Precision Dairy Monitoring Opportunities, Limitations, and Considerations

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Abstract

Technologies are changing the shape of the dairy industry across the globe. In fact, many of the technologies applied to the dairy industry are variations of base technologies used in larger industries such as the automobile or personal electronic industries. Undoubtedly, these technologies will continue to change the way that dairy animals are managed. This technological shift provides reasons for optimism for improvements in both cow and farmer well-being moving forward. Many industry changes are setting the stage for the rapid introduction of new technologies in the dairy industry. Dairy operations today are characterized by narrower profit margins than in the past, largely because of reduced governmental involvement in regulating agricultural commodity prices. The resulting competition growth has intensified the drive for efficiency, resulting in increased emphasis on business and financial management. Furthermore, the decision-making landscape for a dairy manager has changed dramatically, with increased emphasis on consumer protection, continuous quality assurance, natural foods, pathogen-free food, zoonotic disease transmission, reduction of the use of medical treatments, and increased concern for the care of animals. Lastly, powers of human observation limit dairy producers' ability to identify sick or lame cows or cows in heat. Precision dairy management may help remedy some of these problems. Precision dairy management is the use of automated, mechanized technologies toward refinement of dairy management processes, procedures, or information collection. Precision dairy management technologies provide tremendous opportunities for improvements in individual animal management on dairy farms. Although the technological "gadgets" may drive innovation, social and economic factors dictate technology adoption success.

Introduction

Technologies are changing the shape of the dairy industry across the globe. This rapid introduction of new technologies should come as no surprise given the technological culture shift in every facet of our society. In fact, many of the technologies applied to the dairy industry are variations of base technologies used in larger industries such as the automobile or personal electronic industries. Undoubtedly, these technologies will continue to change the way that dairy animals are managed. This technological shift provides reasons for optimism for improvements in both cow and farmer well-being moving forward. Many industry changes are setting the stage for the rapid introduction of new technologies in the dairy industry. Across the globe, the trend towards fewer, larger dairy operations continues. Dairy operations today are characterized by narrower profit margins than in the

past, largely because of reduced governmental involvement in regulating agricultural commodity prices. Consequently, small changes in production or efficiency can have a major impact on profitability. The resulting competition growth has intensified the drive for efficiency, resulting in increased emphasis on business and financial management. Furthermore, the decision-making landscape for a dairy manager has changed dramatically, with increased emphasis on consumer protection, continuous quality assurance, natural foods, pathogen-free food, zoonotic disease transmission, reduction of the use of medical treatments, and increased concern for the care of animals. Lastly, powers of human observation limit dairy producers' ability to identify sick or lame cows or cows in heat.

Precision Dairy Farming

Precision Dairy Farming is often used to describe many technologies aimed at improving dairy management systems. Bewley (2010) described Precision Dairy Farming as the use of technologies to measure physiological, behavioural, and production indicators on individual animals to improve management strategies and farm performance. Eastwood et al. (2004) defined Precision Dairy Farming as "the use of information technologies for assessment of fine-scale animal and physical resource variability aimed at improved management strategies for optimizing economic, social, and environmental farm performance." Spilke and Fahr (2003) stated that Precision Dairy Farming, with specific emphasis on technologies for individual animal monitoring, "aims for an ecologically and economically sustainable production of milk with secured quality, as well as a high degree of consumer and animal protection." With Precision Dairy Farming, the trend towards group management may be reversed, with focus returning to individual cows through the use of technologies (Schulze et al., 2007). Technologies included within Precision Dairy Farming range in complexity from daily milk yield recording to measurement of specific attributes (e.g. fat content or progesterone) within milk at each milking. The main objectives of Precision Dairy Farming are maximizing individual animal potential, early detection of disease, and minimizing the use of medication through preventive health measures. Precision Dairy Farming is inherently an interdisciplinary field incorporating concepts of informatics, biostatistics, ethology, economics, animal breeding, animal husbandry, animal nutrition, and engineering (Spilke and Fahr, 2003). The ideal Precision Dairy Farming technology explains an underlying biological process that can be translated into meaningful action with information readily available to the farmer and a reasonable return on investment. Additionally, the best technologies are flexible, robust and reliable and demonstrated to be effective through research and commercial demonstrations.

