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Care in dairy farming with automatic milking systems, identified using an Activity Theory lens

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ABSTRACT

Context: In Sweden, 34% of herds in official statistics 2021 (77% of the cows) have an automatic milking system (AMS) and keep 19% of the dairy cows.

Objective: This study should be considered in relation to the rapid increase of digitalisation in agriculture. It aimed at investigating Swedish farmers' experiences and reflections in dairy farming concerning AMS use from a care perspective, based on two research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

Methods: A mixed method approach was performed, using method triangulation through a questionnaire, interviews, and field visits. The Activity Theory (AT) was used as a theoretical lens to consider care practice in the dairy farming as a learning system.

Results: AND CONCLUSIONS: Participating dairy farmers were found to be in a continuous learning process on different levels in their system, from detailed problems with an individual cow or the herd to the whole dairy system. Implementation of AMS required learning in order to manage, and thus care for, a system comprising of animals, technology, and humans, to increase business viability. In successful AMS use, willingness to learn, adapt to the local situation, and continually improve practice, or *care* as a patterning of activities, appeared to be the most important factors. With more people involved, differentiations were possible, which in turn accentuated the need for more trained staff who can perform more complicated tasks. The findings indicated high importance of experience and a 'stockperson's eye', in combination with *tool-mediated seeing* using data from the robot, in developing *enhanced professional vision* and good *care*. A good stockperson had broad competence combining a stockperson's eye with experience with robot data. One of the greatest challenges for dairy farms was finding a good stockperson as staff or advisor. Increased flexibility in work and better physical health were important driving forces for implementing AMS, while handling alarms was mentally stressful and gave different perspectives on AMS vulnerability. Overall, the analysis of the collected data showed that AMS had brought major, primarily positive, changes in daily work and increased work satisfaction for most farmers, with a clear majority of the respondents feeling good in their work situation and enjoying their work.

Significance: Application of AT in studying AMS from a care perspective, represents a shift from traditional research that normally addresses technological inventions, to studying farmers' socio-technical system. The AT lens revealed the work practices in performing care, as a patterning of activities accomplished by a tinkering learning process, in the rich and messy matrix of humans, cows, and technology.

1. Introduction

The recent and rapid development of technology-oriented agricultural trends, such as smart farming, digital agriculture and agriculture 4.0, reflects agricultural production within the dominant technocratic paradigm (e.g. Ayre et al., 2019; Clay et al., 2020; Finstad et al., 2021; Klerkx et al., 2019; Lioutas et al., 2019; Rijswijk et al., 2021). Milking robots or automated milking systems (AMS) fit this paradigm, since it

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has entailed new possibilities for data collection on the individual cows as well as the whole herd. The first commercial AMS was installed in the Netherlands in 1992 (de Koning, 2010), and since then adoption has increased steadily, especially in European countries (Salfer et al., 2017). In 2015, there were more than 25,000 dairy businesses with AMS worldwide (Barkema et al., 2015), and some estimates show that there were over 35,000 units on farms in 2017 (Salfer et al., 2017). The Nordic countries and the Netherlands have led in implementing AMS systems, with the highest percentage of AMS herds (Barkema et al., 2015). The first AMS in Sweden was installed in 1998 (Bergman and Rabinowicz, 2013). By August 2020, Sweden had 3250 dairy businesses, with on average 94 cows each (https://www.lrf.se). National statistics for 2021, covering 77% of Swedish cows, indicate that 35% of Swedish herds had AMS (735) (Växa, 2021). With the introduction of AMS, the whole practice of milking and related work practices or *care* has to be re-organised around the new robot device (Butler et al., 2012; Driessen and Heutinck, 2015). The AMS provides much data for each cow, suggesting that the care perspective in AMS could be based on robot data, replacing the physical contact and visual inspection of each individual cow in conventional milking systems (CMS). However, some research indicates that care in AMS must be based on more than robot data to be successful (Lundström and Linblom, 2020; Stræte et al., 2017). It is therefore necessary to consider the interdependencies between humans and analogue and digital technologies, since technologies provide meaning only when embedded in social practice (Barrett and Rose, 2020; Darnhofer, 2020; Finstad et al., 2021; Suchman, 2007). In a socio-technical perspective on dairy farming, the AMS is dependent on the farmer's work practice (Finstad et al., 2021; Rijswijk et al., 2021). Hence, it is not enough to study technology such as AMS in themselves, rather there is a recent quest to study how AMS are integrated into farmers' work practices from a systemic perspective, which includes people, technology, and cows.

There are many approaches for evaluating work practices that include both people and technology. According to Krzywoszynska (2015), among others, the care perspective is becoming central to the current reconceptualisations of agrarian space and practice in modern agriculture. Krzywoszynska (2015, p. 1) paraphrases the classic definition of care by Tronto (1998) as "the totality of those activities which enable the maintenance, continuation, and repair of the farming 'world'". Today, it is acknowledged that good care is viewed as essential for any kind of good farming. The care perspective was applied in the present study, partly because of its criticisms of the technocratic and productivist paradigm in agriculture (Puig de la Bellacasa, 2017). Krzywoszynska's (2015, p. 2) description of care goes as follows: "the totality of practices that make technology and knowledge work", which means that she considers care as a patterning of activities. As pointed out by Mol et al. (2010), care is situated and place-based, as it involves developing local solutions to specific local problems. Moreover, care takes a relational approach that is built on mutual dependencies (Puig de la Bellacasa, 2017). The emerging understanding of care within farming is therefore considered as a non-normative proposition and an amalgam of vital affective states, ethical obligations, and ongoing tinkering practices that have their roots in early feminist social science and political theory (Puig de la Bellacasa, 2012). In this present paper, we investigate and analyse care as a patterning of activities in dairy farming with AMS.

Implementation of AMS on-farm requires learning in order to manage, and thus care for, an entire socio-technical system comprising animals, technology and humans, in order to create a viable dairy business. Learning is required by the farmer to properly manage an automated system, based on robots milking the cows, and by the cows to fit into the particular system. It is a learning process for all to manage the system and provide good care. Thus, care is both considered as a process as well as the outcome of this process in the present paper.

The study of care does not have any accompanying methodological approach other than naturalistic inquiry in general for doing the analysis. We therefore suggest that a viable approach to investigate and analyse care on the dairy farm as a patterning of activities that includes a learning perspective is to use Activity Theory (AT) as a theoretical lens (Kaptelinin et al., 1999; Kaptelinin, 2013). Application of AT in studying a socio-technical system such as AMS represents a shift in the research focus from addressing the technological inventions to considering the ways in which farmers as human actors interact with the technology, the animals, other humans and with each other within a conceptual framework that is regulated by specific requirements and constraints (cf. Bannon, 1995). Therefore, the AT lens can reveal the work practices of performing care as a patterning of activities in the rich and messy matrix of humans, cows, and technology, which can shed some light on the ways in which AMS influence care as well as result in care (Lioutas et al., 2019). A major strength with AT is its focus on learning within the socio-technical system from a systemic perspective. Activity Theory has been widely and successfully applied in research on human-technology interactions in various domains since the mid-1990s (Rogers, 2012), and has recently been suggested for use in studies on automated intelligent systems like robots (Lindblom and Alenljung, 2020), agriculture (Lioutas et al., 2019) and dairy production using AMS (Lundström and Linblom, 2020). We therefore consider that AT fits as hand in glove for a systemic way of studying care in dairy farming with AMS.

This study aimed at investigating Swedish farmers' experiences and reflections from the perspective of care in dairy farming using AMS. The work was based on the following research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

In Section 2, we first summarise previous work on the reasons for and against investment in AMS and outcomes of the transition from CMS to AMS. Next, we introduce the care perspective and its application in AMS studies and then elaborate on the tenets of AT. In particular, we assess the suitability of AT for studying human-technology interaction in general and use of AMS as an advanced socio-technical farm system in particular. In Section 3, we describe the overall study design, while the empirical results obtained are presented in Section 4. The implications of the results are discussed and some areas for future work are indicated in Section 5, while overall conclusions are presented in Section 6.

2. Background and related work

2.1. Development and impact of AMS on humans and cows on the dairy farm

The digital transformation of AMS introduction meant replacement of CMS with milking robots based on digital technology and automation to handle the daily milking of dairy cows (Douphrate et al., 2013; Holloway et al., 2014b; Karttunen et al., 2016; Lunner Kolstrup and Hörndahl, 2013; Lunner Kolstrup et al., 2018; Rijswijk et al., 2021; Salfer et al., 2017). Multiple reasons for farmers investing in AMS have been identified, including economic reasons (Vik et al., 2019). Other common reasons are to increase flexibility, efficiency and animal welfare aspects, decrease heavy physical workload, improve farming lifestyle and wellbeing, reduce the amount of hired labour (Eastwood and Renwick, 2020; Hansen et al., 2019; Stræte et al., 2017), reduce physical risks, and increase the possibility for succession or to grow without additional labour (Stræte et al., 2017). In the Swedish context, improved physical work environment has been identified as the most important reason for investing in AMS, while high capital investment cost is the main reason for not investing (Bergman and Rabinowicz, 2013). Implementation of AMS is complex, due to the interactions between the social, the cyber, and the physical (Rijswijk et al., 2021), where much can go wrong in daily operations (Gustafsson, 2009).

Data on Swedish and UK farms show that AMS does not decrease working hours by as much as expected, but gives farmers greater flexibility and allows them to milk more cows with fewer staff (Gustafsson, 2009; Butler et al., 2012; Stræte et al., 2017). According to a Norwegian study, AMS farmers are more revenue-efficient than CMS farmers are, after a transition period of approximately four years (Hansen et al., 2019). Milk production per cow, labour costs and milk production per robot are the main factors affecting profitability (Salfer et al., 2017). An AMS can result in labour savings, as some work tasks are reduced or eliminated, but new tasks are added (Bergman and Rabinowicz, 2013; Eastwood and Renwick, 2020; Hansen, 2015). Mental stress caused by the monotonous, repetitive, fast-paced and urgent milking work in CMS decreases after switching to AMS (Karttunen et al., 2016; Lunner Kolstrup and Hörndahl, 2013). Mental stress can still arise with AMS, due to night alarms, lack of sufficiently skilled labour/staff and 24/7 readiness of the milking robot (Butler et al., 2012). However, farmers can adapt the AMS to their own needs and thus reduce the number of alarms (Hansen, 2015).

The transition from CMS to AMS also alters the role of the stock person (Ouweltjes and de Koning, 2004; Butler et al., 2012; Holloway et al., 2014b; Stræte et al., 2017). With AMS, a wider range of data are collected on the cow herd, the individual cow and milk quality, which together can improve milk production (Bugge and Skibrek, 2019; Butler et al., 2012). Less time is spent on milking, but more time is needed for analysis and evaluation of AMS data and observation of cowherd behaviours (Stræte et al., 2017). Some even suggest that a change from CMS to AMS changes the meaning of 'stockmanship', from referring to a person with knowledge and skills based on close contact with animals to a computer-based worker with increased distance to the animals, using the robot and computer as intermediaries (Stræte et al., 2017). Holloway et al. (2014b) refer to cows 'hiding' in technology. Another reason for a change in stockmanship is that AMS often means more cows in the herd and increased efficiency in the dairy industry, leading to shorter cow life and thus more limited possibilities for relationships to develop (Burton et al., 2012).

