective of PA in dairy management is to improve the control of inputs and outputs. For example, measuring and establishing protocols in an environment of high variability can facilitate the optimal use of input resources such as feed from outside sources (i.e., Animal Feeding Operation [AFO]) and insemination material. Similarly, the integration of automated data measurements for processes such as feed mix and cost composition, cow heat discovery for insemination and pregnancy, and cow health for optimal lactation is necessary for controlling and optimizing production outputs within a preset range of variability (Banhazi & Black, 2009).

The establishment of data integration and the transfer of data analysis into an automated decision-making process with limited human intervention are necessary for minimizing human error leading to reduced product defect (contaminant milk) and process variability (overlooked heat discovery). Activated control systems are either automated or documented as standard operating procedures (SOP). Automated data analysis can be used by technicians, consultants, and business managers to monitor production output. Procedures that monitor the outcome or actions taken by the farmer are subsequently applied for quality assurance (QA) purposes. Milk quality assessment methods and product tracking for contaminated milk are also necessary for food safety purposes. Thus, we argue that the application of the Banhazi and Black (2009) evaluation scheme could support reduced variability in dairy management and PA.

POs 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 have to account for these variations in their production processing (Meade & Sarkis, 1999). Thus, agriculture, which heavily relies on natural resources, would greatly benefit from controlled production. However, the literature suggests that the application of IT in agriculture is minimal (Thomas & Callahan, 2002). A Schmidt and colleagues (1994) study showed that during the 1980s and 1990s, farmers did not take advantage of IT. Similarly, many cattle operations were slow to adopt and utilize IS (Blezinger, 2001).

Despite the limited adoption of IT in agriculture, DMIS have been developed and implemented in large dairy farms in the past two decades (Devir, Renkema, Huirne, & Ipema, 1993). The following section describes one of the more advanced contemporary DMIS–AfiMilk®. We intend to show that the AfiMilk® system partially supports Six Sigma capabilities as suggested by Banhazi and Black (2009). In addition, it is a simplified transaction processing system with some management support capabilities. The system partially supports strategic and long-term executive decision-making as suggested by Thomas and Callahan (2002).

## THE DAIRY INDUSTRY

The U.S. dairy industry tends to have large herd-size farms with 1,000–2,000 units per farm (MacDonald et al., 2007). Yet, 30% of U.S. dairy farms are still relatively small with less than 30 units per farm, and 92% have less than 200 units, deeming those as SMEs (see Figure 1). By definition, the U.S. government considers farms with 200 or fewer units as small-size operations (EPA, 2007). Although there has been some consolidation of small herd-size farms in recent years, the fact remains that most dairy farms in the United States (much like in other countries) are relatively small.

Similarly, in the United Kingdom, over 11,000 of the dairy farms are SMEs, with an average herd size of 113 cows per farm (Dairy Farming UK, 2011), while in Ireland the majority of farms have 50–60 cows (Donnellan, Hennessy, Keane, & Thorne, 2011), and in Canada herd size average is just over 60 units per farm (Painter, 2007). In South Korea, nearly all

TABLE 1
Six Sigma comparison

| 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 SOP control systems<br>Procedures to monitor the outcome of control actions and documentation for QA purposes |

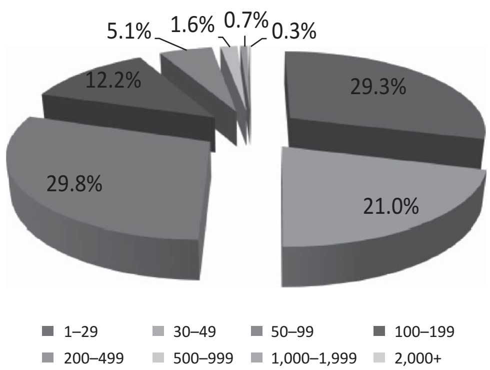


FIG. 1. Herd size distribution for dairy farms in the United States (adapted from MacDonald et al., 2007).

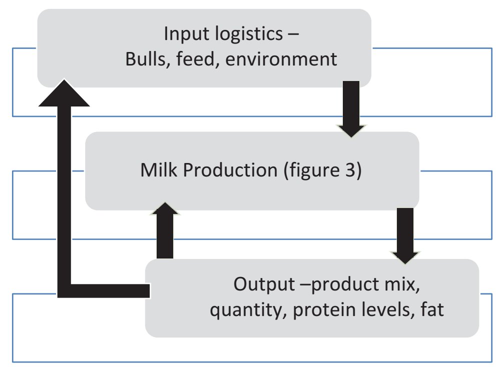


FIG. 2. Dairy farm supply chain (color figure availabel online).

dairy farms are family operated and have a herd size of less than 100 cows (Berger, 2012). Contrary to most countries, farms in New Zealand are much larger, averaging over 300 units per farm (Painter, 2007).

In addition, a survey of 30 dairy farm equipment dealers from 17 countries that service over 2,000 farms suggests that 69.5% of these farms have less than 200 units while only 2.8% are corporate farms with greater than 2,000 cows per farm (Berger, 2012). Therefore, our basic assumption is that most dairy farms are small herd-size and managed by farmers rather than business managers, regardless of country (developed or otherwise).