The list of Precision Dairy Farming technologies used for animal status monitoring and management continues to grow. Because of rapid development of new technologies and supporting applications, Precision Dairy Farming technologies are becoming more feasible. Many Precision Dairy Farming technologies, including daily milk yield recording, milk component monitoring (e.g. fat, protein and SCC), pedometers, automatic temperature recording devices, milk conductivity indicators, accelerometers for monitoring lying behaviour, rumination monitors, automatic oestrus detection monitors, and daily body weight measurements are already being utilized by dairy producers. Despite its seemingly simplistic nature, the power of accurate milk weights should not be discounted in monitoring cows, as it is typically the first factor that changes when a problem develops (Philpot, 2003). Other new Precision Dairy Farming technologies have been introduced to measure jaw movements, ruminal pH, reticular contractions, heart rate, animal positioning and activity, vaginal mucus electrical resistance, feeding behaviour, biological components (enzymes, antibodies or

microorganisms), odour, glucose, acoustics, progesterone, individual milk components, colour (as an indicator of cleanliness), infrared udder surface temperatures, gain analysis and respiration rates. Unfortunately, the development of technologies tends to be driven by availability of a technology, transferred from other industries in market expansion efforts, rather than by need. Compared with some industries, the dairy industry is relatively small, limiting corporate willingness to invest extensively in development of technologies exclusive to dairy farms. Many Precision Dairy Farming technologies measure variables that could be measured manually, while others measure variables that could not have been obtained previously.

Realistically, the term "Precision Dairy" should not be limited to monitoring technologies. Perhaps a more encompassing definition of Precision Dairy Management is the use of automated, mechanized technologies for refinement of dairy management processes, procedures or information collection. This definition incorporates monitoring technologies, automated milking systems, automated calf feeding systems and precision feeding systems. Automated milking systems have already been widely adopted in Europe. Adoption rates in North America have increased in recent years. The introduction of robotic milking components to rotary parlours will increase mechanization of milking in larger farms in the near future. Automated calf feeding systems have created a paradigm shift in how to raise dairy calves. Despite initial concerns about increased disease transmission, the benefits to automated calf feeding seem to outweigh the drawbacks when managed properly. New options for monitoring total mixed ration delivery and consumption will also improve how lactating dairy animals are fed. This is a particularly important economic and social concern given increased feed prices and concern for dairy efficiency and greenhouse gas emissions.

Benefits

Perceived benefits of Precision Dairy Farming technologies include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts, and improved animal health and well-being. These technologies are likely to have the greatest impact in the areas of health, reproduction and quality control (de Mol, 2000). Realized benefits from data summarization and exception reporting are anticipated to be higher for larger herds, where individual animal observation is more challenging and less likely to occur (Lazarus et al., 1990). As dairy operations continue to increase in size, Precision Dairy Farming technologies become more feasible because of increased reliance on less skilled labour and the ability to take advantage of economies of size related to technology adoption.

A Precision Dairy Farming technology allows dairy producers to make more timely and informed decisions, resulting in better productivity and profitability (van Asseldonk et al., 1999). Real time data can be used for monitoring animals and creating exception reports to identify meaningful deviations. In many cases, dairy management and control activities can be automated (Delorenzo and Thomas, 1996). Alternatively, output from the system may provide a recommendation for the manager to interpret (Pietersma et al., 1998). Information obtained from Precision Dairy Farming technologies is only useful if it is interpreted and utilized effectively in decision making. Integrated, computerized information systems are essential for interpreting the mass quantities of data obtained from Precision Dairy Farming technologies. This information may be incorporated into decision support systems designed to facilitate decision making for issues that require compilation of multiple sources of data.

Historically, dairy producers have used experience and judgment to identify outlying animals. While this skill is invaluable and can never be fully replaced with automated technologies, it is inherently flawed by limitations of human perception of a cow's condition. Often, by the time an animal exhibits clinical signs of stress or illness, it is too late to intervene. These easily observable clinical symptoms are typically preceded by physiological responses which are evasive to the human eye (e.g. changes in temperature or heart rate). Thus, by identifying changes in physiological parameters, a dairy manager may be able to intervene sooner. Technologies for physiological monitoring of dairy cows have great potential to supplement the observational activities of skilled herdspersons, which is especially critical as more cows are managed by fewer skilled workers (Hamrita et al., 1997). Dairy producers with good "cow sense" are the ones who will benefit the most from technology adoption. Those who view technologies as a way to do something they don't like to do are likely to struggle.