The introduction of AMS requires learning on how to handle a highly automated system based on robots that milk the cows, instead of people doing it (Hansen et al., 2019; Tse et al., 2017). There are challenges in integrating conventional work practices with multiple technical and digital systems in a dairy farming context (Eastwood et al., 2012; Lunner Kolstrup et al., 2018). Farmers' engagement with AMS data varies widely (Holloway et al., 2014b; Stræte et al., 2017). Some use data intensively and others are either unaware of the kind of data available or unable/unwilling to use these data. Increased use of technical and digital systems could result in significant changes in the relationship between humans and animals, giving rise to various socio-ethical dilemmas (Stræte et al., 2017). On the one hand, farmers with AMS are expected to care for their cows using AMS data. On the other hand cows are expected to look after themselves and behave according to the demands set by the AMS or, if not, they must be persuaded, enticed or forced (Holloway et al., 2014a).

Regardless of their reasons for changing milking system, farmers must be motivated to learn and develop relevant skills to use AMS in the local situation on their dairy farm (Stræte et al., 2017). This means there are learning costs connected with the transition from one milking system to another (Hansen et al., 2019). Thus, AMS farmers/companies need to have a genuine interest in both cows and technology (Bergman and Rabinowicz, 2013).

To summarise, from a socio-technical system perspective shifting from CMS to AMS does not simply involve introduction of a new kind of technology, but also requires an entirely new management system with altered milking and working practices both humans and cows. The focus on work practices is a well-established research field within socio-technical systems in general, but has not been applied to AMS in particular. Inclusion of new technology in an existing socio-technical system is a more complex issue than technology acceptance, because it requires integration into existing complex work practices that sometimes are implicit (Lindblom et al., 2017; Lundström and Lindblom, 2018). A promising approach to gain a systemic view on the practice of including technology, humans and work is to apply the care perspective as a patterning of activities.

2.2. Care as a practice

The care perspective has been used in relation to farming (Mol et al., 2010), wine production (Krzywoszynska, 2015), permaculture (Puig de la Bellacasa, 2017) and agricultural soils (Krzywoszynska, 2019, 2020; Puig de la Bellacasa, 2015, 2017) and concerns humans as well as non-humans and natural settings (Krzywoszynska, 2019; Puig de la Bellacasa, 2017). Using care as a perspective is a way to highlight the value of experiential and situated knowledge, an ethos built on attentiveness, responsibility, and interdependent relations in a practice. Care is not considered an obligation, a principle, a role or an emotion, but the result of all practices that make technology and knowledge work in complex domains (Krzywoszynska, 2015). Care, from our point of view could be considered a process of development and learning as well as the resulting outcome, in practice. Accordingly, the care perspective is useable to describe what Finstad et al. (2021) call a relational learning process in adoption, integration, and use of AMS as well as a way to conceptualise farming as a relational process, which according to Darnhofer (2020) is dynamic, changing, emerging, and difficult to predict. Hence, we consider that the care perspective encompasses this shift from focusing solely on technology or an engineering mindset (Jacob, 1977), and instead focuses on the patterning of activities as a relational process as well as the resulting outcome of these activities. This means that care is both the means and the end.

Farmers' daily work practices are complex, as they require knowledge and consideration of a wide range of biological, technological, practical, political, legal, economic, ethical and social factors and circumstances (e.g. Lindblom et al., 2013; Nitsch, 1994). The farmer needs to manage a wide range of competences, including: 1) knowledge about the subject (dairy etc.), 2) skills in formal planning (economic records etc.), 3) practical skills, and 4) knowledge of the institutional environment (legislation, market conditions etc.) (Nitsch, 2009). However, "*The crucial element is the ability to apply them in the coordination of the complexities of farming on a specific farm*" (Nitsch, 1994, p. 32). This kind of knowledge practice and skills, expressed as care in this paper, is personal. The increase in technology aspects of farming entails an increased risk of concealing or blurring reciprocal relationships and dependencies, which the care perspective may be able to clarify. Nothing impedes any kind of technology in care according to Mol et al. (2010, p. 15): "*Technologies, what is more, do not work or fail in and of themselves. Rather, they depend on care work. On people willing to adapt their tools to a specific situation while adapting the situation to the tools, on and on, endlessly tinkering*". This makes the care perspective a suitable perspective for studying learning processes in complex agricultural systems.

At first glance, dairy farming involves individually rather easy interventions, such as feeding cows, cleaning floors, milking, etc. On closer inspection, however, dairy farming is complex and demands tacit knowledge and highly complicated skills in simultaneously handling animals, technology and more. The overall management of the dairy system is a question of routines, technology, knowledge, experience, planning and a stockperson's eye, to perform good care in dairy production. With adoption of AMS, farmers' physical distance to the animals increases and care changes (Bergman and Rabinowicz, 2013; Driessen and Heutinck, 2015; Stræte et al., 2017). Adoption of new technology can limit, change, improve and even jeopardise the individual's possibility to develop good and broad relations to non-humans within the farming context. The crucial factor is the need for tinkering within existing strategies and use of attentiveness and experiential knowledge to deliver as good care as possible in continually evolving situations.

When a dairy farm changes from CMS to AMS, this brings major changes in how care is expressed and manifested in the daily work (Bergman and Rabinowicz, 2013; Driessen and Heutinck, 2015; Stræte et al., 2017). In AMS, the lives of the cows are less controlled, especially with free cow traffic. Holloway et al. (2014b) claim there is also a change in the meaning of good stockmanship on changing from CMS to AMS. In CMS, good stockmanship is based on knowledge and skills developed from long-term first-hand contact with the cows and acquired experience of e.g. milking. In AMS, good stockmanship is mostly based on computer usage, data interpretation and responding to suggested computer-based interventions, with increased distance between the stockperson and the animal(s) (Holloway et al., 2014b). 'Knowing' or 'seeing' through a technical device, instead of in reality, means *tool--mediated seeing* (Goodwin and Goodwin, 1996). In CMS, experiential knowledge of milking and handling cows results in a *professional vision* (Goodwin, 1994), but in AMS farmers must develop *enhanced professional vision* (Lundström and Lindblom, 2018), in order to use technology to 'see' the cows and thus use AMS effectively. Consequently, AMS restructures the relationships between humans and animals (Holloway et al., 2014b). Farmers receive more data on each cow, and can get to 'know' each cow better via the digital management system of the AMS, while cows have more freedom to decide concerning milking, resting, and feeding.

The transformation from CMS to AMS means a lateral shift in responsibility from the farmer to the individual cow (Driessen and Heutinck, 2015; Holloway et al., 2014b). In AMS, cows are expected to make the correct choices and can be "*variously persuaded, motivated, forced or 'tricked' into doing so through, for example, installing devices which enforce particular patterns of movement, or by direct human interventions such as 'fetching' or culling reluctant cows*" (Holloway et al., 2014a. p. 139). Thus, the cows need to learn to 'take care of themselves' within the AMS, but care is also distributed in the sense that the cows are simultaneously worked on/taken care of by the farmer (Driessen and Heutinck, 2015). "*The freedom for both cows and humans promoted by the manufacturers as a benefit of robotic milking becomes a responsibility to take care/be taken care of and to foster productive life*" (Holloway et al., 2014a, p. 140). The farmer must provide good prerequisites for the dairy system, but the individual cow must in turn adapt to the particular system.

Although the care perspective is very promising and accurate in describing the means and ends of care in work practices at the intersection of technology, humans, and cows on dairy farms that use AMS, there is currently no explicit way or methodology suggested for investigating and analysing the care perspective in a systemic way. Most care studies are conducted using various naturalistic study approaches (Mol et al., 2010; Krzywoszynska, 2015). As argued in the Introduction, Activity Theory (AT) could enable a more structured approach to study the wider socio-technical system of AMS in dairy farms, as it has a broader unit of analysis, focusing on the mediating role of technology use while situating the users at the centre of the social and material context. The focus in AT on studying so-called contradictions during technology mediation also provides insights for learning and development, which are aspects well aligned with the care perspective.

2.3. The conceptual framework of Activity Theory (AT)

Activity Theory, sometimes called Cultural-Historical Activity Theory (CHAT), provides a comprehensive conceptual framework that can be used for grasping and portraying the structure and development of human activity situated in its technical and social context (Kaptelinin et al., 1999; Kaptelinin, 2013). Activity Theory emerged in the 1920s–1930s and has since undergone three generations of research (Engeström, 2001). It provides a broad and complex framework for describing and evaluating the structure, development, and context of human activity, considering individuals, artefacts and other humans and subjects, as well as their interrelations (Duignan et al., 2006; Kaptelinin et al., 1999). According to AT, the only way to understand the human mind is in the context of human interaction with the world, and this interaction, i.e., activity, is socially and culturally constructed (Kaptelinin, 2013).

Since its inception, the underlying principles of AT make up an intertwined system forming a whole that represents several aspects of human activity. This creates a need to apply these principles from a systemic perspective, because of their interrelatedness, which unfolds over time. One way to do so is to use the extended AT framework called Activity System model (Engeström, 2001, 2015) (Fig. 1). The Activity System model is a way to visualise the different interactions between various elements when performing an activity and its outcome from a systemic perspective.

In the Activity System model, the interactions between subject (user, which in this context is the farmer), object (cows on the dairy farm), main mediating artefact (the milking robot and supporting instruments and digital tools) and community (society, advisors etc) are mediated by specific mediational means. These are: mediating artefact and tools/instruments for the subject-object interaction, rules (e.g., norms, work practice, and legislation) for the subject-community interaction, and division of labour for the community-object interaction (Engeström, 2001, 2015; Kaptelinin, 2013). The Activity System model also includes the outcome of the activity system as a whole, namely the transformation of the object generated by the activity in question into a suggested outcome. This visualisation approach highlights the continuous process of transformation and development over time (Fig. 1). It should be pointed out that Engeström (2001, 2015) applies a systemic approach to theorise humans' intentional activities, without considering humans as passive factors lacking any internal properties or motives. This way of thinking highlights the continuous process of transformation and development over a time horizon of learning.

A critical step when analysing an activity system is looking for so-called contradictions within the system, i.e., any misfit within an element in the system, between elements in the system, or between the current activity system and other activity systems (Engeström, 2001, 2015). The use of the contradiction term within AT should not be mixed up with common usage of the term. In AT, contradictions are manifested as challenges, problems, interruptions, workarounds, or breakdowns that need to be handled or coped with. In AT, these contradictions are usually regarded as sources of development, because human activities are often a work in progress to handle the current contradiction(s) (Engeström, 2001, 2015; Kaptelinin, 2013; Lindblom and Alenljung, 2020). These contradictions do not always address themselves explicitly, but rather are manifested implicitly via small changes in the subject's mundane work actions (Engeström, 2000).

According to Engeström (2015), when an activity system is under transformation, the actors within the system must develop new forms of activities that are not yet present in the system, often by contradictions, and therefore new activities are learned as they are created. Engeström (2015) describes the learning process as developmental cycles, in which contradictions are the driving force, as expansive cycles. Therefore, it is of major importance to study contradictions from several perspectives, shifting focus from the actions and operations of the individual to zooming out to the broader activity context and then zooming in again (Lindblom and Alenljung, 2020).

An activity can be understood as a purposeful, transformative and developing interaction between actors (subjects) and the world (objects). In the present paper, *care* is considered both as the activity as such and as the intended outcome of the activity system in dairy farming with AMS. In order to gain a deeper understanding of the activity concept that is fundamental in AT, the five central principles that AT is built upon are briefly presented below: hierarchical structure of activity, object-orientedness, tool mediation, internalisation-externalisation, and development. These principles are aligned with the view of care as the patterning of activities.