Dairy farms are divided into grazing farms and AFOs where the feed (input) is brought to the animal. AFOs rely on outside logistics for feed (outsourcing) while grazing farms have more control over the feed since it is internally managed (vertical integration). The scope of our analysis is limited to AFO farms.

## Dairy Farm Supply Chain

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 (SCC), color, and calcium.

## Milk Production Cycle

The cow production cycle traditionally begins with calving (Figure 3). However, from a business and manufacturing perspective, cow pregnancy is the key to an optimal milk production cycle. Biologically, it is possible that a cow would not get pregnant on the first try, resulting in delayed calving and lactation (i.e., loss of productivity). However, if the dairy farmer misses inseminating during a heat period, 20 production days are lost until the next insemination window. Thus, we suggest that insemination can be equated to inbound logistics. Just as having parts and materials is a necessary but not sufficient condition to precision manufacturing, timely insemination is a necessary but not sufficient condition to optimal milk production. Thus, we define "rest" as the time between the end of a lactation period and the next insemination window.

Ideally, dairy farmers need to reduce the wait time (time between the end of one lactation cycle and the beginning of the next one) and optimize the average of days in milk (DIM) of their overall herds (approximately 305 DIM; Ptak, Satola, & Hanna, 2004) to maximize milk output. Similar to other types of manufacturing, dairy farmers are concerned with product

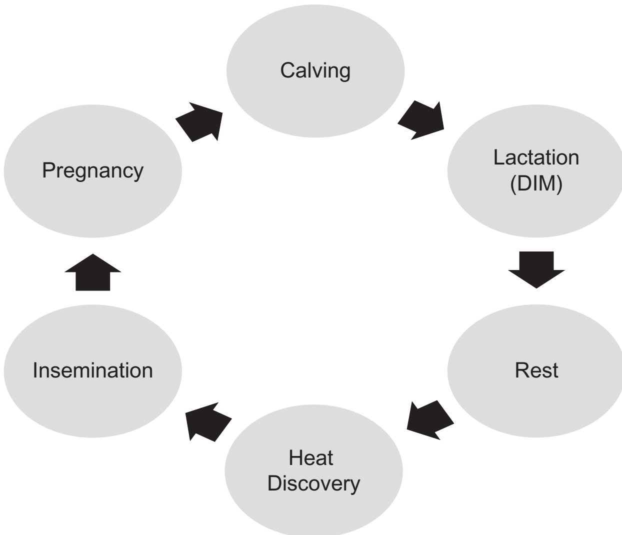


FIG. 3. Milk production cycle.

quality, supply, demand, product mix, operation efficiencies, and labor management.

## Product Quality

Although milk standards vary by country, dairy 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))" (USDA, n. d.).

Similar to other industries, product defects and spoilage are major issues for dairy farmers (Champagne et al., 1994; Jakobsen & Narvhus, 1996). For example, if a bottling manufacturer 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 & 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 health standards and regulations. 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. The following scenarios and resulting economic damage can occur:

- The contamination is discovered prior to the distribution and the milk is discarded. The dairy farmer loses $5,000.
- The contamination is discovered at the processing center, resulting in losses to the dairy 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 marketplace. 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 & Hooker, 2001).

Similar scenarios could take place with bacteria and other foreign agents. The extent of the loss may also depend on the severity of the spoilage, spread of the product (distribution distance), regulations, and liability. A critical control point (Banhazi & Black, 2009) would be the ability to detect contaminated milk before it is introduced to the main tank. Therefore, we propose the following:

*Proposition 1: The adoption of Six Sigma based DMIS is likely to reduce milk product defect.*

## Supply and Demand and Product Mix

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, past milk and cheese consumption for Korea was minimal. With the increase of travel and exposure to western culture, the younger generation consumes more milk than the older generation (Kim, Moon, & Popkin, 2000; Wyne, Lee, & Moon, 1993). Conversely, the melamine scare of 2008 (Chinese Milk Scandal, 2008) 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 ("Milk Supply Shortage," 2009). This abrupt increase in fresh milk consumption could not have been planned or anticipated.

Managers also need to balance supply and demand. Since milk products are perishable, they need to be distributed and consumed within a short time period. In addition, perishable products cannot be redistributed or sent to discounted channels. In some regions, specialty products are seasonal. For example, during late fall and early winter, the consumption of heavy-cream, butter, and cheese in the United States increases (Manchester & Blayney, 2001), while in the summer consumers prefer skim milk and yogurt. Fluid milk is unique in that cows produce every day and the milk has to move to the market regardless of demand (Manchester & Blayney, 2001). Therefore, dairy managers need to produce the proper amount of a given product (i.e., yield, fat and protein content) at the right time, thus reducing over supply, spoilage, and discards. The application of automated feeding control enables farmers to adjust the fat and protein in the milk and to achieve a variety of product mix (Maltz, Antler, Halachmi, & Schmilovitch, 2009). Automated feeding strategy can also manipulate production volume (Tylutki, Fox, & McMahon, 2004) to support variation in demand.

Therefore, we suggest the following propositions:

*Proposition 2: The adoption of Six Sigma based DMIS supports optimal product mix.*
*Proposition 3: The adoption of Six Sigma based DMIS supports optimal product quantity.*

## Operation 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 DIM.
- Minimizing downtime due to disease.

### *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 raw material. Similarly, a herd should have the proper mix of cows in various stages of production (Figure 3) depending on the farmer and market projected needs. Mating time and estrus level are key determinants of animal farm productivity (Banhazi & Black, 2009). Heat discovery is a critical process in optimizing DIM and maximizing herd profitability (Senger, 1994). 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 3, a delay in heat discovery and cow insemination may cause delayed pregnancy and calving, and ultimately reduces milk production and herd profitability.