Adoption

The list of Precision Dairy Farming technologies used for animal status monitoring and management continues to grow. Despite widespread availability, adoption of these technologies in the dairy industry has been relatively sparse thus far (Gelb et al., 2001, Huirne et al., 1997). Perceived economic returns from investing in a new technology are always a factor influencing technology adoption. Additional factors impacting technology adoption include degree of impact on resources used in the production process, level of management needed to implement the technology, risk associated with the technology, institutional constraints, producer goals and motivations, and having an interest in a specific technology (Dijkhuizen et al., 1997, van Asseldonk, 1999). Characteristics of the primary decision maker that influence technology adoption include age, level of formal education, learning style, goals, farm size, business complexity, increased tenancy, perceptions of risk, type of production, ownership of a non-farm business, innovativeness in production, average expenditure on information, and use of the technology by peers and other family members. Research regarding adoption of Precision Dairy Farming technologies is limited, particularly within North America.

To remedy this, a five-page survey was distributed to all licensed milk producers in Kentucky (N=1074) on July 1, 2008. Two weeks after the first mailing, a follow-up postcard was mailed to remind producers to return the survey. On August 1, 2008, the survey was re-sent to producers who had not returned the survey. A total of 236 surveys were returned; 7 were omitted due to incompleteness, leaving 229 for subsequent analysis (21%). The survey consisted of questions covering general farm descriptive demographics, extension programming and decision-making behaviour. With regard to Precision Dairy Farming the following question was presented to survey participants: *"Adoption of automated monitoring technologies (examples: pedometers, electrical conductivity for mastitis detection) in the dairy industry has been slow thus far. Which of the following factors do you feel have impacted these modest adoption rates? (check ALL that apply)."* Data were entered into an online survey tool (KeySurvey, Braintree, MA). Statistical analyses were conducted using SAS® (Cary, NC). Surveys were categorized by herd size, production system, operator age and production level. Least squares means among categories were calculated for quantitative variables using the GLM procedure of SAS®. Statistical differences were considered significant using a 0.05 significance level using Tukey's test for multiple comparisons. For qualitative variables, χ^2 analyses were conducted using the FREQ procedure of SAS®. Statistical differences were considered significant at a 0.05 significance level.

Among the 229 respondents, mean herd size was 83.0 ± 101.8 cows and mean producer age was 50.9 ± 12.9. Reasons for modest adoption rates of Precision Dairy Farming technologies and dairy systems software are presented in Table 1. The reasons selected by the highest percentage of respondents were (1) not being familiar with technologies that are available (55%), (2) undesirable cost to benefit ratios (42%) and (3) too much information provided without knowing what to do with it (36%). The high percentage of producers who indicated that they were unfamiliar with available technologies indicates that marketing efforts may improve technology adoption. Actual or perceived economic benefits appear to influence adoption rates, demonstrating the need for economic models to assess technology benefits and re-examination of retail product prices. As herd size increased, the percentage of producers selecting "poor technical support/training" and "compatibility issues" increased ($P < 0.05$), which may be reflective of past negative experiences. In developing technologies, manufacturers should work with end-users during development and after product adoption to alleviate these customer frustrations. Few significant differences were observed among age groups, though the youngest producers were more likely to select "better alternatives/easier to accomplish manually." Prior to technology development, market research should be conducted to ensure that new technologies address a real need. Utilizing this insight should help Precision Dairy Farming technology manufacturers and industry advisors develop strategies for improving technology adoption. Moreover, this information may help focus product development strategies for both existing and future technologies.