The hierarchical structure of activity, i.e., the care perspective in dairy farming with AMS, organises an activity into three levels, activity, action and operation, which are related to motive, goal and condition (Kaptelinin, 1996, 2013; Rogers, 2012). The top level is the activity itself, carried out to fulfil a motive, i.e., providing good care in dairy

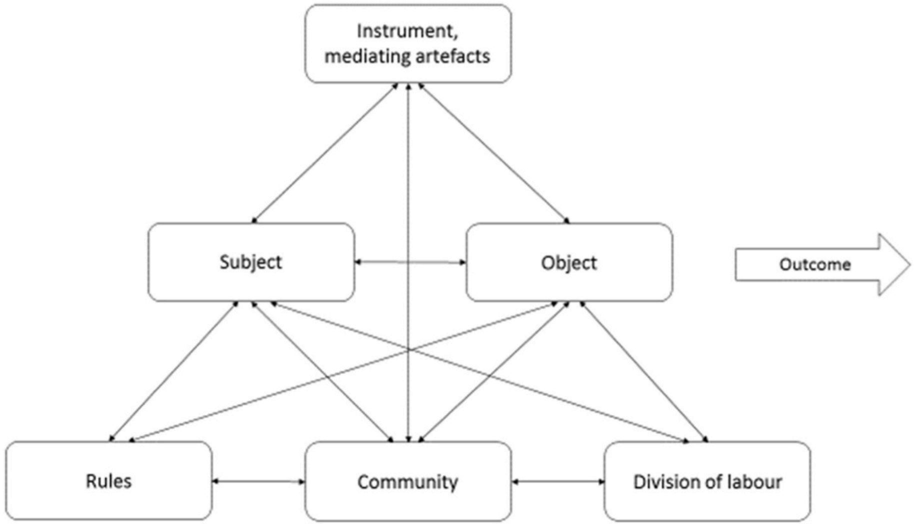

Fig. 1. The Activity System model includes the interactions between the elements of the overall activity and its outcome (modified from Engeström, 2015, p. 63).

farming. The middle level, action, is described as conscious processes subordinated to the activity. Actions correspond to what must be done such as feeding, cleaning stables, washing AMS items, and milking cows and are directed at specific goals, which may be decomposed into sub-goals, sub-sub-goals etc., which means that multiple actions and operations may be nested to fulfil the activity. Thus, each action of milking cows is decomposed into hierarchical levels. In the bottom level, the operations function as lower-level units of actions (Kaptelinin, 1996; Rogers, 2012). As such, operations do not have their own goals, but are rather a result of prior actions that have been transformed into automated operations (Kaptelinin, 2013). Hence, viewing human activity as a three-layer system offers the possibility for combined analysis of motivational, goal-directed and operational aspects of human activity of care in the socio-cultural and material world, by interrelating the issues of "why", "what" and "how" within a coherent framework (Kaptelinin, 1996, 2013; Lindblom and Alenljung, 2020; Rogers, 2012).

The principle of *object-orientedness* states that all human activities are directed towards different objects (e.g. cows on the dairy farm) and these objects motivate and direct activities. Activities such as providing care when running a dairy farm are coordinated around objects, so analysis of objects is necessary for understanding human activities, both at the individual and collective levels. In other words, object-orientedness refers to the current context and setting of usage, where the human (subject) interacts 'indirectly' with the context (objects, the cows on the farm) through various mediating tools/artefacts (Kaptelinin, 1996, 2013; Lindblom and Alenljung, 2020). In this paper, the most prominent mediating artefact is the AMS.

The principle of *tool mediation* is at the core of Russian cultural-historical psychology (Vygotsky, 1978; Lindblom and Ziemke, 2003). The tool concept is broadly applied, and embraces material, physical tools (e.g., computer screens, milking robot) and psychological tools (e.g. charts, tables, and figures from the AMS software), shaping the ways users interact with the world. Placing tool mediation in the broader social context means that mediation enables various forms of acting in and interacting on the world (Kaptelinin, 2013). The object of activity is the actual setting and meaningful context in which the milking robot is used, i.e., the cows on the dairy farm.

The principle of *internalisation-externalisation* stresses that human activity has a double nature, because every activity has both an external and internal side. Hence, the internalisation-externalisation principle is characterised by the ongoing shifting back and forth between what happens internally "in the head", i.e., what the farmers think and reflect upon and what happens practically and externally "in the open" in human activity, i.e., how the farmers acquired practical knowledge and skills are manifested in their actions and operations of milking and conducting care in dairy farming with AMS. The internal and external sides of activity are gradually becoming more intertwined in human work practices and daily life from a developmental perspective manifested in the shift from CMS to AMS (Kaptelinin et al., 1999; Kaptelinin, 2013; Kaptelinin and Nardi, 2018). The socio-cultural dimension of tool mediation which is evident in the fact that mediation enables various *developed* forms of acting in the world. (Engeström, 2015). However, use of tools not only transforms the objects themselves, but is a mutual 'two-way process', where tools reflect previous experiences of using the tool and how to design the tool, i.e., tools embody a set of social practices and their current design reveals a history of particular usage, such as current AMS compared to CMS.

As pointed out by Halverson (2002), the Activity System model has been widely used to analyse various work settings, particularly when there are problems with current or newly implemented technology, where the model enables investigators to identify both micro- and macro-level issues. A suggested approach to frame Activity System model analysis is the eight-step model developed by Mwanza and Engeström (2005), which offers a structured way to describe the activity and sub-activity triangles in the model. The challenges arising on changing from CMS to AMS can thus be considered a shift between two activity systems of milking that raises contradictions, which are managed through learning by developmental cycles from an established care to another new form of care.

3. Method and research design

The present study used a mixed methods research design (Creswell and Clark, 2017; Patton, 2002). Mixed methods is a research design approach where researchers collect and analyse both quantitative and qualitative data within the same study. The growth of mixed methods research design has increased as a way to study increasing complexity on the object of study within the social sciences community. Applying mixed methods design allows researchers to explore diverse perspectives and uncover relationships that exist in multifaceted research challenge. As pointed out by Creswell and Clark (2017), numerous classifications of mixed methods designs are found to exist in the literature, and we have chosen to use triangulation design. Triangulation design is the most common and well-known approach to mixing methods and the main purpose of this design is to collect different but complementary data on the same topic to gain a deeper understanding of the particular research questions and the study's aim. We apply an *inductive drive* which means that the study design is qualitatively driven with the purpose to expand qualitative results with quantitative data (Schoonenboom and Johnson, 2017).

Data triangulation (Patton, 2002) was performed using different data collection techniques (questionnaire, interviews, and field visits). Taking on a *sequential* design (Schoonenboom and Johnson, 2017), data collection started with interviews, in order to gain an initial understanding of farmers' experiences and perceived pros and cons with AMS. Nine farmers (eight with AMS and one who had invested in AMS, but then changed back to CMS), four advisors and two AMS representatives were interviewed (Table 1). The farmers interviewed had 2-8 robots, in use for 2–11 years. The number of cows on the farms varied from 120 to 425, and the sample included farms with both free and guided cow traffic. The farmers were purposely sampled, in order to get as much information as possible (Patton, 2002). The interviews were semi-structured, lasted 1–2 hours and were conducted in real life (all farmers and the company representatives), by telephone (two advisors) or by Skype (two advisors). All interviews were audio-recorded except for the telephone interviews, where notes were taken. The questions concerned experiences of AMS in relation to work environment, production, advisory services, and technology use. The companies interviewed were DeLaval, Lely, Växa Sverige, and a sole proprietorship. The sole proprietor was suggested by one farmer, who contacted the first author due to the project.

A questionnaire was developed based on initial analysis of the interview responses, which means that the questionnaire design was *dependent* on the initial analysis of the collected data from the interviews (Schoonenboom and Johnson, 2017). The final questionnaire comprised 29 questions, some with sub-questions, structured into seven topics: 1) background, 2) milk production, 3) experiences of AMS, 4) experienced mental stress, 5) advisory aspects, 6) future possibilities and challenges, and 7) the work situation. The questionnaire included questions with Likert scales ranging from false to true, multiple-choice questions and five open questions, thus mainly subjective results based on farmers' opinions. In Sweden, no complete official statistics exist that collect information about what kind of milking system a particular farm uses. The Swedish cattle statistics 2021 from the company Växa Sverige comprise 77% of the Swedish cows and 35% of the herds (735 herds) had AMS (Växa, 2021). Therefore, we asked the leading AMS companies, DeLaval and Lely to spread the link to the questionnaire, through their newsletters. In addition, the same invitation was sent through a Facebook group for Swedish AMS farmers that comprises of more than 3000 members. Swedish farmers are well educated and we assumed that this approach could reach many AMS farms in Sweden.

Completed questionnaires were submitted via a link, and therefore anonymous. Accordingly, it was impossible to calculate the response rate. In total, 293 responses to the questionnaire were submitted. Since this study examined the whole milking system on dairy farms, only answers from those who defined themselves as owners are presented in the results section (207 owners). With dropouts due to few questions answered, the results presented represent answers from 188 respondents. When a question concerned a comparison between CMS and AMS, only answers from owners with experiences of both systems were included. No statistics were performed on the questionnaire data given the inductive drive in the mixed methods design approach. It should be pointed out that we did not aim for generalisability with the questionnaire, but to add additional and complementary quantitative data to the qualitative data.

Table 1
Data on the farmers interviewed and the farms visited.

Farm	Nr of robots	cows/ robot	Introd/ end of AMS	Organic/ conventional	Cow traffic	Interview/ field visit
1	2	65	2008	conventional	guided	Interview
2	4	65–75	2010	conventional	guided	Interview/ field visit
3	0	–	2011/ 2018	conventional	–	Interview
4	4	68	2010	organic	free	Interview
5	2 and 1 rotary milk. parl.	60–65	2017	organic	free	Interview
6	8	50	2014	conventional	free	Interview
7	4	70	2011	conventional	free	Interview
8	2	60–65	2009	conventional	guided	Interview/ field visit
9	2	45–50	2008	conventional	guided	Interview/ field visit

Field visits were conducted on three dairy farms in order to gain a deeper understanding of how AMS work and are used in work practice. The farms were located in western Sweden in the former county of Skaraborg and Jönköping, which are two of the regions with the highest densities of dairy cows in Sweden (Svensson et al., 2018). The farms represented: i) a large family farm with a very technology-interested female farmer who had relatively short experience of dairy farming but sometimes tests new technology for DeLaval (Farm 2); ii) a family farm with one female farmer who had medium interest in technology and long experience of dairy farming (Farm 8), and iii) a farm with one male farmer with long experience of dairy production (both CMS and AMS) and an interest in new technology (Farm 9). See Table 1 for data on all three farms. Each field visit took 1–2 h. The first and second field visits were performed by the first author in conjunction with interviews with the farmers. No systematic observations were conducted on the farms. During the farm visits, interviews were held in farm offices, where the computerised AMS software was demonstrated, and in cowsheds where the AMS were installed. Visits were conducted together with the farmer or an employee, in order to observe and gain a deeper understanding of the whole activity system. The third field visit (Farm 9) was conducted as a follow-up by both authors during analysis of the collected data. In addition, field notes, photographs, and video-recordings were made during the visits to the cowsheds.

The collected data were analysed as follows: The transcripts from the interviews and the field notes were read through a couple of times and analysed thematically, using the focal points of AT (Mwanza and Engeström, 2005). An AT lens was then applied to analyse care (Mol et al., 2010; Krzywoszynska, 2015; Tronto, 1998). The questionnaire responses were analysed in Excel, and included in the above thematic content analysis, especially the responses of the open ended questions. The unstructured observations from the field visits were used to complement the other sources of data. It should be emphasised that although the data collection was done sequentially the overall analysis was done through several analytic *points of integration* were quantitative and qualitative components were brought together (Schoonenboom and Johnson, 2017), with the support of the focal points of AT. As pointed out by Creswell and Clark (2017), a primary way to connect qualitative and quantitative data is to use a theoretical framework to bind together the data sets. Qualitative data was used to *illustrate* quantitative results as well as qualitative data was used to describe the underlying *process* for the obtained quantitative results (Schoonenboom and Johnson, 2017).

4. Results

In this section, we apply the eight-step model of focal points developed by Mwanza and Engeström (2005) (subsection 4.1) and present more detailed findings on the focal points related to success factors and challenges in using AMS. We then zoom out and consider the activity of learning and using AMS on dairy farms from a *care* perspective (subsection 4.2).

4.1. Application of the activity system on dairy farms using AMS

To support the analysis of AMS from an AT lens, we used the eight-step model of focal points as depicted in Table 2. The first step refers to

Table 2
The eight-step model of focal points (adapted from Mwanza and Engeström, 2005, p. 459) in the activity system adapted to analyse the activity: *care,* on a dairy farm with an automated milking system (AMS).

Step	Focal points	Description
1	Activity	Managing a dairy farm using AMS described from the perspective of care
2	Objective	The objective on the dairy farm is a viable business, where the farmer or the farm leadership define what viable means. The motives that drive the farmer to use the available mediating artefacts and additional tools to transform the object of activity (the *cows* on the dairy farm) to accomplish a viable farm
3	Subject	The farmer or the farm leadership
4	Mediating artefact and other tools and instruments	External: the milking robot(s), including the accompanying digital systems, is the main mediating artefact, together with digital information systems, sensors on cows, feeding system etc. Internal: knowledge, skills and experience (as a stockperson's eye) of taking care of cows
5	Rules	Safety and animal welfare legislation and other work-related rules, norms, routines and practices that regulate the use of AMS on the dairy farm and cow care. The regulations of actions and interactions within a dairy farm using AMS as an activity system
6	Division of labour	Distribution of responsibility of the work in relation to milk production between the farmer or the farm leadership, family members and potential employees on the dairy farm. To a large part this refers to the work environment
7	Community	Advisors, employees, family members, bankers, friends, colleagues, veterinarians and salesmen
8	Outcome	Good care, meaning a learning and tinkering process aiming for a viable dairy farm, where "viable" is defined by the farmer or the farm leadership

describe the activity under investigation. The second step refers to asking the "why" motive behind the activity. The third step refers to identify the actors/subjects who perform the activity in the first step. The fourth step refers to identifying the main mediating artefact and the tools that mediate this activity. The fifth step clarifies the rules that constrain and regulate the activity. The sixth step tries to grasp and describe how labour is divided and distributed among the actors/subjects who participate within the activity system. The seventh step refers to explaining the community of actors involved in the activity.

Applying the activity system on a dairy farm made continually ongoing work, including collaboration and other influencing factors on the farm, more visible, highlighting the activity within the whole system. The *activity,* in this paper was managing a dairy farm using AMS from the perspective of care. Good care for the dairy farm business was regarded as the *outcome* of the activity system, where *good care* meant a learning process aiming to create a viable (defined by the farmer or the farmer leadership) dairy business, which in turn motivated (the *objective*) the farmer. The *subject* of the system was the individual farmer (or the farm business leadership), who interacted with several *tools*, of which the milking robot was the *main mediating digital artefact,* together with additional tools and instruments, and psychological tools such as a stockperson's eye, to manage dairy production. The main *object* in the activity system was the cow herd consisting of individual cows. Many implicit and explicit *rules*, norms, and procedures are relevant in the case at hand, e.g., safety and animal welfare legislation and other work-related rules, routines, norms, and practices that regulate the use of AMS on the dairy farm and cow care. The *division of labour* in the case referred to the distribution of responsibility of the work in relation to milk production between the farmer or farm leadership, the farmer's family members, and potential stockpersons and/or employees at the dairy farm. The *community* considered in this study was limited, but advisors, bankers, friends, colleagues, veterinarians, salesmen etc. could be a part of the community in this kind of activity system (Table 2).

One of the research questions posed in this study was "What kinds of success factors and management challenges do farmers experience with AMS usage?" The outcomes identified were mapped out onto the focal points of the underlying activity system. Below we present more detailed findings for each focal point, starting with the farmer's objective and general reflections on AMS usage. One central issue addressed was the work environment, under the focal points of *rules* and *division of labour*.

4.1.1. The farmers' objectives and general reflections on AMS usage

In total, 293 responses to the questionnaire were obtained. In order to study the whole milking system on the farm, only answers from those who defined themselves as owners are presented here. Those comprised 207 owners (61% male, 39% female; 50% Delaval (www.delaval.com/), 48% Lely (www.lely.com), 2% SAC (www.sac.dk). According to official Swedish statistics covering 77% of Swedish cows, there were 735 dairy companies with AMS 2021 (Växa, 2021). Following dropouts because of few questions answered, answers were analysed for 188 respondents, of which 154 also had prior experience of CMS. The results from the questionnaire were grouped into owners with experience of both CMS and AMS (n = 154) and all owners (n = 188). The age distribution was: 3% < 31 years, 13% aged 31–40 years, 34% aged 41–50 years, 35% aged 51–60 years of age, and 15% aged 61–70 years. The respondents had the following distribution of numbers of cows: 3% of the farms had <50 cows; 48% of the farms had 51-100 cows; 28% of the farms had 101-150 cows; 10% of the farms had 151-200 cows; 7% of the farms had 201-300 cows; 3% of the farms had 301-400 cows and finally 1% of the farms had 401-500 cows.

45% of the farms had only one robot. 32% of the farms had two robots, and the rest had more than two robots. Most commonly, there were 51–60 cows per robot (44% of farms), but 14% had a maximum of 50 cows per robot, 36% had a range of 61–70, and 6% had more than 71 cows per robot. Most farms had free cow traffic (62%), conventional production (70%) and at least one employee (83%). The interviewed farmers fitted the descriptions in Table 1.

The overall picture from analysis of the data obtained in interviews, the questionnaire and field visits was that most farmers were positive to AMS usage and deployment of new technology in general. In the questionnaire, some respondents queried the robustness and functionality of the new technology or claimed that it is too expensive, and some had ethical concerns. This ethical concern considered, what he experienced as a focus on technology instead of animals. Two of the farmers interviewed were quite critical of AMS usage. One had returned to CMS and the other was winding down the business due to staffing problems. In the questionnaire responses, more than 90% of owners with experience from both CMS and AMS agreed, in part that introduction of AMS had brought major differences in daily work, primarily with positive changes, and that their work satisfaction had increased (Fig. 2).

None of the farmers interviewed mentioned income or profitability and just a few mentioned time saving as main reasons for introduction of AMS. In fact, some farmers reported that running and servicing the AMS was expensive and that they do not work any less with AMS. However, almost 90% of the questionnaire respondents with experience of both CMS and AMS reported that time spent per cow decreased with AMS, at least to some extent. In addition, more than half of the respondents who answered the question thought that AMS increased profitability, and 70% had seen an increase, at least to some extent, in milk production per cow (Fig. 3).

The questionnaire did not ask about motives for implementing AMS. Instead, it asked an open question about the greatest advantages with AMS. In the replies, 58% of the respondents mentioned flexibility, 41% mentioned improved work environment and less physical strain, and

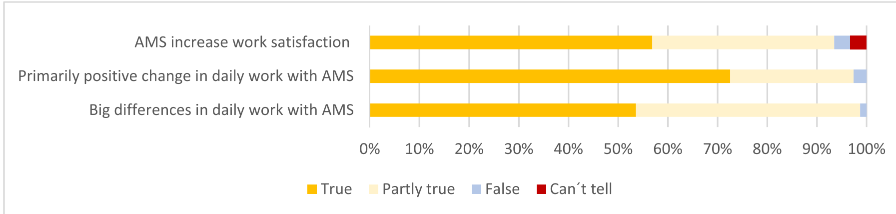

Fig. 2. Differences in daily work and work satisfaction after changing to an automated milking system (AMS) according to owners (n = 154) with experience of both AMS and conventional milking systems (CMS).

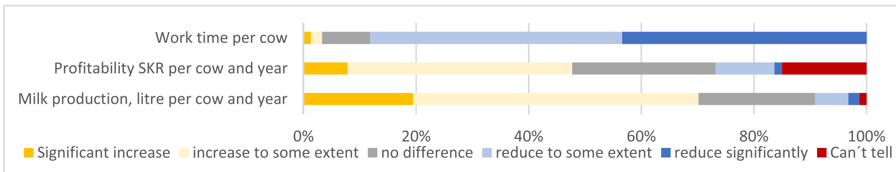

Fig. 3. Differences in profitability, working hours and milk production per cow between conventional and automated milking systems (CMS and AMS), according to owners (n = 154) with experience of both systems.

26% mentioned improved animal health. A few also mentioned interest in robot data, decreased working time, increased milk production, more joy in work, more time for the animals, easier to find staff and improved udder health. When asked why they had invested in AMS, the farmers interviewed gave several reasons. One said that the choice was either AMS or no dairy cows at all, for his own health: "*I want to be able … I don't want to hobble around on new hip joints … my knees must work … I want to be a human being*". Improved flexibility was mentioned by others, possibly including flexibility in private life as robots make it possible to stop work early now and then. Having AMS also lowers the dependency on hired labour. One farmer said: "*If all the staff leave … I can still keep going here for a while*". Some farmers interviewed described AMS as a strategy to attract employees with higher competence.

In the beginning of the AMS era, such systems often had lower production than conventional systems in Sweden (Bergman and Rabinowicz (2013), which is not the case today (https://www.vxa.se/fakta/styrning-och-rutiner/mer-om-mjolk/). One of the advisors explained this as follows: "*Now dairy farmers who are interested in the animals have started to buy robots … in the start it was only the tech freaks who didn't like cows … bit of an exaggeration … but they're still living creatures … and they must come in calf in time and be taken care of.*"

4.1.2. Cows as object

Animal welfare legislation sets rules for dairy production and care of individual cows, but this was beyond the scope of this study. However, AMS usage entails changes for the cows, with the nature of these changes depending on the previous and current system. The changes include increased demands on physical conformation of the cows, such as the shape of the udder and the teats, and the distance between udder and floor. If the cow's appearance does not fit the robot, this could be a problem when milking and the cow will sooner or later be replaced. In cowsheds with free cow traffic, the cow has greater control over her daily life. The stockperson influences the cow's needs by implementing a feeding strategy to attract her to behave in a certain way. Instead of being driven to be milked two or three times a day or standing in her own stall and being milked and fed without doing anything, the cow must choose to walk to the robot.

In systems with guided cow traffic, the possibility for the cow to take responsibility and decide for herself is more limited by smart gates steering her way through the cowshed, but she must still walk to the robot. If not, sooner or later she will appear as a catch cow (or fetch cow, push cow) in the robot system and then be driven or helped to be milked. A majority of the farmers interviewed reported there was always some cow or cows who needed help or must be driven to the robot.

High-ranking cows can be a problem for lower-ranking cows by impeding their access to the robot. According to one company representative; "*some* [cows] *are incredibly dominant and stubborn and refuse to let the other cows pass, so they risk disrupting the whole traffic*". In some cases, farmers mentioned keeping cows with different problems (e.g. udders that did not fit the robot or cows posing a threat to other cows or stockpersons) in another cowshed with CMS. On a dairy farm with both AMS and CMS with a rotary milking parlour, the strategy was to let all heifers calve in the AMS and keep all cows in the CMS. According to the farmer, that resulted in 10 kg more milk per heifer in the AMS compared with heifers in the CMS from the beginning. The farmer attributed this to three instead of two milking occasions per individual in the AMS and a more peaceful environment. If the cow accepts and learns to be milked by the robot, the robot "behaves" more predictably from one occasion to another than CMS operated by different persons.

4.1.3. AMS as a tool – the milking robot as the main mediating artefact

In AMS, the primary mediating artefact is the milking robot, including the computerised system/software that collects, processes and presents the data from the robot. According to the farmers interviewed here, AMS have good functionality and their credibility has increased over the years. Some of the farmers thought that the robots nowadays are very reliable. One said: "*there is no tractor … nothing runs as well as our milking robots*".

A central issue in AMS usage is how to handle the cow traffic. A major challenge is to have highly productive cows visit the robot two to three times a day and then milk rapidly, without delay. The individual cow needs to find her own individual rhythm in order to use the robot optimally. Many cows per robot, slow-milking cows or dominant cows increase the vulnerability in the system. The number of cows per robot varied widely (from 45 to 75) between farms (see Table 1).

4.1.4. Rules - handling of milking robots, AMS data and alarms alter work practices

Implementation of AMS is a learning process among all involved, people and cows. It alters the work practices, comprising actions and interactions carried out when handling the milking robot. AMS companies or advisors could support farmers in the initial phase with implementing new strategies for functional cow traffic, feeding and robot data follow-ups. The AMS software provides a wide range of ratios and an advisor could support the farmer in creating a strategy for selecting ratios to investigate in more detail, and how often to assess each ratio. The results from the questionnaire showed that a majority of the respondents considered that the statements "AMS require more computer experience than expected" and "Much more time is spent sitting in front of the computer screen" were at least partly true (Fig. 4). Almost 90% reported that the AMS provided data that increased their knowledge of the individual cow (Fig. 4). However, one advisor said: "*there is a jungle of key data … so you need to boil these down to: It's important that you do this*!" Later on, other ratios can be more interesting.

One farmer said: *"Lely was really good at helping us with the lists we should check in the morning and those we should check at night"*. The same farmer remarked how valuable the robot data are: "*We identify sick cows really quickly … We have very few cadaver cows or cows that fall seriously ill …. . We are so good at using the lists that we often find cases of sickness before the cow has become really ill."* Another aspect, reported by an advisor, was that it is easy to spend too much time sitting by the computer. She said that routines are very important to avoid this, since: *"Otherwise you can easily spend all your time at the computer and cow care then takes place there"*. According to the questionnaire responses, one-third of respondents felt at least some mental stress concerning interpretation and/or setting up their AMS.

Measurements and collected data from the milking robot's software, *if interpreted correctly*, can mediate information and increase staff knowledge about the cows. Data and robot information were reported to be used as input for discussions and contributed to learning among staff. AT states that a tool comes fully into being only when being used. Knowing when to use the collected robot data and how to use these data, i.e., correctly interpret the figures presented and put them into context based on prior knowledge, is a crucial part of tool mediation. Robot data, when correctly interpreted, can signal problems or act as a good management reference. Some farmers interviewed claimed that when the AMS actually 'identifies' a sick cow, that cow should already have been discovered by humans walking in the herd. It should be emphasised that learning to interpret the collected data from the AMS is an interpretative sense-making process, in which prior knowledge and experience provide the frame of reference for reaching reasonable and sound outcomes. Hence, successful robot management also depends on proper actions taken, such as routines for taking care of the milking robot (washing, maintenance, service etc.) and selecting relevant data and being able to make credible interpretations.

Implementation of milking robots fostered new perceptions among the farmers. During one of the visits, the farmers suddenly stopped talking because she heard a signal from one of the robots that a cow needed help. On another farm visit, that farmer suddenly said: "*I can hear that the robot has problems … now I have to stop. My husband can't hear the noise, but I can*". This could be considered *tool-mediated hearing* (cf. Lundström and Lindblom, 2018 on the topic of *tool-mediated seeing*).

Continual milking round the clock is a prerequisite for AMS, since a stoppage in the milking system is critical. All farmers interviewed reported some stress in relation to alarms from the AMS, but differed in their possibilities to share responsibility for the alarms. "*I can't even go to the cinema without finding out, when I switch my phone back on, that it may have been ringing for an hour*". It is not easy to let employees take responsibility for alarms, since they work in daytime and are employed. One farmer had a rather interesting solution. "*We have learnt how to go on holiday … we travel as far as possible so we end up in another time zone … so we can have the night alarms and the like in the evening … we fly to the USA … there we can walk on the beach and milk cows*!". Of course they need a back-up person at home who can solve problems *in situ*, but the farmer claimed that many problems could be solved over the internet. Good routines for washing, maintenance, service etc. could minimise the alarms, but some will still be present. "*The technology works … but the problem with alarms differs … we can shut off a lot of things and manage, so we avoid alarms … and we decide a lot ourselves*". Nightly alarms caused at least some mental stress for 50% of the respondents and the rest reported insignificant or no stress. When responsible for the AMS all the time, approximately half of the respondents reported stress concerning those issues, but only 10% reported significant mental stress (Fig. 5).

A great majority of respondents had experience of both CMS and AMS, and they considered that AMS increase udder health, animal welfare and cow comfort, at least to some extent (Fig. 6). One farmer reported that they learnt to wash the outside of the robot teat cups with hot water and washing-up liquid once a day, instead of just hot water, and suddenly milk quality considerably improved. This very small and certainly not high-tech or complicated intervention had a great impact: "*No new cases of mastitis*". Nobody had told the farmer about this intervention, he had to draw his own conclusions and learn.

4.1.5. Division of labour – shifting from milker to stockperson

On a small farm, the individual farmer must have competence in many areas. As the business grows, employees, partners or other family members can complement each other with different skills, competences and areas of interest, which can result in higher competence in different areas and less vulnerability. When the number of employees increases, the demand for better communication within the team also increases. The robot software is one such communication channel, where some or all personnel can interpret a cow as a catch-cow or make other decisions about the cows. One of the farms reported arranging a personnel meeting every week and had a designated Facebook group to improve communication. This farm had chosen AMS in order to retain their Swedish personnel, and the farm's stockperson was given much influence in planning the system from the very beginning.

The most obvious shift in division of labour with introduction of AMS seemed to be the change from milker to stockperson. An advisor commented: "*If you have a robot … you often have personnel with more training … or at least experienced personnel*". Hence, the stockperson needs a stockperson's eye, animal interest and skills to act appropriately.

Some farmers described AMS as a strategy to get Swedish staff, as this facilitates communication and mutual interchange of knowledge and experience. Farmers wanted long-term cooperation and stable solutions in order to make working hours more enjoyable. "*You know how it is with a good colleague … they lift you … you are happy about coming in to work and you become a better person yourself"*. The required competences were described as taking responsibility, having a stockperson's eye, thinking autonomously and acting on issues uncovered: "*The robot system is based more on making your own decisions and taking care of things yourself* (as employee) … *so you need a much higher level of basic knowledge compared with standing in a milking pit*".

One of the advisors interviewed summarised success factors for

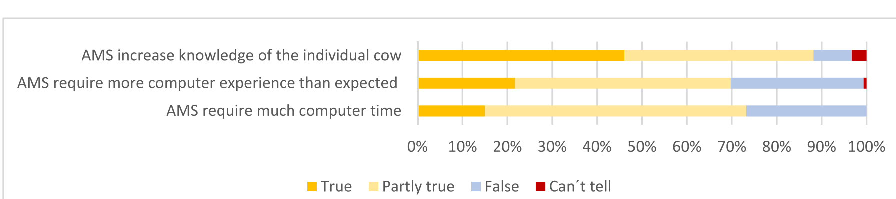

Fig. 4. Opinions on need for computer experience, computer time with an automated milking system (AMS) and increased knowledge concerning the individual cow, according to all owners, with and without experience of conventional milking systems (CMS) (n = 188).

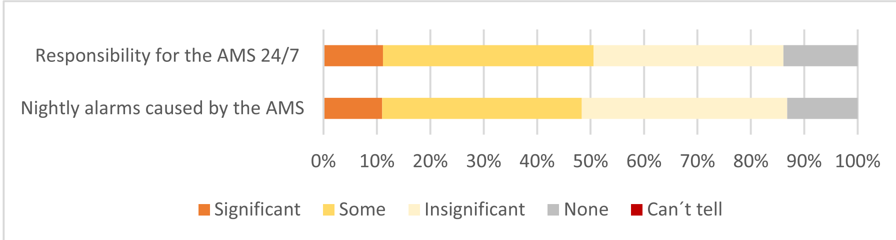

Fig. 5. Perceived mental stress in relation to alarms and full-time responsibility for the automated milking system (AMS) among all dairy farm owners (n = 188).

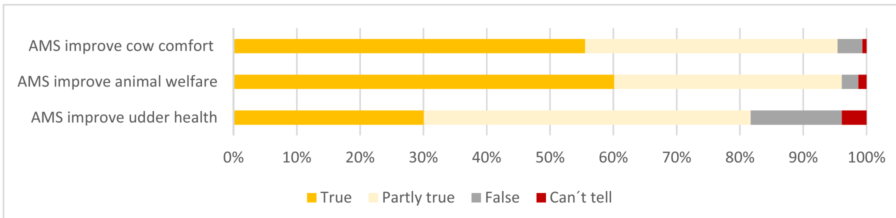

Fig. 6. Differences between conventional and automated milking systems (CMS and AMS) regarding cow comfort, animal welfare and udder health, according to owners (n = 154) with experience of both systems.

farmers in modern dairy production: "*They must keep up with developments but still not be the kind of person who goes for everything … I think they must be very interested in cows and cow comfort … I think actually that cow comfort is the most important thing for production … and they must also be very interested in feed production and they must be very good at managing their staff … There are very few of the small businesses left and those that can manage their staff well, I think, they'll be the winners in the future … So staff management, cow comfort and feed … I think that will take you a long way.*"

A topic of particular interest was farmers' perceived working environment when using AMS, which was considered an important part of social sustainability in this study.

4.1.6. *Outcome of AMS usage on work environment*

More than 90% of respondents to the questionnaire agreed that a change from CMS to AMS decreased the physical strain on farmers, at least to some extent. For mental stress the picture was more varied. Approximately one-third had experienced an increase in mental stress, one-third had experienced a decrease, and the remaining one-third experienced no difference between AMS and CMS (Fig. 7).

Mental stress could have different causes. One of the open questions in the questionnaire was about the greatest challenges with AMS. The most common challenge reported (25% of respondents) concerned the robustness and operational reliability of the robots. The second most common challenge was managing cow traffic and the related feeding strategy (20%). The responses to questions grading stress-related issues reinforced the earlier answers, with 26% of respondents reporting significant stress in relation to AMS vulnerability and risk of downtime and 68% at least some stress in this regard. However, 15% reported significant stress concerning the AMS's operational reliability and 36% at least some kind of stress (Fig. 8).

The farmers had different kinds of agreements with robot companies for service and repairs. The interviews showed that relations with representatives of the robot companies were very important. One farmer said that they were the first to have AMS in their neighbourhood, in 2008. An important reason for choosing AMS, and DeLaval as the supplier, was personal contact with a representative from DeLaval, who helped them. If that representative had sold another brand, the farm would have bought that instead. "*It's about personal chemistry and trust*". Relations with AMS companies caused at least some stress among 25% of the respondents, while the corresponding figure for stress caused by maintenance and service of the AMS was 34% (Fig. 8).

Finally, the respondents were asked some questions about the social situation in their business. More than 95% reported enjoying their work and more than 80% felt good in their current work situation (Fig. 9). Despite this high percentage of satisfied owners, many reported having some problems. Almost 80% believed they worked too much and approximately 50% felt stressed because of their workload and had some kind of physical problems caused by the work (Fig. 10). Almost 25% felt stress concerning the financial situation in the business. [It is worth noting that number of responses to these questions varied quite widely.]

4.1.7. *Community – focusing on advisory inputs*

The community consisted of the farmer(s), employees, the bank, advisors, sellers, vets, colleagues and others connected to the farm and providing information, knowledge or other input influencing the subject, object or tools. When a dairy farm shifts to AMS, the community must learn new strategies and activities, literally simultaneously as they are created. There is actually no competent teacher in that specific system, although advisors, vets or others with experience from similar systems can support the learning process on the farm. At the end of the day, the new social-technical system, with people, animals, technology and structures, must all adapt, or be adapted, to the local prerequisites (Fig. 12).

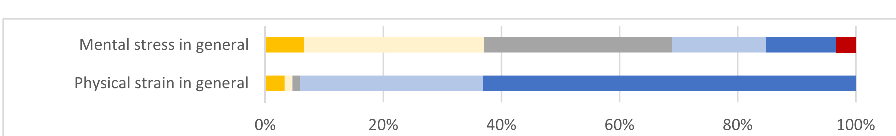

Fig. 7. Changes in mental stress, physical strain and injury risk with animal handling when changing from conventional milking system (CMS) to automated milking system (AMS), according to owners (n = 154) with experience of both systems.

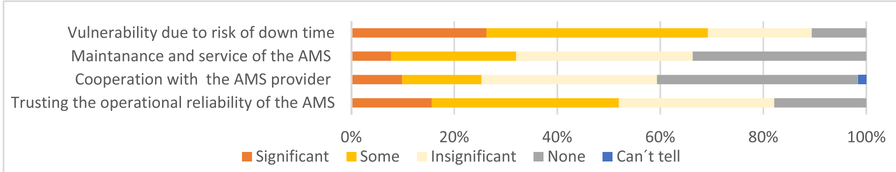

Fig. 8. Perceived mental stress in relation to vulnerability for downtime, operational reliability, cooperation with automated milking system (AMS) retailers, and maintenance and service of the AMS among all owners, with and without experience of conventional milking systems (CMS) (n = 188).

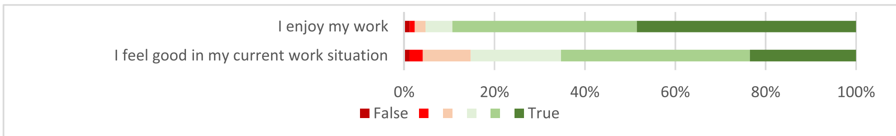

Fig. 9. Owner's opinions concerning their work situation (n = 170).

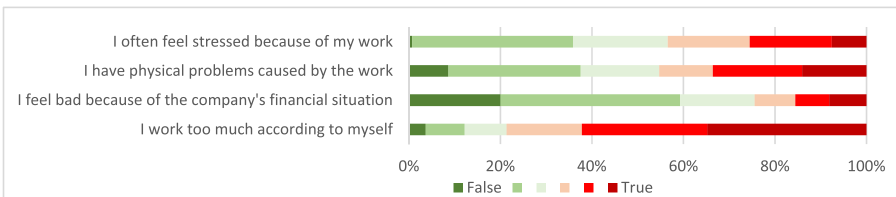

Fig. 10. Owner's opinions concerning stress (n = 145), physical problems (n = 128), financial situation (n = 135) and amount of work ((n = 165).

The respondents to the questionnaire were quite satisfied with the advisory services they bought and a majority bought feed advice. Concerning AMS data handling, there was a gap between bought advisory services and need for support. Approximately 50% of the farmers reported needing more support to improve AMS data usage. However, less than 40% bought some kind of advisory service from AMS companies and less than 30% reported that they discuss AMS settings with their production advisor (Fig. 11).

Advisors could be an important part of the farm community, but not all farmers paid for advisory services on milk production. One farmer said that they wanted to focus more on their family life, and did not have the time to change their work practices and learn. "*We have what we need financially and we don't need anything more complicated than that … we haven't time just now*". Some of the farmers were critical of advisory service quality. One struggled to change the advisory concept that the local firm offered and one bought advisory services from abroad. Some of the farmers were very goal-oriented, wanted continual learning in order to improve their production and claimed that they could not find what they were looking for in Sweden. Some claimed that Swedish dairy advisors concentrate on small and middle-sized farms, leaving the largest and maybe most up-front farmers to develop their production and business on their own: "*The best farmers are driving development*".

Networks of other farmers or colleagues were important for all farmers interviewed. One said that with the telephone, Facebook and YouTube, colleagues are never far away. One of the interviewed farmers described with great satisfaction groups organised by advisors, where farmers regularly exchange experiences and data on their production. In a few other cases, farmers had organised such groups by themselves.

One advisor mentioned that the bank often wanted the farmer to have as many animals as possible in the herd. "*You think this will bring in a lot of money … but that's not always the case*". She claimed that different farmers can handle different amounts of cows per robot "*It depends partly on the farmer and partly on how much they trim the system … how much they're involved*". The goal is to find an optimal number of cows in the specific herd, with the specific staff. There is no point in having more cows without getting more milk. One of the farms had 70 cows per robot and one of their robots milked around 2850 L per day, among the best in Europe. However, another farmer had 50 cows per robot and said: "*We believe that the robots should have a bit of free time … at the start we ran them at the limit and then we had more sick cows … those that don't compete as well, they … fall through … so better with slightly fewer cows … then they milk more and feel better*". That farmer had worked a lot on streamlining the production, but increasing the number of cows per robot was not an option. When they built a new cowshed, production increased: "*There was more space, so the cows were healthier and had better feet … an extra milking … feed all the time and … yes most was positive for the cows … and they thanked us by producing more milk*".

To summarise, this section analysed the data and defined and

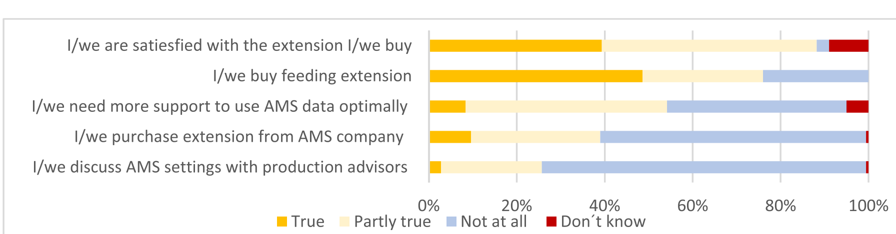

Fig. 11. Questions concerning purchased extension, automated milking system (AMS) support and need for additional support among all owners, with and without experience of conventional milking systems (CMS) (n = 188).

Fig. 12. Images from the field visits.

characterised the elements of the Activity System model. The bigger picture, about the interrelations between the components and the learning dimension within the AMS from a care perspective, is presented in the next section.

4.2. *Care practices - the outcome in the activity system*

In order to improve *care* and increase the viability of the farm, the individual farmer needs to have the motivation to learn, act and reflect. Learning can thus be considered a practice situated in a social-cultural context (Lave and Wenger, 1991). This learning practice is mediated by individual incentives and involves knowledge, tools and other resources. The activity on the dairy farm and the outcome can be considered two sides of the care component, more or less under continuous learning and improvement. Thus, an ongoing care activity is based on attentiveness, responsiveness, knowledge, and relations (Krzywoszynska, 2015) that keep the whole socio-technical system running and becoming. Care help us consider AMS usage as a dynamic, changing and emerging practice, difficult to predict. We used the Activity System model to highlight the developmental transformations involved when re-organising and re-mediating the current care activity at the local farm based on the contradictions that arise on shifting from CMS to AMS. Resolution of these contradictions could be considered a developmental cycle in running a dairy farm.

4.2.1. *Two different activity systems for cultivating care*

As seen in section 4.1, changing a dairy system from CMS to AMS results in contradictions (problems, challenges or benefits) in many parts of the system. The majority of farmers reported that the benefits outweighed the problems when changing from CMS to AMS, but a broad range of new ways of care needed to be developed. We identified three major contradictions when changing system from CMS to AMS: i) ongoing milking round the clock, ii) cow traffic and related strategies, and iii) care accomplished by combining robot data with a stockperson's eye. Although these contradictions only had an impact on certain areas of the Activity System model (Fig. 13), the model should be considered as a web where changes in one entity result in changes being distributed across the whole system.

The *first contradiction* is that milking goes from being a task performed twice or three times a day to an operation that runs continually. The impact on the physical and mental work environment on study farms, as discussed in sub-section 4.1.6, included both positive and negative changes. However, milking 24/7 means that milking are especially vulnerable to problems with the AMS, since a robot can only milk one cow at a time and, with a full schedule for the robot, there is little space available for recouping lost time. Dairy cows are sensitive to irregular milking, which can result in decreased milk production and, on longer time horizons, health issues. Thus, the AMS must not be interrupted or, if interrupted, must be re-started quickly. Therefore, it is important that the farmer develops good routines, has the AMS serviced regularly and reacts quickly to alarms.

The *second contradiction* with introduction of AMS is how to manage the cow traffic. Either cows move as they wish in the cowshed (free cow traffic) or there is a gate system that steers cow movements. A critical influencer of cow traffic is the feeding strategy, which should tempt the cow to visit the robot. Regardless of the system used, voluntary milk visits are essential in order to use AMS capacity effectively. To maintain high production, each cow must be milked two or three times a day. Thus, a major challenge is to have cows with udders that fit the robot and that are also highly productive and voluntarily visit the robot two to three times a day, milking fast without delay.

The *third* and most important *contradiction* in care of an AMS farm concerns the change from looking at every cow and touching every udder to letting the robot do the milking and making use of robot data, in combination with a stockperson's eye, in order to develop good care. First, decisions must be made concerning what data to look at and when, and how to interpret these data, in order to provide good care. The digital robot software can provide much data, but cannot measure cow health directly. Hence, a person needs to interpret the information from the software and relate the information to prior experience and acquired knowledge, as well as having first-hand contact with the cows. Therefore a stockperson's eye is still needed in AMS (Fig. 14). When robots have

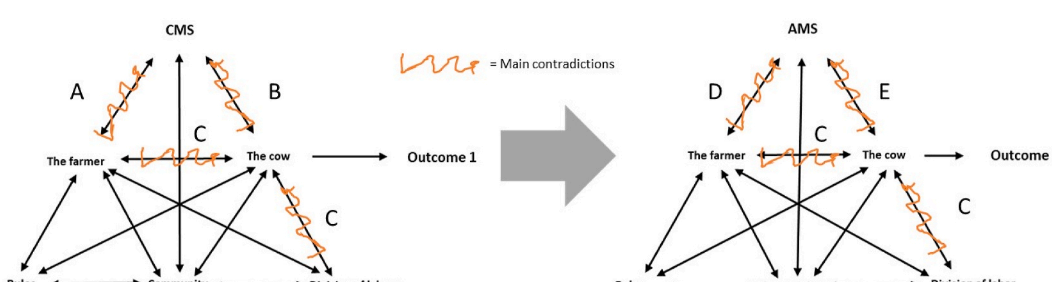

Fig. 13. A change in dairy system from conventional (CMS) to automated milking (AMS) requires adaptation, learning and thus a change in care. Contradictions could be problems, challenges or potential for change. Identified contradictions depicted in the Activity System model are: A) Physical strain, B) limited access to cow data, C) stockperson's eye, D) milking 24/7 and use and interpretation of robot data, and E) cow traffic and related issues. It should be emphasised that the contradictions are present between the same entities in CMS and AMS, but the content of the contradictions differs.

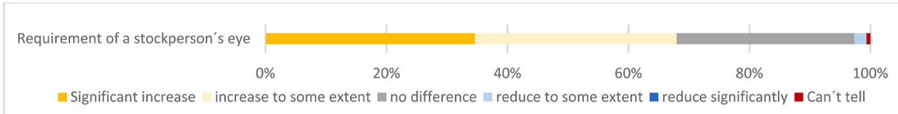

Fig. 14. In requirements for a stockperson's eye after change from conventional to automated milking systems (CMS and AMS), according to owners (n = 154) with experience of both systems.

taken over the milking, time and space for development and use of a stockperson's eye must be incorporated in other kinds of daily work or by spending time in the herd, to complement the available robot data.

According to one of the advisors interviewed, "(AMS) *actually needs a better stockperson's eye*". That was confirmed in the questionnaire, where almost 70% reported a greater need for a stockperson's eye to some extent on changing from CMS to AMS (Fig. 14). Just a few percent believed that this requirement decreased to some extent when implementing AMS. One farmer expressed it like this: "*The robot system works really well if you want to be half a day too late all the time … because all facts are based on the cow having visited a feed station or a robot … that's where it transmits all information on the amount of milk it produces, or how much it weighs or how much it eats … a sick cow doesn't go to the feeding station, a sick cow doesn't go to get milked … so you don't react until it's too late*!"

Accordingly, robot data alone are not sufficient for provision of good care, while the same is true for a stockperson's eye alone. In Fig. 15, the AT lens is applied to two Activity System models based on two different mediating artefacts: robot data and a stockperson's eye. It is clear that neither kind of care is good enough on its own, rather both kinds are needed. Another farmers said: "*"You can't gauge the general condition of the cow from data"*, and continued: *" … when you enter a robot system you have to have that feeling that something might be wrong … go up and check, temperature … then you can react early and prevent the cow from getting very sick"*. One of the farmers interviewed claimed that the robot is a decision support system, meaning that one cannot depend on the technology alone to obtain a good result, but it can certainly support and act as a good check-up tool (Fig. 16).

With many cows in the herd, it is difficult for the stockperson to recognise all individuals. However, one farmer said: "*We spend much more time on the animals now* [compared with CMS], *we don't need to talk to each individual cow … and each individual might not want to talk to us … and they are very clear about that … but we have one who always wants to engage and help … and who comes and tells you in the morning if something has happened … she runs over and stands there by the gate … then you know there is a calf on the floor or something*". This farmer did not recognise all the individual cows in the herd, but she did recognise the very social cows. Likewise, she and others recognised cows repeatedly listed as catch cows. Thus, relations between the stockperson and cows within a herd depend much on the individuals (both cows and humans). Catch-cows are reported by the robot and identified by the cow's unique number. Cows that want to be scratched or stroked or that want to 'tell' the stockperson something try to communicate with the stockperson, and the stockperson must be attentive and have the competence to interpret and respond adequately to the cows' behaviour. This demands relations between humans and non-humans, in examples of mutual care. For stockpersons with a poor or limited eye for stock, such relations will not be developed. As one of the farmers stated: *"Not everyone has it"*. Unfortunately, those who don't have it won't miss it, or will find it difficult to develop.

4.2.2. Requirement of care competence among advisors

Advisors also need experience and a stockperson's eye. In one interesting example, a farmer talked about a very competent foreign advisor who wanted to see the wholeness and started the visit with approximately 1 h by himself in the cowshed. "*How the cows are, and the like … that gives him an idea of whether it's working … or not working. He doesn't need to see any figures and things … he sees that in the cowshed … how many are lying, how many are ruminating, what the manure looks like … the coat … that gives him a feeling for when things aren't right … … then he starts to check the data … milk yield, feed, diseases and the like"*. This is an example of a person first using his attentiveness, experience and knowledge to provide advice concerning care for dairy cows. Later, different sources of robot data are used as input to the discussions, which also requires theoretical knowledge, to support the farmer in a broad range of topics.

One advisor said that she started with a university degree in agriculture and then worked for eight years in practice in Sweden and abroad. "*Then I changed sides.*" She commented that she had gained experience both from dairy production and from being the farmer in an advisor-farmer relation: "*Piecemeal advice is not good!*" but "*it's difficult to cover everything*".

Automated milking systems, or other systems that provide a lot of data (Dela Rue et al., 2019), change farmers' need for support. Data that were previously handled, interpreted and presented to the farmer by advisors are now produced, interpreted and available on the farm. This changes the role and possibly the power relation between advisor and farmer.

One farmer made a comparison between crop production and dairy production advisors. "*I would say that crop production and economics are easier than the production side …* [milk production] *is tricky … many crop*

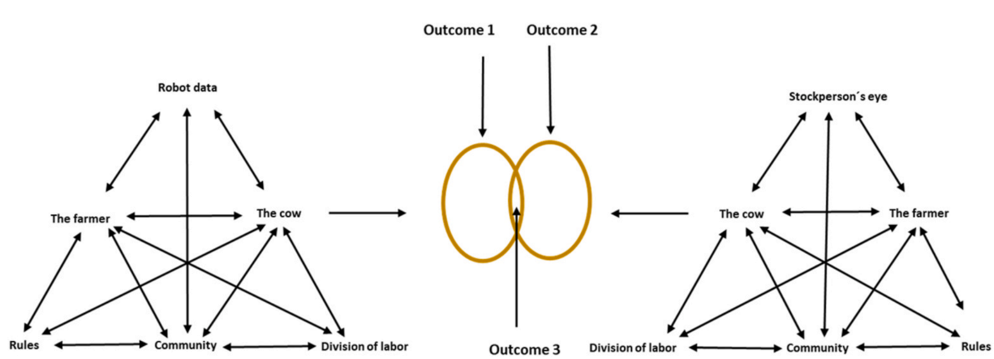

Fig. 15. Two interactive Activity System models applied to different mediating tools, robot data and stockperson's eye, resulting in two different kinds of care outcome: (1) Care based on robot data and (2) care based on a stockperson's assessment. Outcome 3, care based on both systems, would give the best results. (Based on Engeström (2001), p. 136).

Fig. 16. Images of cows from the field visits.

advisors have their own farm, and grow crops and test products … so even it if it is at hobby level, they are passionate about their work … but there are no young women who work as production advisors and run their own dairy farm". Thus, first-hand experience-based competence must come through their work as an advisor, so 1) farmers play a central role in educating advisors; and 2) it is easier to start an advisory career with interventions and support related to some kind of robot data or control. Another farmer expressed it thus: "*Unfortunately today there are many very young* [advisors] *with little experience from their own farm … so you have to sit and teach the advisor about a lot of things … and pay 900 Krona an hour for that*".

To summarise, care in dairy farming is a complex matter. As one farmer said concerning what it takes to be a successful dairy farmer: "*It's quite complex to run a farm like this. You have to go to school and learn things … you have to think that it's interesting to calculate and see connections here and there … many think that you're only a farmer, but it's not that easy, you have to be an all-rounder and know a lot … you have to be an economist and a stockman, handle technology … you should also have a social network … to cope … to ring for help*". New care processes need to be developed for everyone involved, humans and non-humans in an ongoing learning process. This care encompasses robot data, which are used as input for making proper decisions on results to check at different intervals and in interpretation of viewed data, to plan feeding strategy and cow traffic, teach cows how to be milked, choose regular intervals of service for the AMS, handle alarms, find staff and advisors if needed and finally combine information from robot software or other devices with a stockperson's eye, in order to provide as good conditions for the cows as possible.

5. Discussion

The care perspective applied in this study to robot milking is opposed to the dominant technology-oriented view on agricultural production, commonly referred under labels like smart farming, digital agriculture and agriculture 4.0 (e.g. Ayre et al., 2019; Clay et al., 2020; Finstad et al., 2021; Klerkx et al., 2019; Lioutas et al., 2019; Rijswijk et al., 2021). Applying the care perspective emphasised the need to use a systemic perspective in farming, which were stated by, for instance, Darnhofer (2021), Klerkx et al. (2019) and Rijswijk et al. (2021). Using the perspective of care, considers the interdependencies between farmers and the technologies in robot milking (Finstad et al., 2021; Rijswijk et al., 2021), because AMS provides meaning only when it is enrolled in its work practices (Suchman, 2007). Applying the socio-technical perspective to dairy farming implies that the AMS is dependent on the farmer's work practice in which it will be implemented and used in such a way that it shapes the nature of the work practices of running a dairy farm (Finstad et al., 2021; Rijswijk et al., 2021). We applied the care perspective because of its criticism of the technocratic and productivist paradigm (Puig de la Bellacasa, 2017), where care is characterised as the result of all practices that make technology and knowledge work, considering care as a patterning of activities.

The aim to study Swedish farmers' experiences and reflections from the perspective of care in dairy farming using AMS was examined here based on two research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

We used AT to enable a more structured approach to investigating and analysing care in the socio-technical system of AMS in dairy farming. The focus in AT on studying contradictions during technology mediation also provided insights for learning and development when shifting from CMS to AMS, aspects well-aligned with care.

The majority of farmers who participated in the study saw more advantages than disadvantages with AMS. A possible bias is that farmers who have made large investments in AMS might focus on the advantages. However, the obvious improvements in physical health and workload for the majority of the farmers, despite increased mental stress caused by frequent alarms, the increased profitability and milk production for most farms provide a positive picture of AMS in Swedish dairy production. However, farmers also reported poor service from the AMS companies, problems concerning the entire management on the farm and challenges to find competent employees as well as advisors.

The findings showed the importance of local adaptation. The main starting point was the interests, motives, knowledge and experience of those responsible for milk production. There was no general 'truth' concerning e.g. the optimal number of cows per milking robot. Some farmers preferred to intensify production by having many cows per robot, while others chose a lower number of cows per robot to increase cow health and cow comfort, thus increasing milk yield per cow. Variation in the number of cows per robot was also reported in a survey of Canadian dairy farms (range 27–72 cows per robot, median 52) (Tse et al., 2017). Different farmers have different motives and goals for their businesses, as long as they consider it viable. High milk production and profitability are not the only motives for a farmer, e.g. cow comfort, flexibility in work hours, work satisfaction etc. are other relevant motives.

5.1. *Contributions, challenges and need for an interest in animals and a stockperson's eye*

The most important finding of the study was the need for a stockperson's eye or a *professional vision* (Goodwin, 1994) regarding cows. Less surprising was the need for *tool-mediated seeing* (Goodwin and Goodwin, 1996), to choose and to use robot data in a value-creating way. Even though milking robots provide much data, the stockperson's eye cannot be replaced. Thus, *professional vision* and *enhanced professional vision* (Lundström and Lindblom, 2018) using robot data are needed in order to use AMS effectively. In this context, *tool-mediated seeing* (Goodwin and Goodwin, 1996) means being able to interpret credible robot data and apply the outcomes in care for cows. This study identified two examples of *tool-mediated hearing*, when a farmer could hear that the robot needed "help".

On implementing AMS, farmers working with robot data enter a continuous learning process, in which they start to recognise what data to focus on and learn how to apply and use it in practice to manage the individual cow and the herd. This means that farmers develop *tool-mediated seeing* in order to improve their *professional vision* (Goodwin, 1994). The experienced farmer's combined *professional vision* and *tool-mediated seeing* emerge from the process of learning to choose, interpret and correctly use data from computerised technology like AMS, which we call *enhanced professional vision* (Lundström and Lindblom, 2018). To be successful in dairy production, farmers need to adapt their practice and technology to the local situation, thus improving their *care*, where care is the sum of all practices that make technology and knowledge work (Krzywoszynska, 2015).

Another way to express this is that AMS is not for high-tech farmers, but for cow farmers (Driessen and Heutinck, 2015). This was obvious from the responses in interviews and to the questionnaire, and has also been mentioned by others (Butler et al., 2012). The robot technology can be used as an expert system, a decision support system (Lindblom et al., 2017) or for check-ups. Our results show that AMS technology cannot supersede human experience and a stockperson's eye in providing good care in milk production. To use AMS effectively, farmers also need to develop their *enhanced professional vision* (Lundström and Lindblom, 2018) to choose and interpret robot data in specific situations in an on-going learning process. Consequently, good care in AMS dairy production must be based on AMS data and on interest in animals and a stockperson's eye. This applies to the farmer, the stockperson and the advisor. The challenge for educators and the dairy industry is to facilitate more systemic training of future farm staff and dairy production advisors.

There are training opportunities available for people working with cows concerning the skill to read cow behaviour. For example, Växa Sverige, the largest advisory service company for dairy production in Sweden, educates animal handlers in reading so-called cow signals, i.e. how to interpret cow behaviour (https://www.vxa.se/). However, reading cow signals is a rather technical description concerning cow behaviour, which needs to be recognised and then interpreted and acted accurately upon. In order to interpret the signals from cows, the individual needs attentiveness, experience and knowledge of cows, which are the key elements in the care perspective.

The care perspective builds on the ethics of care (Gilligan, 1977) as a relational matter, i.e. not as acting on, but rather living with (Puig de la Bellacasa, 2017). Care ethics do not build on roles and moral principles, but on interdependent, contextual relations in practice, in the vicinity, in relations where people have or take responsibility (Puig de la Bellacasa, 2017). Instead of rules or moralities, care ethics build on compassion, sympathy, relations and mutual dependency (Lonkila, 2021; Puig de la Bellacasa, 2017), creating good solutions in practice within a local situation (Mol et al., 2010). To care is to be in a relationship with humans, non-humans and/or natural settings, and continually develop relevant patterning of activities.

In the technological fix approach (Black, 2000), which is well-aligned with the dominant technology-oriented view on agricultural production, some challenges persist. In our view, there is a lack of ongoing discussion concerning the requirements for establishing good relations built on mutual dependency between the user of technology and the non-human or natural setting in which the technology facilitates action in order to deliver good care. The possibilities to build (mutual) good relations through a filter of technology, i.e. by *tool-mediated seeing*, are currently limited. On the contrary, there is a risk of the rapid and recent implementation of technology increasing the distance between humans, non-humans and natural settings that they act upon. According to AT, the tools used, i.e., AMS as the main mediating artefact, should not be viewed as an interaction device between the farmer (subject) and the cows (object). Rather, the interaction with cows is *mediated* by the AMS. Consequently, the use of technology increases the need for alternative strategies for creating *mediating* relations. Based on our findings, a relation-creating strategy with AMS might be spending time within the herd, and systematically observing the cows. It is possible to use AMS without other forms of relation creation, but the result will not be very satisfactory, as is obvious from the results in this study. Since the experienced dairy farmer with a good stockperson's eye knows the importance of contact with individual cows (i.e. relation creation), they develop strategies to achieve this.

Using care as a perspective forced us to think of mutual dependences and relations to humans, non-humans or natural settings in the case of AMS. Use of technology also increases the need for new relation-creating strategies among decision makers with responsibility for strategic decisions, who must have an understanding of the importance of reciprocal relationships. As Mol et al. (2010: p 15) state: "*Technologies …. do not work or fail in and of themselves. Rather, they depend on care work*". Without understanding and insights into the dependence on relationships with humans, non-humans and natural settings, it is easy to overlook the fact that performed measures are necessary, but not sufficient, to cultivate good care. AMS is a very clear example of connections that exist everywhere, but are not always noticed. AMS is an animal-dependent operation using technology, but cows are high-value individuals with possibilities to live long lives. Cow comfort or a holistic view on the dairy system is important to achieve business viability. Dairy farmers often have a great interest in animals and a stockperson's eye, and thus understand the value of human-cow relations. The need for good care based on relations between humans, non-humans and natural settings also arises for instance in crop production. However, the connections and mutual dependencies are probably not as obvious as with cows in AMS. Cow comfort and soil health are interrelated by the holistic perspective, but the cow is much easier to recognise, acknowledge and relate to than the very small creatures in the soil. Cow comfort also has a direct and obvious influence on farm profitability, in both the long and short term, while soil health is much more elusive. Nevertheless, the care perspective shows that a relational approach towards non-humans and natural settings, based on attentiveness, experience and responsiveness, could be valuable in a broad range of agricultural topics. We are hopeful that the socio-technical systems approach to dairy farming with AMS will have additional attention, as recent publications within the field emphasise the need for studying the work practices from a systemic perspective (Darnhofer, 2020; Finstad et al., 2021; Rijswijk et al., 2021). We interpret recent attempts from what Rijswijk et al. (2021) call socio-cyber interactions and socio-physical interactions as a perspective of care.

5.2. Limitations

The scope of this study was narrow and there were some limitations that could have influenced the results. For example: i) No farmer with only one robot was interviewed, but single robot farmers was the dominating group among questionnaire respondents. ii) The interviewed farmers came from a limited area within Sweden. iii) The field visits were limited in scope due to the pandemic. iv) All results from the questionnaire are not reported in this paper. Finally, v) since there is no Swedish actor with statistics on all Swedish AMS farmers, we chose to use newsletters from the two dominating AMS companies and a Facebook group for AMS farmers to invite respondents to answer the questionnaire. Swedish farmers are well educated and due to an investigation 2021, 73% of all Swedish farmers used digital tools for communication and 87% have rather good or very good internet connection on their farms (lantbrukspanel_maj_2021_den-digitala-lantbrukaren.pdf (landshypotek.se). That was the main reason for us to use digital newsletters and Facebook to reach the farmers, even though we realised that it may have precluded some AMS farmers from answering the questionnaire. This strategy also, made it impossible to calculate a response rate. However, this study do not claim any generalisability, rather it has a descriptive approach. Despite these weaknesses in collection and analysis of the data, the results are interesting and provide deeper knowledge and insights into the socio-technical system of AMS in dairy production.

The purpose of using a mixed methods research design conducted via triangulation was to combine several sources of quantitative and qualitative data to reveal how care on dairy farms with AMS was manifested. This research design and analysis of the collected data is rather descriptive, and aims to provide initial step towards an increased understanding of how care is manifested as a socio-technical system of dairy farming via an AT lens. The AT lens was mainly due to the care perspective not having its own analytic method. The analysis was inspired by thematic analysis but constantly informed by AT and its focal points and their interrelatedness. However, there were trade-offs between the level of granularity for the analysis and the concepts included in the analysis due to the scope of the paper. Our main focus was on care as the main activity, and future work could go into much more detail about how the patterning of activities are realised in practice via the entities and basic principles in the AT framework at several farmers with AMS. The AT lens proved suitable for the analysis, and the Activity System model visualised the main contradictions within the socio-technical system of dairy farming. Using AT as a lens for studying care, including the Activity System model, forced us to pay attention to all entities in the model and interrelations that might otherwise have been neglected, as well as focusing on the learning and development perspective originating in the notion of contradictions. However, there were some limitations with the use of AT, e.g. it can be rather cumbersome to apply and, as in Rogers (2012), it was used here as a conceptual tool-making sense of a dairy domain rather than for offering ready-made answers. While AT is one of the most prominent approaches used for studying socio-technical systems, its success still relies on the analyst's skill in interpretation and orientation when analysing the collected data and relating these to AT concepts (Lindblom and Alenljung, 2020; Rogers, 2012). Therefore, it takes time to obtain an acceptable level of understanding and competence in using AT appropriately. However, the structure provided by the AT lens and the Activity System model offered a viable way to unravel several aspects of the care perspective.

5.3. Future work

This study suffered from limitations regarding the amount and duration of field visits on dairy farms with AMS. Future work should involve more extensive ethnographic studies with participatory observations on one or a couple of specific farms, in order to collect more in-depth data and gain further insights on care. Future work should also involve a deeper theoretical analysis of the relations between the care perspective and the entities and basic principles of the AT lens, in order to confirm that the approach used in this study can provide viable insights on how technology such as AMS is integrated into the work practices on the farm.

Some farmers reported mental stress in handling and interpreting robot data. Examination of farmers' digital work environment, by integration of knowledge and methods from Human-computer interaction (HCI), in particular from a user experience (UX) perspective, is one future need of research. In HCI, researchers study and evaluate the quality of interaction in a systematic way (ISO 9241–210:2019; Lindblom and Alenljung, 2020).

Future work could also apply the care perspective through an AT lens to other agricultural systems. If farming should be considered as: "*an ongoing and open process of transformation, involving manifold humans and nonhumans who are themselves conceptualised as processes connected to other processes.*" (Darnhofer, 2021, p. 15) and "*The aim is thus to identify and better understand how relations and constellations enable or impair transformation and change, how these relations are constantly made and remade, stabilised or undone*" (Darnhofer, 2021, p. 15). Then, the perspective of care, analysed with AT, would be a valuable tool and a possible way forward.

To conclude, the obtained contributions in this paper emphasise the need to consider the rapid increase of digitalisation in agriculture beyond the technocratic paradigm. In a similar vein as addressed in the emergence of Industry 5.0 (Longo et al., 2020), we want to highlight the need for a similar emerging Agriculture 5.0, which we view as taking more profound care perspective. Industry 5.0 is characterised as an approach that focuses on the symbiotic relationship between technology and humans as well as addressing the need for putting the farmers and their work practices, ethical issues, and value-based aspects back at the centre of attention.

6. Conclusions

By focusing on the ongoing transformation of actions that characterise handling of contradictions as expansive cycles of learning, application of an Activity System model to dairy farming revealed that the work practice of care is constantly evolving when using AMS. The activity of managing a dairy farm for producing milk is continual, and the alterations and modifications of the milking robot and its related tools change work practices, in turn re-shaping the tools used in dairy farm management.

6.1. Success factors and challenges in AMS

In successful dairy farming with AMS, willingness to learn, adapt to the local situation and continually improve practices seem to be the most important factors. This requires learning strategies for the farmer and strategies to get support from others, e.g. on feeding strategy, crop production, interpretation of data, cow comfort, service of technology etc. Conditions will differ depending on farm size and number of people involved. With more people involved, knowledge and competence could be differentiated. In that case, competent people who understand why things are done, are attentive and then act upon what they have found are needed. This study revealed the importance of experience and a stockperson's eye, in combination with *tool-mediated seeing*, for developing *enhanced professional vision* and good care in dairy farming. A good stockperson has broad competence, combining a systemic view of cow health and comfort, assessed using a stockperson's eye, and experience with robot data. Finding competent staff for AMS farms is a major challenge. Another challenge is finding advisors with experience and broad competence in AMS dairy production. Combining *robot-mediated seeing* with a stockperson's eye is demanding, but is an important component of achieving good care in AMS dairy production, whether farmer, stockperson or advisor.

6.2. Farmers' experience of work environment in AMS

Increased flexibility in work and better physical health appear to be important driving forces for implementing AMS. Handling alarms was mentally stressful for almost half of the respondents to the questionnaire. Other issues that caused mental stress were perceived AMS vulnerabilities. A questionnaire-based survey clearly showed that AMS had brought major, primarily positive, changes in daily work and increased work satisfaction for most farmers. More than 80% of the respondents reported feeling good in their work situation and enjoying their work.

Author statements

The authors declare no conflict of interest.

Declaration of competing interest

The authors declare that they have no known competing financial interests or relationships that have influenced the work reported in this paper.

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