### *Minimizing Downtime*

Similar to a faulty assembly line, early detection of disease (especially mastitis) is instrumental for minimizing production downtime. Manual detection of mastitis could result in an average of 4.4 days of infection 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, & Voet, 1998). Thus, a computer-based early detection of mastitis reduces cow downtime in days by 8.9% ($p < 0.005$) and milk loss by 31%.

Herd management in PLF can be equated to assembly line efficiencies (i.e., shop-floor control). Regulations mandate a maximum number of cows per square foot. Thus, dairy managers have to optimize their herd composition to meet production requirements. Therefore, we suggest the following:

*Proposition 4: The adoption of Six Sigma based DMIS supports optimal operational efficiencies.*

## Labor Management

Agriculture is a labor-intensive industry relative to manufacturing (Roe & Diao, 1994). 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., the United States and Western Europe) where the cost of labor is higher. Six Sigma is expected to improve labor skills (Aboelmaged, 2010). In addition, the adoption of automated controls, SOP, and automated loop-back should reduce overall labor cost.

*Proposition 5: The adoption of Six Sigma based DMIS can reduce labor cost.*

# METHODOLOGY

For this study, we have selected a multiple case design with a single unit of analysis for each case (Yin, 2003). This design can provide more compelling evidence by supplying multiple data points and rich descriptions. We selected AfiMilk® as an example of a DMIS since it is considered an industry leader and as a convenience sample. However, the analysis and results of the study are not limited to one specific product and can be applied to other DMIS. 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 five facilities that use the system in two countries.
- Reviewed official technical and 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. Follow-up questions were asked when clarifications were needed. The questions were phrased in such a way as to be "neutral" so that the respondent 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 uncertainties.

## 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 analyzers, 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 article 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 February 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™, 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 applicable for large or grazing farms and thus will not be addressed in detail.

## THE APPLICATION OF SIX SIGMA TO DMIS

The core of PA and its use of Six Sigma are to minimize variation in production. The AfiMilk® system, as an example of a DMIS, uses exception reporting to support these goals. 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 introduced the five phases of Six Sigma implementation and their proposed adaptation to agricultural systems (Banhazi & Black, 2009). AfiMilk's® support of these phases is partial and is summarized in Table 2. AfiMilk® system support 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 (Figures 2 and 3) 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® also 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 3) and labor efficiency, and partially supports strategic decision-making. The system does not provide economic and labor cost/benefit analysis. Labor analysis is

TABLE 2
Application of the AfiMilk® system to Six Sigma

| 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 | Lacks 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 decision support 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 |

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 (i.e., product defect prevention). 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 adjustments based on milk yield.

## ANALYSIS

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

### The Application of DMIS to Product Defects (P1)

The AfiMilk® system measures the levels of blood and SCC, 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 DMIS supports automated measurements and data analysis for product defect management as defined by Banhazi and Black (2009) supporting proposition 1. Figure 4 illustrates the economic benefits resulting from milk quality improvements (Farm A).

**SIDE-BAR A: Revenue Analysis**

A farmer in Korea receives ₩900 per Kg of grade 1 milk and ₩780 per Kg of grade 2 milk, a difference of ₩120 per Kg

**Farm A (40 cows)**
Using a DMIS system, the farmer was able to upgrade their milk from grade 2 to grade 1. Average production is 35Kg per cow per day resulting in 35Kg*30 days*40 cows = 42000 Kg per month.
42000 Kg* ₩120= ₩5040000 per month ($4580) – twice the average salary in Korea.

**Farm B (80 cows)**
Using a DMIS automated feeding where the feed intake remains constant, the farmer was able to increase production by 2 Kg per cow per day for a total of 2Kg*30 days*80 cows = 480Kg per month. 480* ₩900= ₩432000 ($400).

FIG. 4. Economic benefits from milk quality improvements (color figure available online).

### The Application of DMIS to Product Mix and Quantity (P2 and P3)

AfiMilk® enables farm managers to analyze the effectiveness of its feeding operations by comparing cost of feeding to yield (Figure 5). By measuring milk quantity and composition, the DMIS alerts the farmer of feeding problems and helps create better-fitted rationing for the entire group or individual cow. In addition, the DMIS enables automated feeding adjustments for individual cows based on an algorithm developed by Maltz and colleagues. (2009). Figure 4 illustrates some of the economic benefits resulting from optimal feeding (Farm B).

The AfiMilk® system also enables an optimal utilization of product mix. The system inspects the composition of the milk (i.e., fat, protein, lactose) for each cow in real time (Figure 6) and stops the milking process based on the composition of the milk. In addition, farm managers can use the system to select high yielding cows for extended lactation (Arbel, Bigun, Ezra, Sturman, & Hojman, 2001) to meet these forecasted demands. Extended lactation also enables the farmer to manipulate the fat and protein content of the produced milk (Arbel et al., 2001), achieving an optimal product mix.

### The Application of DMIS to Operational Efficiencies (P4)

*Managing Product Life Cycle*

The AfiMilk® system helps farm managers in achieving product life-cycle efficiencies. Mating time and estrus levels are key determinants of animal farm productivity (Banhazi & Black, 2009). Similarly, heat discovery is a critical process in optimizing DIM and maximizing herd profitability. Using the DMIS heat detection system compared to manual detection increases the number of pregnancies by 12.6% with a $p < 0.005$ (Gelb et al., 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, Lewis, & Aizinbud, 1992; Pennington, Albright, & Callahan, 1986). In addition, using the system, managers can track the number of wasted days and optimize production.

*Minimizing Downtime*

A DMIS can also enable an early detection of disease. For example, AfiMilk® early detection of mastitis reduces a cow's downtime in days by 8.9% ($p < 0.005$) and milk loss by 31%

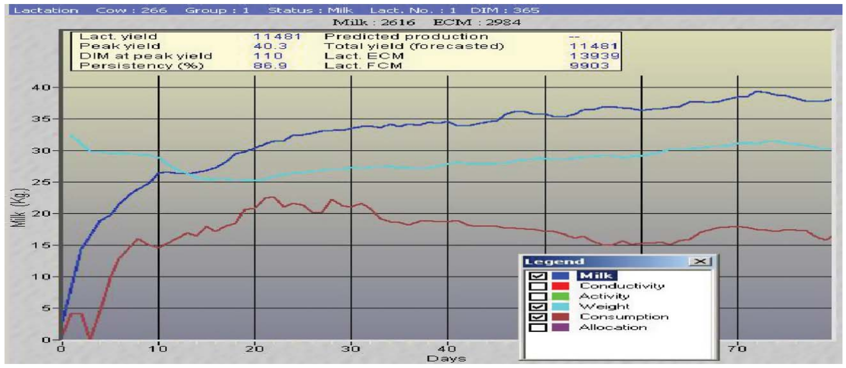


FIG. 5. Feeding efficiency (color figure available online).

Milk Component (Day) (15/08/2008 - 24/08/2008) (24/08/2008 12:24:36)

Save Save As... Design Refresh

| Index | Date | Total yield | Avg. yield per milk cow | Total milk cows | Total cows | Avg. yield per cow | Daily FCM | Fat % | Protein % |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 15/08/2008 | 28872 | 35.9 | 804 | 931 | 31.0 | 36.0 | 4.07 | 3.10 |
| 2 | 16/08/2008 | 28805 | 35.7 | 806 | 932 | 30.8 | 36.4 | 4.12 | 3.07 |
| 3 | 17/08/2008 | 28008 | 34.8 | 804 | 932 | 30.1 | 36.0 | 4.25 | 3.05 |
| 4 | 18/08/2008 | 27667 | 34.3 | 806 | 934 | 29.6 | 35.4 | 4.19 | 3.02 |
| 5 | 19/08/2008 | 26946 | 33.4 | 807 | 934 | 28.8 | 34.9 | 4.30 | 2.93 |
| 6 | 20/08/2008 | 26700 | 33.4 | 799 | 934 | 28.6 | 33.1 | 4.00 | 3.13 |
| 7 | 21/08/2008 | 26232 | 32.6 | 804 | 936 | 27.9 | 32.2 | 3.90 | 3.19 |
| 8 | 22/08/2008 | 26337 | 32.7 | 806 | 938 | 28.1 | 31.9 | 3.85 | 3.19 |
| 9 | 23/08/2008 | 26424 | 32.7 | 809 | 940 | 28.1 | 32.0 | 3.84 | 3.21 |
| 10 | 24/08/2008 | 26828 | 33.2 | 809 | 940 | 28.4 | 32.1 | 3.79 | 3.20 |
| Total | -- | 272819 | -- | 8054 | 9351 | -- | -- | -- | -- |
| Avg. | -- | -- | -- | -- | -- | -- | 33.7 | 4.00 | 3.13 |

FIG. 6. Product mix based on fat and protein content (color figure available online).

(Figure 7). In addition, the system enables the early detection of metabolic disease using AfiLab$^{TM}$.

*Herd Management*

In addition to product life cycle and downtime management, a DMIS for herd management has the capability to 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 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 (Figures 8–9). We acknowledge that herd management capabilities are mostly applicable to large farms and thus have little relevance to this particular case study.

## The Application of DMIS to Labor Management (P5)

The DMIS studied does not directly support labor cost and skills analysis. However, farmers indicated that by implementing the system they were able to reduce production (milking) time by approximately 40–50%. For large herd-size farms, the

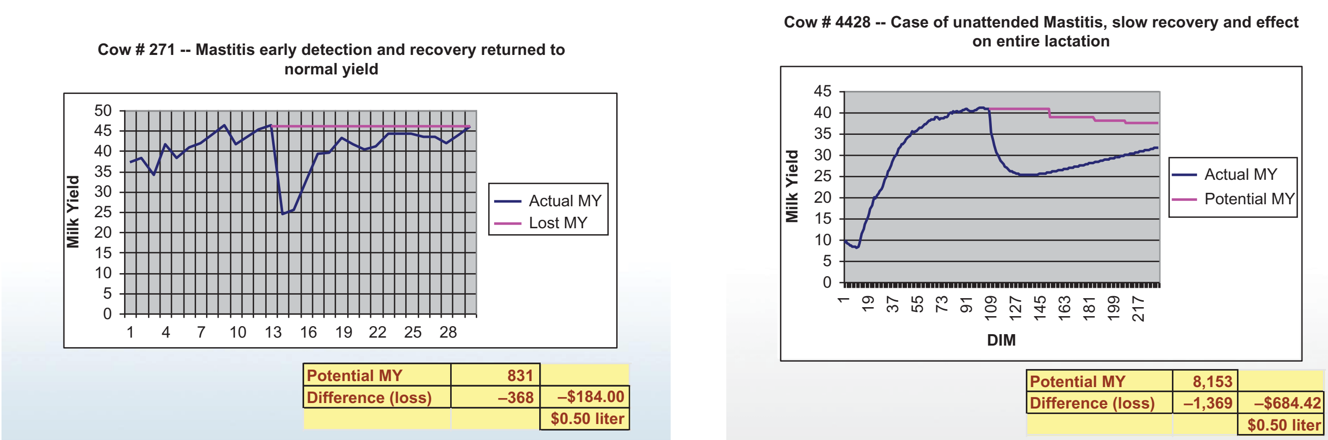


FIG. 7. Early and late detection of disease total loss (color figure available online).

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 |

FIG. 8. Quota management (color figure available online).

| Index | Cow | Gyn. status | Lact. no. | DIM | ∧3 STD yield 305 DIM | Daily yield | Fat <%> | Protein <%> | SCC | Breed. no. | ∇2 Priority factor | ∇1 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 |

FIG. 9. Cull planning (color figure available online).

system also automates otherwise manual processes. For example, the AfiSort™ subsystem allows farmers to divert cows to separate pens as they return from milking (i.e., separate sick cows and cows in heat) with no human intervention.

In addition, grazing cows can be remotely monitored and identified using AfiTag™. This minimizes the need for herdsmen to visually find, identify, and monitor largely disbursed herds. Therefore, it appears that DMIS support for labor management pertains to large more than small herd-size farms. However, at present, the number of large farms is relatively few.

## DISCUSSION

In the above analysis, we used the AfiMilk® system as an example of a DMIS. Our analysis suggests that this DMIS supports two of the Six Sigma steps, measure and analyze. These are relatively simple to accomplish as IS have been used for data collection and basic reporting since the 1970s. The system, to some extent, supports the third step, improves and enables automated decision-making. However, at present, most of the decision-making is performed by the farmer. Given our contention that most farmers are not business managers, it is likely that their decisions will be farming rather than business centric. The system also partially supports automated control and minimally supports automated loop-back. Although, an automated feeding adjustment system is available, it is rarely implemented on farms. This suggests that although DMIS exist, they are still in their early stages of development (from a business management perspective) and are mostly designed to support operational processes.

Current business trends require farm managers to respond to market demands in a relatively short time, forecasting expected market exigencies and potential production shortage. The basic premise of PA is that inputs and processes can be controlled (i.e., by reducing variability), producing more stable outputs. IT is often used to facilitate quality control in the manufacturing and service industries. In this article, we illustrate that DMIS can be used to support operational efficiencies, minimize product defects, help optimize product mix, and balanced supply and demand. Our case study also illustrates that Six Sigma principles can be adapted to the agricultural industry and be used to promote PA.

In addition, we found that, 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. From a Six Sigma perspective, insemination can be equated to inbound logistics. Just as having parts and materials is a necessary but not sufficient condition to precision manufacturing, timely insemination is a necessary but not sufficient condition to optimal milk production.

## STUDY LIMITATIONS AND FUTURE RESEARCH

AgIS research is in its nascent stage and is mostly technical and farming centric. This exploratory study aims to describe a DMIS in business terms and analyze its effectiveness in the context of Six Sigma and PA. However, the analysis described above is subjective and 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 policy, economic, social and technical drivers and inhibitors for the adoption of such systems.

Although the DMIS studied is implemented in various dairy farms around the world, the relations between the level of utilization of the various modules, herd size, farmer's education, environmental conditions, and the economic benefits of the system are unclear. Our analysis illustrates that the system can improve some processes. However, it is unclear what the overall system's impact on agency and transaction costs, labor needs, and productivity across cultures.

PA attempts to reduce variation in agricultural production. Extending DMIS to include automated decision and executive support components could improve decision-making on the farm and increase uniformity. This is especially important for small herd-size farms where the manager has limited business know-how. 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 unskilled laborers for cleaning, feeding, and general cow maintenance. The automation of functions such as disease and heat detection is likely to reduce the labor force of a farm. In addition, automating herding activities such as moving, directing, and selecting cows to their respective pens could reduce manual labor and potential human error. Future research should develop models to quantify the labor-related economic value for these systems in large corporate farms and grazing operations.

Finally, food safety and the shortage of staple foods are of major concern in developed and developing countries respectively. 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 testbeds, 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 IT and IS. One example of a dairy management system is AfiMilk®. This article set out to examine the maturity level of the system in the context of Six Sigma and its support of PA. We proposed that by utilizing Six Sigma based processes facilitated by a DMIS, farmers can implicitly implement best practices, improve operational efficiencies, reduce product defects, optimize product mix, and improve the balance between supply and demand. Using the AfiMilk® case, we were able to support four of the five propositions. Although we can stipulate that a DMIS could reduce labor cost (at least for very large farms), at present, we do not have support for that assertion.

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## REFERENCES

Aboelmaged, M. G. (2010). Six Sigma quality: A structured review and implications for future research. *International Journal of Quality & Reliability Management*, *27*(3), 268–317.

*Agricultural Revolution*. (2010). Retrieved January 3, 2010, from http://en.wikipedia.org/wiki/Agricultural_revolution

Alvarez, J., & Nuthall, P. (2006). Adoption of computer based information systems: The case of dairy farmers in Canterbury, NZ, and Florida, Uruguay. *Computers and Electronics in Agriculture*, *50*, 48–60.

Andersson, R., Eriksson, H., & Torstensson, H. (2006). Similarities and differences between TQM, Six Sigma and lean. *The TQM Magazine*, *18*(3), 282–96.

Antony, J. (2006). Six Sigma for service processes. *Business Process Management Journal*, *12*(2), 234–248.

Antony, J. (2008, January 7). *Pros and cons of Six Sigma: An academic perspective*. Retrieved January 3, 2010 from http://www.improvementandinnovation.com/features/articles/pros-and-cons-SixSigmaSixSigma-academic-perspective

Arbel, R., Bigun, Y., Ezra, E., Sturman, H., & Hojman, D. (2001). The effect of extended calving intervals in high lactating cows on milk production and profitability. *Journal of Dairy Science*, *84*, 600–608, American Dairy Science Association.

Arnheiter, E. D., & Maleyeff, J. (2005). The integration of lean management and Six Sigma. *The TQM Magazine*, *17*(1), 5–18.

Baker, S. H. (1973). Risk, leverage and profitability: An industry analysis, *The Review of Economics and Statistics*, *55*(4), 503–507.

Banhazi, T., Dunn, M., Cook, P., Black, J., Durack, M., & Johnnson, I. (2007). Development of Precision Livestock Farming (PLF) Technologies for the Australian pig industry. In S. Cox (Ed.), *Precision Livestock Farming '07* (pp. 219–228). Wageningen, The Netherlands: Wageningen Academic Publishers.

Banhazi, T. M., & Black, J. L. (2009). Precision livestock farming: A suite of electronic systems to ensure the application of best practice management on livestock farms. *Australian Journal of Multi-disciplinary Engineering*, *70*, 1.

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, *19*(3), 275–292.

Berger, R. (2012). Determinants of information technology adoption in the dairy industry: An exploratory study of organizational and environmental factors. (Unpublished Dissertation). Seoul National University, Seoul, Korea.

Bewley, J. (2009). *Precision dairy farming: Opportunities, challenges, and solutions*. In a presentation at The Dairy Practices Council 40th Annual Conference, November 2009, Latham, NY, USA.

Bingi, P., Maneesh, K. S., & Jayanth, K.G. (1999). Critical issues affecting an ERP implementation. *Information Systems Research*, *16*(3), 7–14.

Blezinger, S. (2001, May). Many tools are available to help build a quality herd. *Cattle Today Online*. Retrieved January 3, 2010 from http://cattletoday.com/archive/2001/May/CT147.shtml

Cassman, K. G. (1999, May). Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. In *Proceedings of the National Academy of Sciences*, *USA*, 96, 5952–5959, Colloquium Paper.

Champagne, C. P., Claude, P., Laing, R. R., Roy, D., Mafu, A. A., Griffiths, M. W., & White, C. (1994). Psychrotrophs in dairy products: Their effects and their Control. *Critical Reviews in Food Science and Nutrition*, *34*(1), 1–30.

Chassin, M. R. (1998). Is health care ready for Six Sigma quality? Improving the quality of health care., *The Milbank Quarterly*, *76*(4), 565–591.

*Chinese milk scandal*. (2008). Retrieved January 3, 2010, from http://en.wikipedia.org/wiki/2008_Chinese_milk_scandal

Conlin, M. (1998). Revealed at last: The success of Jack Welch's success. *Forbes*, *16*(2), 44.

Crawford, H. K., Gray, D. I., Parker, J. W., & Edwards, N. (1989). Characteristics of seasonal dairy farms achieving high per cow production in the lower North Island of New Zealand. *In Proceedings of the New Zealand Society of Animal Production*, *55*, 71–75.

Daberkow, S. G., & McBride, W. D. (2000). Adoption of precision agriculture technologies by U.S. farmers. In *Proceedings of the 5th International Conference on Precision Agriculture*, edited by P. C. Robert, R. H. Rust, & W. E. Larson (ASA/CSSA/SSSA, Madison, WI, USA).

Daberkow, S. G., & McBride, W. D. (2003). Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. *Precision Agriculture*, *4*, 163–177.

*Dairy farming in the UK*. (2011). Retrieved June 27, 2011 from http://www.wspa.org.uk/wspaswork/factoryfarming/UK_dairy_farming.aspx

De Mast, J. (2003). Quality improvement from the viewpoint of statistical method. *Quality and Reliability Engineering International*, *19*, 255–264.

Deane, T. H. (1993). The relationship between milk fat production per hectare and economic farm surplus on New Zealand dairy farms. *In Proceedings of the New Zealand Society of Animal Production*, *53*, 51–54.

Devir, S., Renkema, J.A., Huirne, R. B. M., & Ipema, A. H. (1993). New Dairy control and management system in the automatic milking farm: Basic concepts and components, *Journal of Dairy Science*, *76*, 3607–3616.

Donnellan, T., Hennessy, T., Keane, M., & Thorne, F. (2011). Study of the international competitiveness of the Irish dairy sector at farm level. Retrieved June 27, 2011, from http://www.rte.ie/news/2011/0623/teagascdairyreport.pdf

Edwards, N., & Parker, W. J. (1994). Increasing per cow milk solids production in a pasture-based dairy system by manipulating the diet: *A* review. *In Proceedings of the New Zealand Society of Animal Production*, *54*, 267–273.

Eichhorn, J. H (1989). Prevention of intraoperative anesthesia accidents and related severe injury through safety monitoring. *Anesthesiology*, *70*, 572–577.

EPA. (2007). *Regulatory definitions of large CAFOs, medium CAFO, and small CAFOs*. Retrieved January 3, 2010, from http://www.epa.gov/npdes/pubs/sector_table.pdf

Fernando, R. S., Rindsig, R. B., & Spahr, S. L. (1982). Electrical conductivity of milk for detection of mastitis. *Journal of Dairy Science*, *65*, 659–664.

Gelb, E., Kislev, Y., & Voet, H. (1998). *Measuring the Benefit of a Computer in the Milking Parlor: The Yavneh Dairy Case Study*. Department of Agricultural Economics and Management, Faculty of Agriculture, Hebrew University, Rehovot, Retrieved March 1, 2010 from http://departments.agri.huji.ac.il/economics/gelb-measuring-7.pdf or http://departments.agri.huji.ac.il/economics/en/publications/discussion_papers/1998/index.htm

Gorlach, I., & Wessel, O. (2008). Optimal level of automation in the automotive industry. *Engineering Letters*, *16*(1), Advance online publication: 19 February 2008.

Grigori, D., Casati, F., Dayal, U., & Shan, M. C. (2001). Improving business process quality through exception understanding, prediction, and prevention. In *Proceedings of the 27th VLDB Conference*, Roma, Italy, September 11–14.

Hendricks, K. B., & Singhal, V. R. (1997). Does implementing an effective TQM program actually improve operating performance? Empirical evidence from firms that have won quality awards. *Management Science*, *43*(9), 1258–1274.

Jakobsen, M., & Narvhus, J. (1996). Yeasts and their possible beneficial and negative effects on the quality of dairy products. *International Dairy Journal*, *6*(8–9), August-September, 755–768.

Kim, D. S. (2010). Eliciting success factors of applying Six Sigma in an academic library: A case study. *Performance Measurement and Metrics*, *11*(1), 25–38.

Kim, S., Moon, S., & Popkin, B. M. (2000). The nutrition transition in South Korea. *American Journal Clinical Nutrition*, *71*, 44–53.

Landesberg, P. (1999). In the beginning, there were Deming and Juran. *The Journal for Quality and Participation*, *11*, 59–61.

Lehrer, A. R., Lewis, G. S., & Aizinbud, E., (1992). Oestrus detection in cattle: Recent developments. In S. J. Dieleman, B. Colenbrander, P. Booman, and T. Van Der Lende (Eds.), *Clinical Trends and Basic Research in Animal Reproduction Science* (p. 335). Amsterdam, Netherlands: Elsevier Sci. Publ.

Levidow, L., & Bijman, J. (2002). Farm inputs under pressure from the European food industry. *Food Policy*, *27*(1), 31–45.

Linderman, K., Schroeder, R. G., Zaheer, S., & Choo, A. S. (2003). Six Sigma: A goal-theoretic perspective. *Journal of Operations Management*, *21*, 193–203.

Lunn, J. N., & Devlin, H. B. (1987). Lessons from the confidential enquiry into perioperative deaths in three NHS regions. *Lancet*, December *12*, 1384–7.

MacDonald, J. M., McBride, W. D., O'Donoghue, E., Nehing, R. F., Sandretto, C., & Mosheim, R. (2007). *Profits, costs, and the changing structure of dairy farming*. Retrieved June 27, 2011, from http://www.ers.usda.gov/publications/err47/err47b.pdf

Maltz, E., Antler, A., Halachmi, I. & Schmilovitch, Z. (2009). Precision concentrate rationing to the dairy cow using on-line daily milk composition sensor, milk yield and body weight, precision livestock farming. In *2009 Proceedings of the 4th ECPLF,* June 6–11, *2009*, Wageningen, Netherlands, 17–23.

Marino P. & Dominguez, M. A. (1997). Artificial vision for automated manufacturing systems in communications industry. In *Proceedings of the 6th International Conference on Emerging Technologies and Factory Automation*, Los Angeles, California, September 9–12, 1997.

Meade, L. M. & Sarkis, J. (1999). Analyzing organizational project alternatives for agile manufacturing processes: An analytical network approach. *International Journal of Production Research*, *37*(2), 241–261.

Mertens, K., Decuypere, E., De Baerdemaeker, J., & De Ketelaere, B. (2011). Modelling animal systems review: Statistical control charts as a support

tool for the management of livestock production. *Journal of Agricultural Science*, *149*, 369–384.
*Milk supply shortage to continue in short term.* (2009). Retrieved September 23, 2010, from http://www.taiwantoday.tw/ct.asp?xitem=62342&ctnode=427&mp=9
Morris, C., Loveridge, A., & Fairweather, J. (1995). Understanding why farmers change their farming practices: The role of orienting principles in technology transfer. *AERU Research Report*, 232. Lincoln University, Canterbury, New Zealand.
Orkin, F. W. (1993). Patient monitoring during anesthesia as an exercise in technology assessment. In L. J. Saidman and N. T. Smith (Eds.), *Monitoring in Anesthesia*, (3rd ed.). London, U.K.: Butterworth- Heineman.
Painter, M. J. (2007). A comparison of the dairy industries in Canada and New Zealand. *Journal of International Farm Management*, *4*(1), 41–60.
Pennington, J. A., Albright, J. L., & Callahan, C. J. (1986). Relationships of sexual activities in oestrous cows to different frequencies of observation and pedometer measurements. *Journal of Dairy Science*, *69*, 2925–2934.
Premkumar, G. P. (2000). Interorganization systems and supply chain management: An information processing perspective. *Information Systems Management*, *17*(3), 1–14.
Ptak, E., Satoła, A., & Hanna, C. (2004). Prediction of 305-day lactation milk, fat and protein yields using legendre polynomials and test-day yields from different parts of lactation. *Animal Science Papers and Reports*, *22*(2), 173–183.
Roe, T., & Diao, X. (1994, March). The strategic interdependence of a shared water aquifer: A general equilibrium analysis. Economic Development Center, Bulletin Number 95–2. In *Presentation for the International Conference on Coordination and Decentralization in Water Resource Management*, Hebrew University of Jerusalem, Rehovot, Israel, October 3–7, 1994. Retrieved September 24, 2010, from http://ageconsearch.umn.edu/bitstream/7512/1/edc95-02.pdf
Ross, A. F., & Tinker, J. H. (1994). Anesthesia risk. In R. D. Miller (Ed.), *Anesthesia* (4th ed.) (pp.791–825). New York, NY: Churchill-Livingston.
Salin, V,. & Hooker N. H. (2001). Stock market reaction to food recalls. *Review of Agricultural Economics*, *23*(1), 33–46.
Schmidt, D., Rockwell, S. K., Bitney, L., & Sarno, E. A. (1994). Farmers adopt microcomputers in the 1980s: Educational needs surface for the 1990s. *Journal of Extension*, 32(1), Retrieved January 3, 2010 from http://www.joe.org/joe/1994june/a9.php
Schroeder, R. G., Linderman, K., Liedtke, C., & Choo, A. (2008). Six Sigma: Definition and underlying theory. *Journal of Operations Management*, *26*(4), 536–554.
Senger, P. L. (1994). The estrus detection problem: New concepts, technologies, and possibilities. *Journal of Dairy Science*, *77*, 2745–2753.
Snee, R. D. (1999). Why should statisticians pay attention to Six Sigma? *Quality Progress*, September, 100–103.
Stantiall, J. D., & Parker, W. J. (1997). Adoption of technology & information on New Zealand dairy farms. *Report on a Dairy Industry Exchange Forum*, Massey University, Palmerstion North.
Tennant, G. (2001). *Six Sigma: SPC and TQM in manufacturing and services*. Hampshire, UK: Gower Publishing.
Thomas, D, & Callahan, D. (2002). Information technology adoption in agricultural operations: A progression path. *Ideas at Work*, December, *40*, 6, Retrieved from http://www.joe.org/joe/2002december/iw1.php.
Tylutki, T. P., Acan, Pas, Dpl., Fox, D. G., & McMahon, M. (2004). Implementation of nutrient management planning on a dairy farm. *The Professional Animal Scientist*, *20*, 58–65.
USDA. (n.d.). *General specifications for dairy plants approved for USDA inspection and grading service*. Retrieved January 3, 2010, from http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELDEV3004788
Wang, N., Zhang, N., & Wang, M. (2006). Wireless sensors in agriculture and food industry—recent development and future perspective. *Computers and Electronics in Agriculture*, *50*, 1–14.
Woolford, M. W., Williamson J. H., & Henderson, H. V. (1998). Changes in electrical conductivity and somatic cell count between milk fractions from quarters subclinically infected with particular mastitis pathogens. *Journal of Dairy Research*, *65*, 187–198.
Wyne, M., Lee, M. J., & Moon, S. (1993). Dairy product consumption in South Korea. *Journal of Consumer Studies & Home Economics*, *17*(1), 39–56.
Yin, R. K. (2003). *Case study research design and methods* (2nd ed.). Thousand Oaks, CA: Sage Publications.
Zairi, M. (1997). Business process management: A boundaryless approach to modern competitiveness. *Business Process Management Journal*, *3*(1), 64–80.
Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture—A worldwide overview. *Computers and Electronics in Agriculture*, *36*(2–3), November, 113–132.
Zilberman, D., Khanna, M., & Lipper, L. (1997). Economics of new technologies for sustainable agriculture. *The Australian Journal of Agricultural and Resource Economics*, *41*(1), 63–80.

## APPENDIX A: DETAILS OF THE AFIMILK® SYSTEM

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 (Fernando, Rindsig, & Spahr, 1982; Woolford, Williamson, & Henderson, 1998), 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 submodules 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' weights 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 cows' weights 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.