Table 1. Factors influencing slow adoption rates of Precision Dairy Farming technologies

Factor	N	Percent
Not familiar with technologies that are available	101	55%
Undesirable cost to benefit ratio	77	42%
Too much information provided without knowing what to do with it	66	36%
Not enough time to spend on technology	56	31%
Lack of perceived economic value	55	30%
Too difficult or complex to use	53	29%
Poor technical support/training	52	28%
Better alternatives/easier to accomplish manually	43	23%
Failure in fitting with farmer patterns of work	40	22%
Fear of technology/computer illiteracy	39	21%
Not reliable or flexible enough	33	18%
Not useful/does not address a real need	27	15%
Immature technology/waiting for improvements	18	10%
Lack of standardization	17	9%
Poor integration with other farm systems/software	12	7%
Compatibility issues	12	7%

Borchers et al (2014, unpublished data) submitted another survey to assess dairy producer technology needs. A survey to identify producer perception of precision dairy farming technologies was distributed in March 2013 through written publications and email. Responses were collected in May 2013 ($n = 109$) and statistical analysis was performed using SAS (SAS Institute, Inc. Cary, NC). Herd size, producer age and role on the farm were collected and analysed but significant differences were not found ($P > 0.05$). Producers were asked to indicate parameters currently

monitored on their farm from a predetermined list and producers most often selected daily milk yield (52.3%), cow activity (41.3%), and not applicable (producers not currently implementing technologies: 1.2%). Producers were asked to rank the same list on usefulness using a 5-point Likert Scale (1: not useful and 5: useful). Least-squares means were calculated using the GLM procedure of SAS and producers indicated (mean ± SE) mastitis (4.77 ± 0.47), standing heat (4.75 ± 0.55), and daily milk yield (4.72 ± 0.62) to be most useful. Pre-purchase technology selection criteria were ranked using a Likert Scale (1: not important and 5: important) by producers and benefit to cost ratio (4.57 ± 0.66), total investment cost (4.28 ± 0.83), and simplicity and ease of use (4.26 ± 0.75) were found most important. Producers were categorized into United States or an "other countries" category based upon their farm location. Significant differences ($P < 0.05$) were identified between country and the adoption of technologies monitoring animal position and location, body weight, cow activity, daily milk yield, lying and standing time, mastitis, milk components, rumen activity and rumination, with other countries being higher in all cases. Producers were categorized based upon technology use (using technology vs. not using technology) and least-squares means were calculated across technology usefulness, with daily milk yield (using technologies: 4.83 ± 0.07, vs. not using technologies: 4.50 ± 0.10) and standing heat (using technologies: 4.68 ± 0.06, vs. not using technologies: 4.91 ± 0.09) differing significantly ($P < 0.05$). Least-squares means were calculated for technology use categories, with producer pre-purchase considerations and availability of local support (using technologies: 4.25 ± 0.11, vs. not using technologies: 3.82 ± 0.16) differing significantly ($P < 0.05$).

Pre-Adoption Considerations

Precision Dairy Farming technology investments should be considered on an individual operation basis. These technologies do not follow a "one size fits all" model well. Each dairy is different and what works on one may not work on another. To assess whether a technology will work for your operation, start by asking these questions:

Does your dairy's management currently involve a computer? Being comfortable around a computer is important in Precision Dairy Farming. Almost all Precision Dairy Farming technologies work through a computer program and will require daily interaction to produce useful reports and information for decision-making. Dairy operations which are most likely to benefit from these technologies are those that already use dairy management software (i.e. PCDART, DairyComp 305). However, regardless of an individual's familiarity with computers, working with any new computer program will require some training and adjustment.

Is the farm currently using good management practices? Precision Dairy Farming cannot completely correct poor management nor does it replace current management systems. In fact, when applied to unorganized systems, Precision Dairy Farming technologies may make managing the operation harder through information overload. Technologies and computers do not replace good management but can enhance it. Dairy farmers who already understand, evaluate and respond to cow signs and needs and the animal management associated with them are those who will benefit most from these technologies.

Does the operation know its own strengths and weaknesses? Being aware of which areas need improvement on a dairy farm will allow easier decisions to be made about investment in Precision Dairy Farming, including which technologies will work best for you. Focusing on areas that are already strong will result in very few observed benefits. For example, a farm that is already doing a good job with heat detection may not see as much benefit from investing in a heat detection technology.

What is the dairy's willingness to take risks? Many Precision Dairy Farming technologies are rather new and not yet widely adopted. Sometimes investing in an early technology may involve some risk (i.e. the company going out of business or development of a newer, improved model). However, the first adopters of new technologies are generally the ones who benefit from them most because they see returns first.

Do you understand the economic benefits? An investment analysis considers how a potential investment will affect a business. No matter how great a technology is, the benefits of investing in the technology must outweigh the costs. Before investing in any technology, farm management should set a threshold for minimum acceptable returns. A net present value analysis will help determine the true investment and profitability. Some technologies may not prove to be profitable, but investment may still be worthwhile because of improvements in quality of life.

