Exploring the Effects of Precision Livestock Farming Notification Mechanisms on Canadian Dairy Farmers

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Abstract. Modern dairy farms are increasingly adopting technologies to monitor animal health and welfare and send notifications to farmers when issues arise. These *precision livestock farming (PLF)* technologies promise increased animal health and farm productivity. Yet, few studies exist on the effects of these technologies on those who use them. Studies from Europe show the 24/7 nature of potential PLF notifications can make farmers feel always "on call", increasing their overall stress levels. An initial online survey of 18 Canadian dairy farmers was conducted to explore their experiences with PLF notifications. Reported benefits of PLF technologies include improved animal health and dairy products, labor benefits, and ease of data collection. The study also uncovered weaknesses of PLF notifications, including information uncertainty and overload, false alerts, inappropriate timing and communication mediums. Design recommendations are presented to improve PLF notification mechanisms.

Keywords: Precision livestock farming (PLF) technology · Notification mechanisms · Impact of PLF on dairy farmers · Farmers' mental workload

1 Introduction

There is a universal trend towards streamlining and enhancing farming practices in both livestock and crop farming by utilizing various state-of-the-art technologies to automate different farm processes. This modern style of farming is commonly called precision agriculture [1] and precision livestock farming (PLF) [2], referring to crop and livestock farming respectively. PLF involves the integration of software and hardware technologies that offer easier animal farm management by monitoring individual animals 24/7 on farms [3]. PLF technologies aim to improve the health and welfare of animals by reporting detected abnormalities to farm staff so they can take appropriate actions [2]. Thus, farmers can manage larger herds with reduced physical workload and labour costs, and allow them to meet increasing global demand [4].

PLF technologies use sensors to monitor animal behaviours and the state of the farm environment, and computer algorithms and applications to process collected sensor data and generate reports or send alerts to the farmer if necessary [5]. However, to be effective,

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PLF technologies must transform the raw data they collect into meaningful information and communicate this to farmers in a useful manner that facilitates animal care and farm operations [5]. Information from PLF technologies is often automatically sent to farmers in the form of notifications or alerts through various communication mediums (e.g., automated phone call, text message, dashboard application software) to make staff aware of new or ongoing animal or farm environment situations.

Prior research from Europe has shown that these automated communications can be a source of stress and can increase the mental workload for farm staff if the communications are not designed or managed effectively [6, 7]. A recent review [8] of advanced dairy farm technologies concluded:

> *"mental workload (stress) can sometimes be increased [when PLF are used] due to the complexity of the information involved in managing the multiple alarms or alerts and equipment failures…if the tools are not adapted to farmers' needs and skills, PLF can also lead to negative impacts on farmers and animals." (p. 273).*

To our knowledge, no studies have investigated whether automated communications from PLF technologies can be a similar source of stress for Canadian dairy farmers. As farming cultures, practices, and technologies can differ from region to region, it is unclear whether the European studies generalize to the Canadian dairy farming context.

To address this gap, we conducted a survey study to investigate the impact of PLF notification mechanisms on Canadian dairy farmers. Although a larger survey and follow-up were originally planned, the study was scaled back due to complications and additional stresses that dairy farmers faced at the time of data collection related to the onset of the global COVID-19 pandemic and the need for Canadian dairy producers to rapidly pivot operations to meet new health and safety protocols during wide-scale societal lockdowns. So, instead, we report on a pilot study that provides some initial evidence of Canadian dairy farmers' experiences that highlight trends and suggest directions for further research in this area. Note, while various terms are used by PLF technology manufacturers and the farming industry for PLF information automatically sent to farmers (e.g., alerts, alarms, warnings, messages, and communications), herein we collectively refer to these communications as notifications.

The online survey collected data from 18 dairy farmers (owner/operators, herdsmen, and employees) from the province of Ontario, Canada, a large dairy producing region in Canada. Results from this pilot study revealed many positive benefits of the PLF technologies employed on participants' farms, including reduced labour costs, improved appeal of farm work, and reduced difficulty of farm work. The survey also revealed that while the existing PLF notification mechanisms were not perceived as a significant source of stress for survey participants, there were still aspects of their design that sometimes caused stress or anxiety due to factors such as, the timing and medium of communication, false alarms, missed alerts, unclear messages and actions, and unnecessary communications.

To set the context for the study, the paper overviews the literature related to PLF notifications and their impact on farmers, and then details the study methodology. Next, the study results are presented. Finally, we discuss initial insights revealed by the pilot

study for the design of PLF notification mechanisms and directions for future studies to better understand how to meet the informational needs of Canadian dairy farmers.

2 Related Literature

The literature review is focused on understanding the challenges with notification mechanisms of available PLF technologies in both academic and commercial literature that communicate with farmers when any abnormality arises. This section also includes how notification management is done from HCI perspectives in other domains.

2.1 Potential Negative Impacts of PLF Notifications on Farmers

While PLF technologies can reduce physical labour of farmers, studies have also shown these technologies can be a source of stress. For instance, a Norwegian study on automated milking systems (AMS) found that farmers reported feeling "always on call" due to information overload from their AMS [7]. A review on the impacts of PLF technologies on farmers found that excessive notifications and complex information from their PLF technologies sometimes increase farmers' mental workload [8]. To address this mental workload issue, Dominiak and Kristensen [39] suggested that PLF systems should prioritize alerts to help farmers understand which alerts require a response and how quickly they should respond.

PLF technologies can reduce physical and mental workload in some situations because farmers do not have to physically monitor their cows [9]. The health issues that are not easily detected by farmers can be measured by PLF technologies, such as vaginal temperature for artificial insemination, body temperature, heart rate, and exact calving time [9]. Yet, even useful PLF notifications may be stressful if not provided in an appropriate manner or at an appropriate time. This study seeks to understand what PLF notification mechanisms are used in the Canadian dairy industry, how effective they are for farmers, and the impacts they have on farmer's lives, both positive and negative.

2.2 Big Data in PLF and Need for Improved Information Interfaces

Many PLF technologies produce and accumulate a large quantity of data, frequently for long intervals of time, and often in real-time [10]. To cope with these large datasets, PLF researchers have started utilizing different big data processing methods for analyzing various process-generated, machine-generated, and human-generated data associated with their farms [11]. Yet, studies have shown that farmers sometimes find the information generated by PLF technologies too complex to use in their decision-making due to either its sheer volume or when no clear action is indicated [10, 12, 13]. This technology complexity can negatively affect farmers' view regarding integration of PLF technologies with their farms [8].

The volume and complexity of PLF data has prompted researchers to explore information visualization techniques to present data to the farmers in a manner that is more easily understood and interpreted to support farm decision-making [14]. The 'Dairy

Brain' system collected data of cows from multiple perspectives, analyzed, and presented these data in a form that facilitated farmers' decision-making [15]. Its approach used one technology to detect all animal and farm issues instead of a suite of technologies designed for a specific purpose to help reduce the complexity of farm management [15]. A recent survey of big data concluded that data science specialists should be involved in the PLF design process to foster creation of appropriate data representations for farmer decision making [11]. The need for improved data representations in PLF technologies was also found in a study of American dairy technologies [13]. However, discussed below, farmers need to be involved in the design process also.

2.3 The Need for a More User-Centred Approach in PLF Technologies

The PLF field is starting to observe and report that integration of these emerging technologies on farms might be hampered by the absence of user-centred (farmers and animals) design since most PLF technology design is technology- and profit-driven [16, 17]. Research has found that some PLF technologies provide limited utility to farmers, partially due to their complex and unfamiliar interfaces, which a 2013 study found to be largely dissimilar to the interfaces of similar traditional technologies [17]. Consequently, these technologies are not as beneficial to farmers in their farm management decision-making as intended [16, 18]. A PLF adoption study in Australia found that dairy farmers believe that involving them more directly in the design process of PLF innovations would help to make PLF technologies easier to learn and use, and would help to better address their farm operation needs [17].

As early as 2005, precision farming researchers identified the need for standard guidelines to guide the structure and incorporation of different precision farming technologies for more effective farmer decision-making [19]. Our pilot study found that while some technologies provide integrated functionalities, many technologies are still operated independently with different notification systems.

2.4 Lessons from the HCI Literature on Notification Management

The topic of automated notifications and how to manage them has been a subject of intense study in the broader human-computer interaction (HCI) field due to the increasing ubiquity of technology in our lives. Indeed, the website *interruptions.net* offers a comprehensive curated bibliography (currently over 900 articles) from the HCI, human factors, and related fields on the topic of interruptions, their affects, and strategies to mitigate them. As PLF notifications often interrupt farmers from other work or life activities, this body of knowledge may offer solutions or inspiration to improve the design of PLF notification mechanisms. Here we overview some relevant findings from the HCI literature but also encourage interested readers to dig further into this broader body of literature.

The timing, content, and medium used for notifying users have all shown to be important for effective notifications [20]. Today, people receive notifications from many different sources, such as text messaging, social media, emails, and mobile applications [21]. Receiving excessive notifications can reduce a person's productivity and can impact negatively on psychological well-being [22]. Notifications can also have negative effects

on the user's emotional state [23, 24]. Receiving an irrelevant or non-urgent notification can distract from an important task and lead to task errors and poor decision-making [24, 29, 30]. A notification has two sides, including the utility of the information it provides to the users and the interruption users experience in their ongoing tasks [27–29]. Notification senders usually do not always consider the interruption that users experience upon receiving the notification [30].

HCI researchers have proposed several approaches to mitigate the negative effects of notifications. One approach is to assume some notifications are more important to the user than others and then act accordingly. For instance, a system can time the delivery of a notification based on its automatically classified level of importance [31]. Or, a system could allow users to modify the system settings to determine the timing of receiving a specific type of notification [22]. Our pilot study found that some PLF technologies allowed for this type of filtering, for instance, allowing users to have some types of notifications delivered to their phones and others to a system dashboard.

The importance or urgency of a notification has also been used in the HCI to determine how notifications are displayed to the user. For instance, in the 'Scope' system, notifications from various sources (email, instant messaging, task lists, calendar, etc.) were displayed in different areas of a notification visualization window based on their source and urgency, with more urgent notifications displayed more centrally [32]. A key concept in this system was that notifications from different sources were managed together in one place, which may be relevant for PLF as notifications can come from different devices. An assumption underlying any approach that uses importance or urgency in notification management is that this information is known, or can be discovered, by the system. A starting point is for designers to have a strong understanding of farmer's information needs. Our pilot study provides some insights into this issue.

Another approach to notification management is to try to determine whether it is a good time to interrupt a user, based on their mental or physical context, for instance, their cognitive state (inferred from physiological sensors) [33] or their activity (inferred from various sources, including audio sensors and calendar data) [34]. Kern and Schiele [29] combined the notion of importance and user context in their work to determine when to send notifications to a user, asserting that multiple factors are needed to make appropriate system decisions about notifications.

In summary, the literature shows PLF technologies and their notifications can be stressful and ineffective due to information complexity, information overload, and poor usability. The PLF field has acknowledged the need for a more user-centred approach to improve the utility and usability of PLF technologies and their notification mechanisms. Information overload and interruptions caused by automated notifications is a common problem identified in many domains, and existing solutions from the broader field of HCI may provide some guidance for managing PLF notifications. This will be discussed further during the discussion of the study findings.

3 Research Methodology

The goals of this research were to understand what notification mechanisms are currently used in PLF technologies deployed on Canadian dairy farms, and the positive

and negative impacts of these mechanisms on farmers' work and lives. To address these goals, an online survey was conducted of farmers from the province of Ontario, which produces 33% of Canada's milk supply with 3,446 dairy farms [25]. The survey collected both qualitative and quantitative data using the online survey tool Qualtrics®. As aforementioned, a large-scale survey, and follow-up interviews, were originally planned, but due to the onset of the COVID-19 pandemic, and the stress and additional workload that ensued for dairy farmers to meet new health and safety measures, data collection was cut short. Here, we report on the initial data collected, which serves as a pilot study that still provides useful insights into industry trends and highlights directions for further study. Yet, it has limits for broad-scale generalizability and should be interpreted as such.

The study protocols were reviewed and approved by the University of Guelph's institutional research ethics office.

3.1 Survey Design

The survey was designed iteratively. The initial survey questions were based on knowledge gained from the literature, online research of the dairy and PLF fields, and discussion with local dairy experts. The survey was reviewed by HCI experts, academic dairy researchers on our campus, and a dairy industry expert. The survey was revised based on their feedback. The survey consisted of a total of 63 questions, including two questions related to consent and age eligibility. Due to the conditional nature of the question design in some sections, most participants were not asked all questions.

The first block of questions collected demographic information about the participant. The next four blocks related to the notification mechanisms used in four commonly used dairy PLF technologies, including automated milking system (AMS), automated heat detection system (AHDS), automated calving time detection system (ACTDS), and automated activity monitoring system (AAMS).

The questions related to each of the above technologies were displayed only if the participant indicated they used the technology and they received notifications from it. The set of questions in each section were designed to be as similar as possible, to enhance the usability of the survey. Participants were asked how much experience they had with a technology, number of notifications they received in a typical week, medium of receiving those notifications, type of information received, actions they perform after receiving notifications, pros and cons of the current notification mechanism, and overall feedback on the notification mechanism. The final block of questions probed farmers on their perceived level of stress due to PLF notifications and asked for participants' overall thoughts on improving their PLF notification mechanisms.

3.2 Survey Distribution

The survey was advertised through a number of channels, including relevant social media platforms, such as Twitter™ channels of relevant regional farming and agricultural individuals and organizations and regional farming groups on Facebook. Additionally, the research team attended the Southwestern Ontario Dairy Symposium in February 2020 to advertise the online survey in person at a booth at the symposium tradeshow. We provided interested dairy producers with leaflet that included the study advertisement

with the study link and QR code they could scan to access the online survey. We have also contacted dairy technology retailers to distribute the survey. The survey data collection period ran from February 6, 2020 to March 31, 2020.

3.3 Data Collection and Analysis

A total of 51 survey records were recorded. The collected survey records were reviewed for validity. First, any "in progress" (i.e. abandoned) surveys were deleted and unusual surveys, such as those completed within 2–3 min or those with IP addresses from outside Ontario, were also deleted. Only survey records that included reasonable, logical response patterns, and topic-relevant free form comments were included in the data analysis. Data culling resulted in a total of 18 complete, valid survey records that were included in the data analysis. There were 3 female and 15 male participants. Twelve participants were owners/managers, three were herdsman, and three were employees. As per the original informed consent letter, five participants were selected from a random draw and provided with $40 gift cards.

The quantitative data were first explored using Qualtrics® built-in analysis tools, which provide simple bar charts showing frequency statistics, and then in Microsoft Excel® when more controlled charts were needed, based on the survey question. Next, correlation analyses were conducted to determine relationships between stress level of the farmers and their demographics. Pearson correlation was used to investigate whether there were any linear relationships between the variables. Finally, the qualitative data in the form of free-form answers were reviewed for themes and insights.

4 Results

The collected pilot study data provided information on what type of PLF technologies participants used, from what technologies they received notifications, and what communication mediums they received these notifications. We also collected information on the perceived benefits, challenges, and stress levels related to these PLF technologies. Note, due to our ethics protocols, participants were free to skip any question in the survey they wished. Thus, when frequency data are reported, the number of respondents for that specific question is always indicated as "of X participants" or "/X" for brevity.

4.1 Sources of PLF Notifications for Study Participants

In total, 11 of 18 participants (61%) reported using one or more automated milking systems (AMS) on their farms. Of those 11 AMS users, 10 participants (91%) reported that they received notification from their AMS. In total, 16 of 17 participants (94%) reported using and receiving notifications from automated heat detection systems (AHDS) on their farms. In total, five of 17 participants (29%) reported using and receiving notifications from automated calving time detection systems (ACTDS). Given the small sample size of ACTDS users, these data were omitted from further data analyses. Thirteen of 17 participants (76%) reported using automated activity monitoring systems (AAMS) on their farms. Of those 13 AAMS users, six participants (46%) reported that they received notification from their AAMS.

4.2 Notification Mediums

Based on our background research, it was anticipated that current PLF technologies used four main communication mediums to convey notifications to farmers: text messages, phone calls, email, and displaying information in the dashboard of the PLF technology's associated computer application for desktop, tablet, or mobile phone. As shown in Fig. 1 , the study data confirmed this expectation. The data shows that the application dashboard is used most often across PLF technologies as a communication medium (20 responses in total, across AMS, AHDS, and AAMS), whereas other mediums such as phone calls (7 responses for AMS only), text messages (6 responses across AMS, AHDS, and AAMS), and email (4 responses across AMS, AHDS, and AAMS) are not used as frequently. These data show that, at least among the sampled study population, newer technologies like AAMS and AHDS do not use the phone at all as a communication medium, while this is heavily relied on by AMS.

Some AMS users reported receiving notifications via multiple mediums (e.g., by phone calls and application dashboard). One farmer (P11), who had selected text messages from the survey options for medium, clarified in a free-form response that they meant the AHDS system sends alerts using their native mobile phone alerting system via the AHDS mobile application system. It is possible that other participants who indicated text message notifications meant this as well or may also be receiving notifications via native phone notifications, which was not explicitly captured in the survey.

The study found that some systems, by default, use different mediums to communicate information of different importance or urgency. For instance, one AMS user (P2) reported receiving notifications by phone calls for issues that demanded their attention, while general cow health information was sent to the system dashboard, as illustrated in their comment,

> *"I consider an alert something that is brought to my attention. In our case this is phone call regarding system operation. Lots of dashboard notifications about cow health, but [I] search reports, don't get a text/phone call about." (P2).*

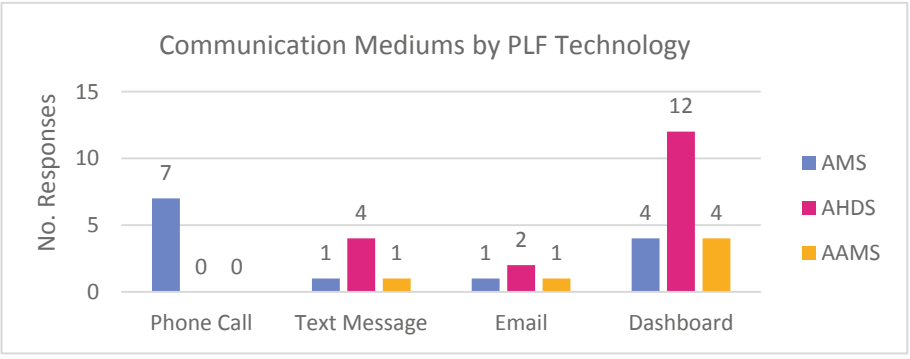

Fig. 1. Reported communication mediums (phone call, text message, email, dashboard) by PLF technology (AMS, AHDS, AAMS)

Some participants reported changing the default factory settings of their AMS to receive different types of information through a preferred medium, for example, changing the settings to receive non-critical notifications through the dashboard instead of through phone calls, as illustrated by the participants' comments, *"Reduced certain non-critical alarms so they don't call but just leave dashboard notice" (P10),* and *"Send heat detection and distress alerts at night, turned off cleaning alarm phone calls. There is no immediate action anyways." (P16).*

4.3 Content of PLF Notifications and Farmers' Responses

Most notifications farmers get from AMS are about cow activities such as rumination and lameness (9/11), system failures (7/11), or cows in heat (7/11). They also get notifications about cows overdue for milking (3/11), substances in the milk (3/11), cases of mastitis (3/11), and abnormal cow temperature (2/11). In free-form comments, participants also reported other types of information reported by their AMS not specifically listed in the survey, including cow weight, feeding system issues, and calving distress.

Upon receiving notifications from the AMS, most of the time farmers checked the system (8/11) and reset the system if necessary (3/11). These findings are consistent with the fact that farmers often receive notifications regarding system failures. Participants also reported checking a cow (5/11) as a common action after receiving an AMS notification. In free-form responses, farmers also reported checking the system upon receiving notifications to determine action.

As expected, most notifications farmers reported receiving from their AHDS related to the identity of a cow who is in heat (14/16) and the breeding status of a cow when she is in heat (10/16). Participants (6/16) also reported in free-form text they received notifications about the optimum insemination time. Two participants also reported that their AHDS provided the location of the cow. This is a relatively new feature available in some AHDS systems. One participant (P5) reported in a free-form response that their AHDS notifications only reports a cow is in heat but does not give the identity of the cow. Thus, they had to open the AHDS application to know which cow was in heat. Farmer's responses to the special-purpose PLF technologies AHDS and ACTDS were not collected since actions related to these PLF devices are more predicable (e.g., check the cow and take necessary steps for insemination or calving).

While AAMS systems were primarily reported to provide farmers information about unusual activity timings, such as unusual lying, standing, ruminating, and walking times (11/13), some participants also reported receiving notifications about heat events (4/11) and calving time detection (1/11) from their AAMS. Three commonly reported actions taken by farmers upon receiving these notifications were to check the cow with the reported issue (4/6), provide necessary care to the cow (4/6), and apply medicine if necessary (4/6). Sometimes they contacted their veterinarian (3/6) and separated the cow with issues from other cows, if necessary (2/6).

4.4 Benefits and Challenges of PLF Notification Mechanisms

Participants reported many benefits of PLF notifications, such as improved livestock health (responses: 6 for AMS; 14 for AHDS; 1 for AAMS), labour benefits, including

increased appeal of work and flexible and reduced work hours (responses: 12 for AMS; 6 for AHDS; 3 for AAMS), improved milk product (responses: 3 for AMS; 11 for AHDS; 4 for AAMS), ease of data collection for the regulatory board and business operations (responses: 2 for AMS; 11 for AHDS; 6 for AAMS), decreased stress (responses: 2 for AMS; 3 for AHDS), and wanting to keep up with technology and meeting future needs (responses: 7 for AMS; 12 for AHDS; 2 for AAMS). Overall, the study data showed that PLF technologies were highly valued by participants and allowed some to work off-farm–common among small farm operators in Canada who often struggle to turn a profit from farming alone given competition from global and large-scale producers, as illustrated by the following comment related to AMS notifications, *"Can't be there 24/7. Pro, I have an off farm job and the AMS [allows] me to be successful in that role while getting the opportunity to farm as well" (P1).*

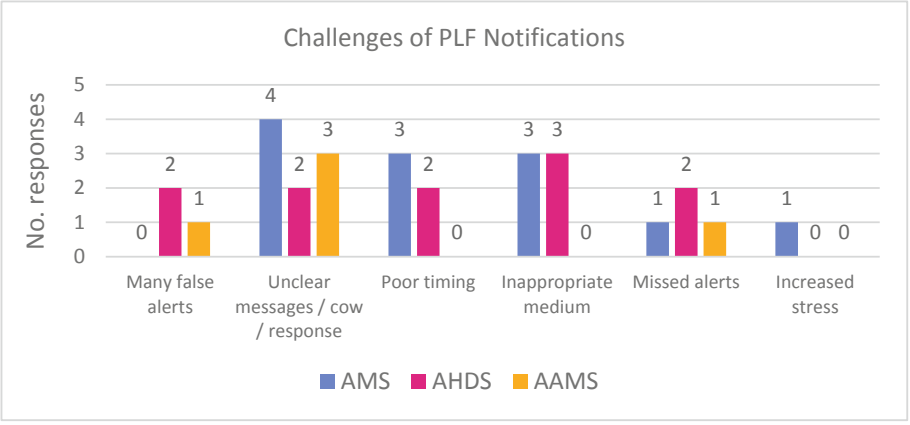

Fig. 2. Challenges of PLF Technologies

Despite these benefits, participants also reported various challenges they experienced with notifications from their PLF technologies, as summarized in Fig. 2. As the data show, the most reported challenge across PLF technologies relates to information uncertainty, for instance, in the form of unclear messages, missing identity of a cow, urgency of the issue being reported, or uncertainty around what, if any, action is needed. One AMS user commented, *"The voice is not always clear and the responsiveness to confirming and resetting the system when you push the appropriate button is not great." (P2).* Some participants reported that notifications are sometimes too generic to be that useful without further investigation. One AHDS user reported that upon receiving notifications from their AHDS they had to go through a *"lengthy process to get into [the] slow app to find out which cow is in heat" (P5).* Thus, sometimes finding the information they required was cumbersome.

Receiving notifications via inappropriate mediums was the next most reported challenge (for AMS and AHDS only). For instance, as discussed in the prior section, farmers preferred non-critical or non-urgent information to be sent to the system dashboard rather than sent via a phone call or text message. The timing of notifications was the next most

reported challenge (for AMS and AHDS only). Some farmers reported that the timing of AMS notifications sometimes interrupted more important work or life activities. An AHDS user reported inappropriate notification timing as a challenge, as illustrated by their comment, *"I wish refresh of data would be more current. Mostly 4 h behind, sometimes. [For example] if it is 10am now, the last data point showing is 6 or 8am" (P2).*

A few participants reported they sometimes missed important information because of the timing and/or medium of communication. One AAMS user reported their dissatisfaction with their system's protocol to wait for a period of time before reporting detected abnormal behaviour, as illustrated by their comment, *"Sometimes it does not alert me soon enough. There is a time delay where it waits to see 2 days of decreased inactivity before an alert. Hoping to contact company to make a change on this." (P11).*

A few AHDS and AAMS users reported that their systems sent many false alarms or inaccurate data related to detected heat events or abnormal behaviour, as illustrated by the comment by an AHDS user, *"I feel like there are a lot of bugs because we do receive false alerts all the time and sometimes the readings are incorrect." (P17).* No AMS users reported receiving false alarms from their systems, possibly because AMS technology is a more mature, and potentially more refined, technology. Only one participant, an AMS user, reported increased stress as a challenge experienced by their AMS notifications due to the fact that they could receive a message at any moment.

Overall, AHDS users reported far fewer challenges with notifications from their systems, with 6/16 participants explicitly adding comments like *"no challenges"* and *"no challenges, very happy with alert system"*. This may be due to the very specialized scope of its detection and notification functionality compared to the much broader types of notifications provided by AMS and AAMS systems.

4.5 Perceived Stress Levels Related to PLF Notifications

Participants were asked to rate how stressed they felt during their daily activities because of the notifications they receive from their PLF technologies on a 11-point scale, with the anchors 0 = not at all stressed and 10 = extremely stressed. Most participants rated their stress level very low, with a mean stress rating of 2.006. Some related participants comments included, *"Not many alarms = no stress" (P15)* and *"Don't mind getting alerts. It's always for a good reason. It does not stress me out. It's all about being proactive on the farm instead of being reactive." (P14).*

However, a few participants commented that they felt stressed because of notifications received from their farm technologies. Extracting information from benefit and challenge data explicitly, the result shows that most participants (84%) said that the communications decreased their stress, with only a few participants (16%) reporting the opposite. Some common themes as sources of stress reported by participants included unclear information and required actions, false alerts, inappropriate timing and communication medium, and missed alerts. Although no question asked explicitly about excessive information, one participant reported receiving unnecessary notifications. This reason was also reported as a cause of stress by the participant, as illustrated by their comment, *"I think the alerts should be less and we should only receive alerts if there*

is a problem. We have done farming for a long time without these systems in place and have done just fine. I think they are good but should just stay in the background." (P17).

Another reported source of stress was the need to drop what they are currently doing after receiving a notification, as illustrated by the comment, *"Could be away from the farm and receive an urgent alert you may have to leave an event for if there is no one else available to fix the alert" (P5).* Therefore, some farmers feel they cannot travel far from the farm without someone on call. This implies that farmers never feel off duty without someone on call, as illustrated by the participant comment, *"Not leave far from the farm without someone on call. This stress was present to the same degree before installing the alert system." (P5).*

Some participants reported stress due to the fact that notifications can be the source of bad news, such as a system breakdown that is expensive to fix or that causes production loss, as illustrated by the comments, *"Cow time away from robots. Having to fix robot" (P1), "Equipment breaking down and if it breaks down it will be expensive to fix." (P3),* and *"I worry that the alert will be something bad and when I hear it I always stop what I'm doing and look and during that time period I get nervous and increased anxiety" (P17).* Stress can also stem from the timing of a notification, for instance, when it requires the farmer to *"[get] up in the middle of the night" (P16).*

A follow-up question asked participants how they coped with stress experienced from PLF notifications. Farmers reported different strategies to cope with the aforementioned stresses, such as having someone on call when they are away from the farm, involving family members so they can help address problems that arise, not being bothered too much about the notification in the moment, and installing backup technology to help manage system breakdowns. The following sample comments illustrate some of these strategies, *"You just let it go and deal with it when it works best, or the next time you are in the barn*" (*P10*), and **"***Other [second] robot can manage while I am at work. Milking 65 cows on 2 robots" (P1).* Some farmers reported getting better at handling notifications in more effective ways over time as they get used to their devices, as illustrated by the participant comment, *"As I get more used to receiving alerts (we just started less than a year ago) I start to feel less anxious. I also changed the alerts on my device so it just vibrates" (P17).*

Collected data were analyzed to determine possible demographic factors in the stress levels reported by farmers due to PLF notifications. Table 1 represents the correlation matrix between stress level and years of farming experience, age of farmer, and size of farm (number of cows). The correlation coefficient (r) for stress level and years of experience is $r = -0.710$, suggesting a strong negative relationship between stress level and years of experience in dairy farming [1]. Thus, as farming experience increased, the reported stress level decreased. This correlation was significant ($p = .002$). A moderate negative relationship ($r = -0.481$) was found between stress level and age, indicating that older farmers experience less stress, potentially because they have more experience with handling stress. This correlation was marginally significant ($p = .0059$). A weak positive relationship ($r = 0.201$) was found between farm size (numbers of cows) and stress. It might be expected that larger farms would receive more notifications, introducing more

[1] Two variables are considered weakly related if the correlation coefficient (r) is $|r| < 0.35$, moderately related if $0.36 < |r| < 0.67$, and strongly related if $|r| > 0.67$ [26].

potential for stress. However, farmers on large farms may have also developed better strategies for notification management, such as adjusting factory settings to minimize alerts. This correlation was not significant ($p = .456$) .

Table 1. Correlation Matrix Values (r) for the Stress Level against Farm Size, Years of Experience, and Age of the Farmer.

	Years of experience	**Age of farmer**	**Farm size**
Stress	−0.710	−0.481	0.201
p-values	0.004*	0.0593+	0.4561

* significant, + marginally significant

5 Discussion

The study revealed several challenges farmers experience related to their PLF notification systems that have implications for the design of future systems. These challenges and related design considerations are discussed below.

5.1 Information Uncertainty

The results show that the information provided by PLF notifications are not always clear or sufficiently meaningful. This uncertainty can cause confusion about what, if any, action they should take upon receiving the notification. This finding is consistent with previous studies on PLF technologies that also found that farmers were sometimes unsure of the content or meaning of PLF notifications [12, 13]. Information uncertainty was reported for all PLF technologies studied in this survey, although the source of uncertainty varied. For AMS users, sometimes the automated voice in notifications received by phone was hard to hear or understand, so the information was not conveyed effectively. For AHDS users, heat event notifications by text messages (or via native mobile notifications) did not contain the identity of the cow associated with the event. For AAMS users, sometimes the content of notifications was too vague to be useful. The study found that farmers would typically have to do further investigation to help clarify the notification's meaning, for instance, by checking a cow or the physical system to determine the issue or by checking the associated software application to determine which cow needs attention and/or what the issue is.

Research from the field of neurobiology shows there is a strong connection between uncertainty and stress and that this type of stress can have negative health impacts [35]. Thus, whenever key information is required for decision-making or action, it should be sent with the notification so that farmers have a clear idea about their required action. Our findings of information uncertainty corroborates previous studies of PLF technologies [7, 8]. Thus, a clear design implication of the study is that PLF notifications should

provide key information related to the source of concern, including needed actions and their urgency. For instance, if a notification concerns a specific cow, the identity of the cow should be provided directly. The farmer may have relevant contextual knowledge about that cow that allows them to make informed judgments of needed actions and their urgency.

The study also found the process needed to clarify a notification can sometimes involve cumbersome steps in the associated software application. For instance, as reported in Sect. 4.4, an AHDS user (P5) expressed frustration of the *"lengthy process"* needed to *"get into [the] slow app to find out which cow is in heat"* because the notification did not identify the cow. Thus, another design implication of the study is the need to streamline any system interactions that may be needed to gain more information about system notifications, which can be accomplished through effective user-centred design that ensures interfaces are highly usable by their target user.

5.2 Matching Communication Timing and Medium to Notification Content

The study findings reveal the contents of PLF notifications contain a variety of different kinds of information related to the systems and the cow they are monitoring. They also show that this content has different levels of importance or urgency. For instance, information about a cow being in heat (i.e. ready for impregnation) is considered very important and highly urgent for a dairy farmer because milk production relies on pregnant cows and because heat cycles are relatively short (e.g., two to 48 h depending on the individual cow and their breed). Thus, being aware of this information in a timely manner is crucial for effective farm operations. However, consistent with prior research [36], this study found that notifications are sometimes sent at times and/or through mediums that are ineffective for farmers to make a decision or take an appropriate action.

AMS, AHDS, and AAMS users reported they sometimes received notifications from their systems at inappropriate times. An AHDS user (P2) reported that dashboard notifications in their AHDS application were about four hours behind. Thus, for cows with very short heat cycles, this delay may mean the loss of a breeding opportunity. An AAMS user (P11) reported that their system notifies farmers about certain abnormal behaviours only after two days of anomalous behaviour is detected. Yet, the farmer felt this was too long to wait to hear about a potential *"health issue that needs to be addressed sooner" (P11)* and planned to contact the manufacturer to change this feature. Communication timing has been shown to play a vital role in making appropriate, timely decisions [37]. The study results indicate a need for more careful design of PLF notification timing mechanisms.

AMS and AHDS users reported sometimes receiving notifications through an inappropriate medium. Surprisingly, twelve AHDS users (75%) reported that they received notifications of heat events via the system dashboard. The dashboard is something that farmers check as desired, but heat events need immediate checking. Thus, it is surprising that dashboard notifications were, by far, the most reported communication medium used by AHDS users (12/16), with other mediums being reported much less often (text messaging: 4/16, email: 2/16, phone calls: 0/16). AMS users reported receiving "unnecessary" phone call notifications late at night, which was frustrating for them.

The issues of notification timing and medium are closely intertwined. The most effective notification would be received at the right time through the right medium so that a farmer can properly attend to the concern without being distracted by other issues and can easily understand the information being conveyed. Clearly some types of notifications are more urgent than others, for example, a cow in distress or in heat. Thus, using a medium that demands the farmer's attention should be used for urgent concerns, for example, a phone call or text message, as they both typically make sound or vibration to capture attention. A potential reason for AMS notifications to rely heavily on phone calls may be that they are a reasonable medium to use for urgent messages. However, the study found that AMS users received phone notifications for all urgency levels.

Beyond the urgency of the concern, the *content* of the message should also be considered when selecting a notification medium to aid in message comprehension. Different mediums provide different affordances for supporting communication [38], such as how well they support *simultaneity* or *reviewability.* A phone call affords *simultaneity*, which forces the receiver to attend to a message at the same time it is sent. Thus, for urgent messages, this may be an appropriate medium. However, the phone call does not afford *reviewability* (the ability for the receiver to review the message content), which can increase the cognitive workload of understanding and recalling messages sent by phone. Lack of reviewability is especially problematic when the message contains *verbatim* content that must be understood, and recalled later, exactly [38]. For instance, communicating a numeric cow identifier via a text message may be easier to understand and later recall than communicating this information by phone. For extremely urgent issues, use of multiple communication mediums, such as phone call and text message or native mobile phone notification, may help ensure farmers are aware of the issue immediately, and have the correct information ready at hand to understand the concern and take timely action.

The study also found that some AMS farmers adjusted their notification settings to address inappropriate timing and medium issues, for instance, to reduce notifications concerning non-urgent issues or those that did not require actions (e.g., notifications related to system cleaning) and to manage the timing of notifications (e.g., turning certain types of notifications off overnight). However, the fact that an AAMS user mentioned a desire to contact the manufacturer to help adjust the notification timing of some of their system notifications suggests that more user control over notification timing and medium may be needed for some PLF technologies.

As suggested by the HCI literature discussed in Sect. 2, interruptions caused by notifications delivered at inappropriate times may also impact the work or life activities of the farmer, impacting decision-making, productivity, and emotional well-being. An emerging solution to minimize distractions caused by ill-timed notifications is the use of location-based notifications [29]. This approach sends a notification to the user when they are in a certain location based on their GPS coordinates. For instance, a farmer could receive text message notification to check their AMS when they enter the barn. The approach takes advantage of context. When the farmer is in or near the barn, they are more likely to be available to attend to barn-related concerns than if they are in the grocery store. While this approach may not be appropriate for urgent messages that

require immediate action, it may be suitable for other types of notifications which are important but less urgent.

5.3 Information Overload

Although this study did not explicitly probe farmers about information overload, several farmers reported they received unnecessary information from their PLF technologies. For example, Participant 17 commented that "the alerts should be less, and we should only receive alerts if there is a problem", and Participant 3 reported that they adjusted their AMS dashboard settings so that only "necessary" information was shown. These findings are consistent with prior research that has reported farmers sometimes receive excessive and unnecessary information from PLF technologies [12, 13], which can be overwhelming and stressful for them [7, 10, 39]. In general, receiving unnecessary information can create information fatigue that can cause users to miss information needed for decision making [40]. A study found that users can experience social media fatigue due to information overload, which leads to intermittent use of social media [41]. Receiving unnecessary information may also hamper effective decision-making and productivity [22]. Therefore, managing notifications to ensure they are not overwhelming for farmers is an important concern for PLF designers. However, ensuring that farmers get sufficient, but not overwhelming amounts of information for them to make proper decisions is difficult.

One approach could be to prioritize notifications where farmers are communicated only relevant issues at appropriate times [29]. For instance, issues such as calving time, insemination time, or severe temperature or lameness, which need immediate attention, could be ranked highest. In contrast, non-urgent matters, such as the slightly reduced amount of milk yield, that could be addressed after a specific period could be ranked lowest. As discussed in Sect. 2.4, using the farmer's context, such as their location (discussed above), or inferred activity (e.g., talking with someone), may help PLF designers determine when (timing) and how (medium) to deliver notifications of different importance and urgency levels to minimize interruptions and also to deliver notifications when the farmer is available and able to attend to the information. Developing effective visualization techniques for PLF applications and their dashboards may also help. For example, the previously discussed 'Scope' system [32], spatially arranged notifications on a screen to indicate their importance level. This contrasts many PLF notification displays that often list system notifications in chronological order. Arranging by order, or distinguishing different types of notifications by colour or intensity may help farmers quickly comprehend the importance or urgency of listed concerns.

5.4 Are PLF Notifications a Source of Stress for Farmers?

While only a few farmers explicitly reported that they experience increased stress from PLF notifications, the study did find many examples of negative user experiences with current PLF notification mechanisms that prior research on notifications and general user interactions with technology, would suggest that cumulatively, these experiences may create stress and anxiety in users over time. For example, participants reported sometimes experiencing frustration, confusion, and uncertainty when receiving and responding to

notifications, and experiencing interruptions to other critical work or life activities. As discussed in Sect. 2.4, these types of user experiences can harm productivity and mental wellbeing. This finding is consistent with prior studies [7, 8], which uncovered several reasons for farmers' stress, including unclear information, unclear required actions, false alerts, timing and medium of alerts, and technology breakdowns.

Participant 1 commented their AMS allows them to have an off-farm job while still farming and reported "decreased stress" as a benefit of their AMS. Yet, the same participant also reported their AMS sometimes interrupted more important work or life activities, that sometimes they missed important/urgent messages from their AMS, and that they experienced increased stress because they could receive a message at any moment. Thus, it seems that managing stress related to PLF technologies is complex, as the same technology can both be a source of stress and a means to decrease stress.

Addressing some of the design concerns around information uncertainty, inappropriate notification timing and medium, and information overload discussed in the prior sections will help to reduce the sources of potential stress from PLF notifications. As it is difficult, perhaps impossible, for any designer to completely anticipate what information all farmers consider important or urgent, allowing farmers to customize system settings to receive notifications based on their own preferences may further help address the negative impacts of notifications.

6 Conclusions and Future Work

A pilot survey study investigating the impact of precision livestock farming (PLF) notifications on farmers found that farmers highly valued these systems, but also experienced challenges that reduced the effectiveness of their PLF systems. Some positive effects experienced by farmers were reduced mental and physical workload, improved livestock health, ease of data collection, and improved milk products. Challenges farmers experienced with PLF notifications included information uncertainty, false alerts, missed alerts, inappropriate communication timing and medium, information overload, and increased stress. Improving the technology's performance and accuracy would help to address information uncertainty, false alerts, and missed alerts. Information uncertainty could also be addressed by more clearly conveying the key information related to the topic of concern. Notification systems should also be designed to use appropriate communication timing and mediums suited to the content, importance, and urgency of the notification. Additional information look-up should be extremely easy and effective to do, minimizing unnecessary mental and physical workload. It is strongly recommended that manufacturers adopt user-centric design approaches from the field of HCI to better incorporate farmers' needs and preferences into their PLF notification mechanism designs in the future to develop simple farmer friendly interfaces. HCI techniques such as iterative design and development, and participatory design methods can be followed to design newer technologies engaging with dairy farmers and stakeholders [16].

As a pilot study, this research has limitations. The extent to which the challenges discussed in this study exist across the broader Canadian farming population is unclear. However, their consistency with prior PLF studies of other farming populations provides some support to their generalizability. Nonetheless, a larger study is needed to confirm the

scale of the findings. Also, following good user-centred design, other types of user studies are needed to help further understand farmers needs relate d to PLF notifications. For example, observational studies and interviews would help to reveal specific workflows and user challenges related to receiving and acting on notifications.

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