The answers to these questions will help determine whether Precision Dairy Farming technologies are a good fit for an operation. However, it is still important to consider other farm-specific and economic factors when making this decision. If Precision Dairy Farming technologies are not a realistic option now, they may be in the future. Continually reassess the dairy operation to determine when Precision Dairy Farming technologies may become a good choice for improving dairy management.

Choosing a Technology

The list of available Precision Dairy Farming technologies is growing rapidly. Once you have decided you are ready for Precision Dairy Farming, the next step is to choose a technology (or multiple ones) to use. An ideal technology will be low-cost, reliable, robust, flexible, easy to maintain and update, and will provide information about something going on within an animal that a producer can immediately turn into an on-farm action. Consider some of these other questions when looking at potential technologies for your operation:

Technology Purpose: Determine whether the technology will bring value to the operation.

- Does the technology fulfill a need for the operation or is it addressing something that does not require changing?
- What will improve on the operation by getting/using this technology?

Company Interaction: Installing Precision Dairy Farming technologies will involve long-term interaction with the company that manufactures it. Be sure to talk to farmers or extension agents who have worked with the company previously to answer these questions.

- Has the technology been used on commercial farms, not just the manufacturing company's research farms?
- What kind of customer service, training and technical support does the manufacturer provide and for what length of time?
- Does the company value farmers' opinions when updating or making changes to the device?

How the Technology Works: Know whether the technology will work in a way that is convenient for your operation before committing your time and money to it. Again, talking to other farmers and extension agents about these concerns may be beneficial.

- What is required for collection of data from the technology?
- How reliable is the technology? How often does it fail to perform as desired?
- Is data measured continuously or does the animal have to make a trip to the parlour to collect the data?
- How frequently are tags misread?
- How do notifications about animals appear on the computer? Are reports easy to understand?
- Does the computer specify what to do with detected animals or do you have to interpret it?
- If the technology is designed for event detection (i.e. heat, mastitis or disease):
    - Can the manufacturer provide data indicating what percentage of cases (sensitivity) are detected (Goal>80%)? A technology should capture most of the desired events to be worthwhile.
- Can the manufacturer provide data indicating how many false alerts (specificity) occur (Goal: <1%)? This is where some technologies fall short. Although this is a strict criterion to use, false alerts can waste time and resources for a dairy producer. A 1% false alert means you will receive 10 false alerts for every 1000 milkings. By comparison, 10% or 25% false alert rates would lead to 100 or 250 false alerts per day.
- How long is the data stored on the computer?
- How does the system handle transferring units (tags, etc.) from one animal to another?

Outlook

Though Precision Dairy Farming is in its infancy, new Precision Dairy Farming technologies are introduced to the market each year. As new technologies are developed in other industries, engineers and animal scientists find applications within the dairy industry. More importantly, as these technologies are widely adopted in larger industries, such as the automobile or personal computing industries, the costs of the base technologies decrease, making them more economically feasible for dairy farms. Because the bulk of research focused on Precision Dairy Farming technologies is conducted in research environments, care must be taken when trying to transfer these results directly to commercial settings. Field experiments or simulations may need to be conducted to alleviate this issue. Because there is a gap between the impact of Precision Dairy Farming technologies in research versus commercial settings, additional effort needs to be directed towards implementation of the management practices needed in order to fully utilize information provided by these technologies. To gain a better understanding of technology adoption shortcomings, additional research needs to be undertaken to examine the adoption process, not only for successful adoption of technology but also for technology adoption failures. Before investing in a new technology, a formal investment analysis should be conducted to make sure that the technology is right for your farm's needs. Examining decisions with a simulation model accounts for more of the risk and uncertainty characteristics of the dairy system. Given this risk and uncertainty, a stochastic simulation of

investment analysis will show that there is uncertainty in the profitability of some projects. Ultimately, the dairy manager's level of risk aversion will determine whether or not he or she invests in a technology using the results from this type of analysis. Precision dairy farming technologies provide tremendous opportunities for improvements in individual animal management on dairy farms. In the future, Precision Dairy Farming technologies will change the way dairy herds are managed.

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Notes: