Journal of Dairy Research

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DairyCare 'blueprint for action': husbandry for wellbeing

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Research Reflection

Cite this article: Knight CH (2020). DairyCare 'blueprint for action': husbandry for wellbeing. *Journal of Dairy Research* **87**(S1), 1–8. https://doi.org/10.1017/S0022029920000679

Received: 20 March 2020
Revised: 30 May 2020
Accepted: 1 June 2020
First published online: 4 August 2020

Keywords:
sensor technology; management; wellbeing

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Abstract

'*Keep calm and carry on*' was a wartime message to the British public that has achieved renewed fame in the last few years. The strategy was simple: in times of extreme difficulty a cool head combined with stoicism is an appropriate response to ensure a successful outcome. The latest major challenge to society (COVID-19) met with a very different response, and only history will reveal whether '*Stay home and worry*' will be equally effective. In devising blueprints or strategies it is extremely important to have a clear idea of what you are trying to achieve, whether it be maintaining world freedom or stopping a pandemic. In the case of livestock agriculture, it is helping to feed a rapidly growing global population in harmony with the needs of current and future generations. I hope that I have stated this clearly, and calmly. If so, I ask you to picture a scene. We are on a Calm Farm. Dairy animals go about their daily lives contented, unhurried and focused on the simple feeding and socialising activities that are so important to them. Unstressed, their productive capacities and abilities to avoid and, when necessary, cope with physiological and pathological challenges are maximised. They are not alone: the exact same characteristics also apply to the farmer and husbandry staff that we meet. How is this calm farming approach relevant to the aspirations we had when we established the EU COST Action DairyCare? Our objective was to harness the power of *computing* technologies to *assist* our *management* of dairy *livestock*. A simple rearrangement leads us to *Computing Assisted Livestock Management*, CALM. In this short Research Reflection I shall assess how far we have come towards the achievement of sensible goals related to technological assessment of dairy animal wellbeing, and speculate on what more things both can and need to be done to finish the job. It is a personal account. DairyCare was a major collaboration involving several hundred active researchers. To involve them all would be impossible, and I do not pretend to speak for them all. As will become evident, the wide skills base that was assembled was so successful in its primary objectives that different skills, chiefly in economics, are now needed to exploit all of the technological advance that has been achieved. DairyCare succeeded in a second direction. Whilst the focus was technology development, by assembling a large cohort of biologists with animal welfare interests, it soon became apparent that technology should run alongside and help to enable improved management practices. This Special Issue is, therefore, in two sections. The first is dedicated to technology development and the second to a novel management practice that has the potential to significantly improve the wellbeing of cows and calves: cow-calf contact rearing. That section is introduced by my DairyCare colleague, Sigrid Agenäs.

DairyCare
COST
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
Funded by the Horizon 2020 Framework Programme of the European Union
Hannah Dairy Research Foundation
CAMBRIDGE UNIVERSITY PRESS

Dairycare

In May 2011 I was fortunate enough to spend four weeks with colleagues and friends in Udine, Northern Italy. During that time we devised a strategy for accelerating the pace of health and welfare-related sensor technology development in dairy farming. We had realised that animal scientists had only a superficial knowledge of the major advances being made in computing technologies, whilst electronic engineers had a similarly superficial knowledge of animal physiology. The need, therefore, was to bring these disciplines together and encourage maximum cross-fertilisation. The vehicle for doing this was available: COST is an acronym for European Cooperation in Science and Technology, a funding organisation for the creation of research networks, called COST Actions. These networks offer an open space for collaboration among scientists across Europe (and beyond) and thereby give impetus to research advancements and innovation. Our application was submitted (COST is a bottom-up funding stream), revised and resubmitted and finally in 2014 COST Action FA1308 DairyCare commenced. Over the next four years we organised five major international Conferences with participants from 33 partner countries around the world, six focused workshops on specific health and welfare-related topics and forty Short Term Scientific Missions (researcher exchanges). Working Groups were established to focus on biomarker-based welfare monitoring, activity-based monitoring and systems level monitoring. Cross-disciplinarity was strongly encouraged, reinforced by the creation of Incubator Groups with funding to pursue specific focus areas, of

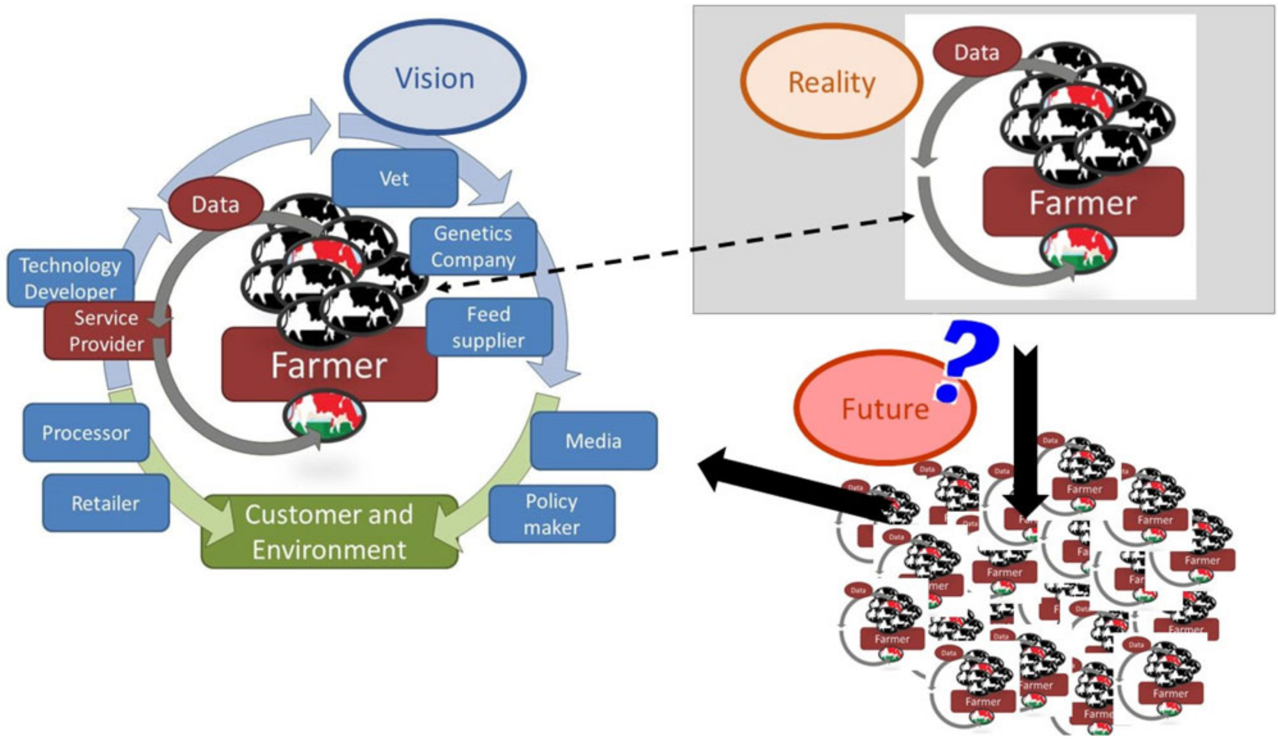

Fig. 1. The InfoConomy business model proposed by the DairyCare COST Action as a means of introducing welfare management technologies into widespread use (shown in Vision). This model contrasts with the current actual use of oestrous detection and related technologies (Reality) and the proposed use of Artificial Intelligence to increase technology use (Future). For more detail see Knight (2020) and ClearFarm (2020).

which small ruminant sensors, sensor validation and cow-calf management systems were examples (Agenäs, 2020). All of the major Conference outputs are now published as a collaboration with the Journal of Dairy Research (JDR Community, 2020) and other outcomes will be added.

The vision

In 2018, towards the end of its four year programme, DairyCare published the *Dairy InfoConomy* vision for utilisation of sensor technology ('the Vision' in Fig. 1). This envisaged a service provider placing appropriate technology onto farms and collecting data that informed the farmer of cows needing special attention and simultaneously used that data to inform businesses servicing the farmer as well as downstream stakeholders in the dairy foods chain, right through to consumers and policymakers. It is described in detail elsewhere (Knight, 2020). How far have we come towards that Vision?

Historical development of sensors for dairy animals

I can be very brief in this section, because the topic has been reviewed before. For a general appreciation of the subject, see Knight (2020) and for a detailed account of technologies that were available at the time of the DairyCare COST Action, see Caja *et al.* (2016). The following discussion is not in any way exhaustive.

Activity-based sensors

The key developments in activity monitoring were radiofrequency identification (RFID) and the tri-axial accelerometer which together enabled the increased activity that accompanied oestrous to be detected automatically in dairy cattle. This technology was adopted widely and rapidly, due to a perceived economic need to rebreed for twelve-month lactation cycles. As explained later in this Special Issue, the use of accelerometers has now broadened to encompass feeding, ruminating and postural behaviours (Michie *et al.*, 2020) and these are likely to be adopted more widely over the next few years. In addition to accelerometers, cow activity can also be assessed using commercially-available GPS location technology combined with local reference points in the barn (see Caja *et al.*, 2016). However, not all sensor technologies have met with success, weight-based analysis being a key example. In the latest issue of Journal of Dairy Research, Ephraim Maltz discusses why some technologies for individual dairy cow management (IDCM) have been successful whilst others have not (Maltz, 2020). As an animal physiologist who has spent a large part of a successful career working closely with agricultural engineers and computer technologists, Ephraim is well placed to address this important issue.

Biomarker-based sensors

For understandable reasons the focus in biomarker-sensing has long been milk, and the main target has been mastitis. Commercial systems have been available for some time, using milk conductivity and/or the content of somatic cells or specific enzymes to detect abnormality indicative of disease, with the major advance being the ability to monitor and compare individual glands, thus reducing the impact of day-to-day background noise. Whilst there is still some scientific debate regarding the accuracy of individual systems, it is true to say that mastitis detection is in widespread and successful use on dairy farms. As

https://doi.org/10.1017/S0022029920000679 Published online by Cambridge University Press

reviewed by Zachut *et al.* (2020), such application has been almost exclusively in dairy cows, and there is a need to expand this to other dairy species and, if possible, to non-dairy livestock. Prospects for using sensor technologies in dairy small ruminants will be considered later in this Special Issue (Caja *et al.*, 2020). Components in milk can also give valuable information related to metabolic and reproductive status (see Maltz, 2020 and Zachut *et al.*, 2020) and, of course, are used extensively to monitor the quality of the downstream product. In addition to milk, technology is available for assessing characteristics of the rumen environment and in as much as pH reflects rumen functionality it could be regarded as a biomarker.

Not all sensor modalities fit neatly into 'activity' or 'biomarker' categories, rumen boluses that measure temperature being an example. As yet, temperature is the only physiological parameter available for monitoring by a commercial sensor, but heart rate, respiration rate, blood chemistry and others are probably not far away (see Michie *et al.*, 2020, for example). Technologies are also available for prediction of calving and for automated measurement of body condition score (Caja *et al.*, 2016).

State of the art

In a technological sense DairyCare succeeded. Discussions with colleagues from Strathclyde University at the start of the project focused on ways of detecting the swallowing and regurgitation movements characteristic of feeding behaviour, and within a short period of time accelerometers were indeed detecting eating and rumination. Studying the pattern of changes in rumen temperature with Austrian colleagues it was quickly apparent that the frequently observed sudden drops in temperature were probably indicative of drinking, and a rumen bolus that reports drinking activity is now available. DairyCare was part of a major effort to interpret welfare-related behaviour from pedometers (accelerometers attached to the hind leg) and more than one company now market such an approach. Technologically then, we have a number of ways in which health and welfare status can be inferred from cow-centric data, be it hanging sensors for feeding and rumination, floating sensors for drinking or attached sensors for lying time.

Despite these technological successes, DairyCare's InfoConomy Vision is currently very far from complete. As depicted in Fig. 1, current reality is that farmers purchase a specific technology from a particular manufacturer and then use that technology to assist their husbandry. No real effort has yet been made to engage other stakeholders, and the range of opportunities presented by different technologies cannot be exploited without purchasing each, and then solving the problem of incompatibility of data (which farmers will probably never be able to do). Crucially, the development of activity-based sensing and biomarker-based sensing is progressing more or less independently (although companies are working towards integrating activity and milk biomarker data: Afimilk, 2020; De Laval, 2020). DairyCare was set up to accelerate technology development and it did that more quickly than was anticipated, such that the network almost certainly lacked some of the skills that were needed for full exploitation.

Clouded visions

From an EU H2020 perspective, the next stage in welfare technology development is represented by the Clear Farming concept (ClearFarm, 2020). The idea is simple: large quantities of data from multiple sources are collected in a cloud portal and interrogated using algorithms to provide solutions for multiple stakeholders across the food chain. At the heart of this concept is the belief that the data sources already exist and what is needed is simply a platform that bolts them together (ClearFarm aims to deliver '*a platform to control animal welfare in pig and dairy cattle farming*'). I have no specific knowledge of the project, but it would appear that the basic animal-centric data for the dairy farming aspect is provided by one company's commercial neck collar sensing activity and deriving feeding and rumination behaviour (Connecterra, 2020), which is then combined in an Artificial Intelligence framework with farmer interpretation and response data. Further data may be collected from the local environment (housing and pasture conditions, for example) and it is likely that the major data sources for the pig farming element are environmental or remote animal monitoring, as I am not aware of any commercially available wearable sensors for pigs. In Fig. 1 this is illustrated as '*Future*', to which a question mark is applied, and in Fig. 3 it appears as the future activity '*AI mining of big data*'. The ClearFarm project is in its infancy and current efforts are aimed at understanding the needs of the different stakeholders, from farmers through to consumers. In some ways this is exactly what was proposed in the DairyCare InfoConomy model, but as I see it there is a major deficiency. The major technology players are two commercial companies (one focused on animal data, the other on environmental) when what is really needed is an independent service provider. Biomarker expertise does not appear to be present in the project. For a further analysis of the prospects and problems associated with Artificial Intelligence for dairy cow welfare, including the vexed issue of data propriety, see Knight (2020). Although I have my doubts, I do hope that in this case clouds will illuminate, not obscure!

CALM farming

I am not the first to use the acronym CALM in relation to farming. In Europe, CALM is Carbon Accounting for Land Managers (eip-agri, 2020), and in New Zealand CALM the FARM is helping farmers transition to regenerative practices (Calm the Farm, 2020), so both uses are environment-focused. It is certainly true that calm as a term is applied to the environment, a calm day being one without wind, for example, but it is also a term that relates to the disposition of a person or animal, meaning (Cambridge English dictionary) peaceful, quiet and without worry. These characteristics are associated with good welfare, so CALM (*Computing Assisted Livestock Management*) is an appropriate acronym for technology used to assist husbandry and thereby improve welfare. IDCM has already been mentioned as another, and in the past I have suggested *Responsible Livestock Farming* as an alternative to the acronym that is most commonly employed, PLF, or *Precision Livestock Farming*.

Achievable endpoints

CALM and PLF are very similar in most respects, but differ in two important details. Both use sensors to generate data that is then analysed in some way and, if the analysis calls for it, the system raises an alert and makes a response of some sort (Fig. 2). PLF starts from the premise that, although animals have inherent variability, most operate sub-optimally in one way or another, but

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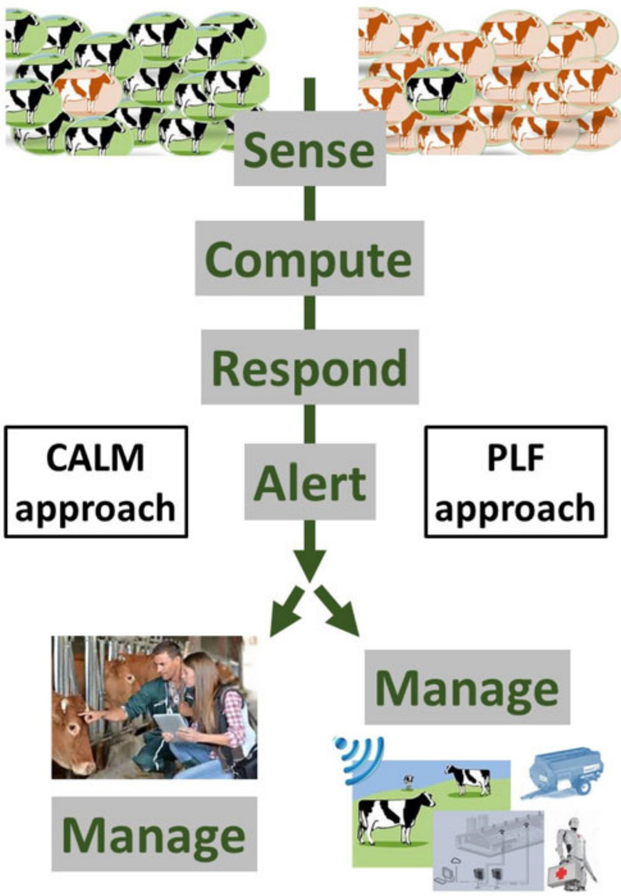

Fig. 2. Comparison of the key features of the Precision Livestock Farming (PLF) and Computing Assisted Livestock Management (CALM) husbandry technology models. CALM aims to automatically identify those animals that are at most need of husbandry support and assist that management, PLF aims to automatically manage all animals for maximal productivity.

could be made more efficient by appropriate management. Further, the PLF system would in theory have the capability to impose that management itself, ie it could change the environment, the feed or other parameters in order to maximise efficiency, and it could do this without input from husbandry staff. CALM, on the other hand, expects the majority of animals to be in a perfectly satisfactory state for most of the time, and uses it's sensing and analysis capabilities to identify those animals that deviate from this desirable state at any particular point in time (note a major virtue of sensing approaches: monitoring can be done more or less constantly so changes occurring across time can be picked up easily). With CALM, the system's response is not to try to correct the situation, but to alert husbandry staff and assist them in reaching the right management decision (consult vet, treat, change feed etc). The assistance would certainly include making the animal readily accessible by diverting it, after milking, to an attention pen and providing the data that triggered the alert. It could also potentially include automatically collecting a sample for biomarker evaluation as the animal was milked by an Automatic Milking System (AMS). This might sound hazardous (should a robot take a sample?) but is not, since this would be a sample of saliva or hair (for example) taken non-invasively (see Vesel *et al*., 2020 in this Special Issue for a description of the use of hair for stress biomarker evaluation). There is an important point here: CALM assists management, it does not manage. Michie *et al.* (2020) make the same point in relation to detection of disease. As we have seen, technologies are already available that are perfectly capable of identifying when something is wrong, but they do not diagnose the specific problem, that is the province of the veterinarian. So, this endpoint (focus your attention on cow x) is achievable. The sort of precision envisaged in PLF that might one day enable maximised efficiency and minimised environmental impact is not with us yet: none of the commercial sensor technology companies mention the term (or the word 'precision') in their marketing.

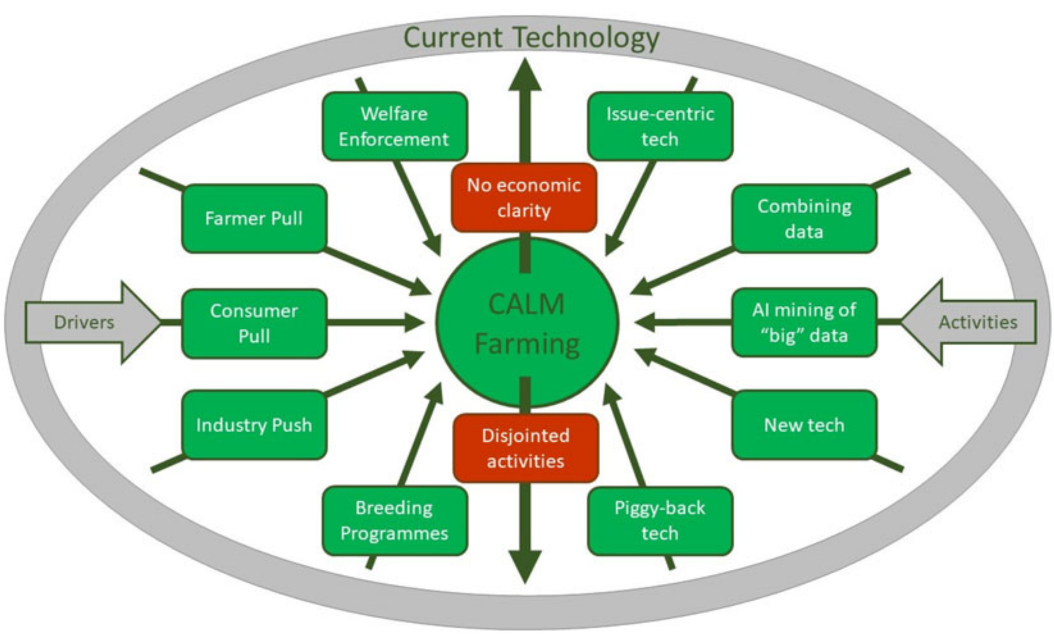

Fig. 3. Major factors (drivers, activities and impediments in red) that will influence progression from the current state of husbandry technology to that envisaged in the CALM model.

https://doi.org/10.1017/S0022029920000679 Published online by Cambridge University Press

Future development opportunities

Drivers

We have already stated our objective, which is to develop technology that will assist husbandry and thereby improve welfare. Is there a need for such technology, and what are the drivers for its introduction? Good welfare clearly has value to the animal in terms of improved quality of life, it almost certainly has value to the farmer both economically and in job satisfaction, it has value to processors and retailers through product differentiation and it provides value for many consumers primarily by creating peace of mind (most consumers have a natural wish that animals should be well cared for). So, there is value along the food chain, but putting figures on these value items is not straightforward. Brscic (2020) in this Special Issue addresses consumer perception and makes the point that welfare is one of several value judgements that consumers in developed countries make, and one which is difficult to disentangle from environmental impact and food waste concerns. There are examples of welfare premiums being paid for food products, the most notable being eggs. Currently in the UK, free range eggs attract a premium of around 80% over the cheapest eggs from caged hens; a significant price differential but only half of the premium paid for organic eggs (which are also free range) in a market place where several major retailers no longer sell eggs from caged birds at all, and where some are able to sell 'breed specified' eggs for five times the cheapest price. Organic milk currently attracts a premium of around 50% (so roughly one-third of the organic egg premium), and there is no real evidence that 'welfare friendly' milk has market value. That said, one consequence of the UK coronavirus response has been a major resurgence of 'doorstep' (delivered) milk sales, with customers prepared to pay twice supermarket price. I am aware of several farmer-retailers operating locally who use 'high welfare' as a selling point. Please do not regard any of these figures as definitive, they are observational, not research based. However, the conclusion is rather simple: the extent to which 'consumer pull' will drive welfare-enhancing technology development in the dairy sector is difficult to predict.

'*Animal health is key to your dairy farm's productivity and economic efficiency.*' This statement is taken from the website of a sensor manufacturer (SmaXtec, 2020) and is almost certainly true, but proving it is another matter. Scientifically, the economic *costs* of specific diseases have been studied quite intensively, but when it comes to the economic *value* of good health there is much less information and for good welfare there is even less (in a simple PubMed search, 5% and 1% of the number of disease-related papers, respectively). This is a serious omission. Oestrous detection was a selling point for accelerometer technologies because farmers were told how they much they would benefit, economically, from short calving intervals. The value that an individual farmer will attach to a reduced incidence of mastitis or lameness will depend entirely on how much he believes that disease is costing him, so the starting point is correction of a problem rather than a proper cost/benefit analysis of whether or not to invest in a sensor technology. Since the manufacturers of the technologies typically sell 'health modules' as add-ons to oestrous detection, relevant information about the desire of farmers to invest is probably available, but only as commercially sensitive data. Jeff Bewley reviewed the many factors that influence a farmer's decision to invest in the first of the DairyCare Conferences and his presentation is available online (Bewley *et al*., 2014). Once again, a simple conclusion: the extent to which 'farmer pull' will drive welfare-enhancing technology development is difficult to predict and, based on the way in which these technologies are marketed, probably not great at present.

Numerous companies are involved in sensor technology development, spanning small high-tech start-ups to major multinational equipment manufacturers. Clearly, there is an industry that is prepared to drive some sort of sensor development. However, all of the activity based technologies (ie accelerometers) that can be used to monitor feeding and rumination and hence derive measures of wellbeing are still marketed chiefly on their ability to detect oestrous. This situation is changing quite rapidly, with health monitoring increasingly appearing alongside reproductive management. The selling point is avoidance of the costs of disease; as we have already said, the economic benefits of healthiness are not established. The SmaXtec rumen temperature bolus is marketed for health monitoring (based on temperature and derived drinking behaviour), but the bolus is not available without the accelerometer that enables oestrous detection (it is entirely sensible that different sensors should be used in combination, nevertheless, the point remains). Until there are proven economic benefits to having healthy contented cows, the industry push will continue to focus on reproduction, with disease avoidance as a bonus at extra cost. Furthermore, the focus will be on specific diseases that are either known to have a major cost element (mastitis, for example) or are believed to have such. Sub-acute ruminal acidosis, SARA, comes into this second category, and was the focus of a dedicated DairyCare Workshop which exposed considerable difficulties in definition, diagnosis and treatment. Even lameness, a costly disease that has been in focus for many years, evokes problems: technology can help the farmer to identify lame cows (DairyCare organised a Training School on the topic), but what is he to do then? Lameness is a multi-factorial disease of complicated aetiology and, whilst there are good practices and restorative measures that can be followed, there is no single and straightforward treatment that will work in the majority of cases. Being able to successfully market sensor technologies for anything beyond oestrous detection is not yet a given!

The need for good welfare of farmed animals is recognised at national and (in the case of the EU) international governmental levels. However, there is no consensus for how to ensure high standards, with the result that different countries operate a variety of welfare assessment schemes (Krueger *et al*., 2020). There is a real opportunity for technology-assisted monitoring to transform welfare assessment, upgrading it from manual, farm level and occasional to automatic, individual animal level and continuous (Maroto-Molina *et al*., 2020). Who will take responsibility for driving this forward? Ideally it should be a respected international organisation that can take an objective view, such as the Food and Agriculture Organisation of the United Nations (FAO). It is encouraging to find that dairy animal welfare does have a dedicated section on the FAO website (FAO, 2020), but less so when one realises that this is simply a collection of documents from a variety of sources, most of them rather old and none focused on technological opportunities. In contrast to the situation in hens (where the EU mandate minimum welfare-related requirements), there is no EU-wide legislation relating to dairy animal welfare and most countries operate on a recommendation basis rather than enforcement (Sweden legislates that cows should spend periods of time outdoors each year, others merely suggest it). Enforcement of specific welfare standards on dairy farmers is unlikely to emerge as a driver of wellbeing technology. That

https://doi.org/10.1017/S0022029920000679 Published online by Cambridge University Press

said, the European Food Safety Authority last issued dairy cow welfare advice in 2009 (EFSA, 2009), but have recently started to recruit for expertise in animal-based measures of welfare. Perhaps sensor technologies are slowly coming onto the political radar, although it would be preferable if governments were to assist progress rather than enforce.

National breeding programmes have transformed the genetic potential of dairy cows over the last half-century. In terms of the genetics offered, many have now moved from selection based purely on production characteristics to a broader set of criteria that includes health and welfare related elements. This signals a recognition of the widespread concern that high genetic merit cows are more prone to disease and, by implication, poor welfare (the truth is probably more complex than this simplistic view but beyond the scope of this article). Clearly, if breeding organisations really wished to improve wellbeing they should be prepared to look beyond genetics and take action to encourage the use of sensor technologies. An ideal service provider in the scenario depicted in Fig. 1 would be a welfare-committed breeding organisation. In the UK, National Milk Records (NMR) is the organisation responsible for milk recording and breeding support to dairy farmers. They have embraced sensor technologies to an extent, first marketing the Silent Herdsman system developed by Strathclyde University (now an Afimilk product), and now marketing the Allflex systems (NMR, 2020). That appears to be the current limit of their ambitions, since as far as I am aware there is no linkage between the Allflex sensor data and all of the other data streams that NMR collect and use in their own software farmer-support models. The likelihood of NMR moving heavily into service provision with a range of sensor technologies from different manufacturers would seem to be very low. It would be useful to know whether this reluctance is shared by other breed improvement bodies.

Activities

In this section I shall address various options for technology development, and I should preface this by reminding readers that, where welfare technology is concerned, innovation has almost certainly run ahead of implementation.

Is there a need for totally new technologies, developed specifically for dairy animal welfare improvement? In a general sense I would suggest that refinement and application of existing technologies should take precedence, but I can give one example of where a new technology should be especially useful, and there may well be others. By '*Issue-centric tech*' in Fig. 3, I mean technology that is specifically directed at one particular health/welfare issue, a prime example being rumen pH sensors for SARA. Unfortunately, pH sensors for inclusion in a rumen bolus are expensive, greedy (they have a short battery life) and prone to 'drift'. In short, it is unlikely that rumen pH monitoring will find widespread adoption by farmers, and the manufacturers recognise that and target these sensors primarily to research use. Rumen function relies on the creation of pressure waves by muscular contraction of the reticulum and the different sacs of the rumen itself. These mix the digesta, force digesta back up the oesophagus for rumination (regurgitation) and expel gaseous products of digestion (predominantly methane: eructation). The pattern of pressure waves is different and characteristic for each of these processes. Craig Michie of Strathclyde University and Andreia Castro Costa of Universitat Autonoma de Barcelona, both active members of DairyCare and authors within this Special Issue, are collaborating to produce a rumen pressure sensor bolus that will be able to characterise the frequency and pattern of pressure waves, allowing continuous and automatic assessment of rumen function, rumination and methane output. This combination of measurements is not currently available and should allow better management of animal health and productivity. Meanwhile, a major manufacturer of rumen pH boluses is currently testing the market for additional biochemical functionalities (ammonium and nitrate) to be added to their sensor. So, there are identifiable '*New tech*' opportunities (Fig. 3) out there, and most probably there are many others sitting in researcher's imaginations or on laboratory test benches.

In addition to totally novel technology, there are other sensor modalities that are not currently used for animal welfare assessment, but which are already available for assessing 'fitness' in human subjects. I have identified these as '*Piggy-back tech*' in Fig. 3. Most human fitness trackers are essentially accelerometers, but one in particular takes the assessment further. Mindstretch (Mindstretch, 2020) is an app that uses proprietary algorithms to compute partitioning of energy between basal metabolism, production and mental energy expenditure (presumed to be a measure of stress) using activity and heart rate data together with environmental temperature. It is marketed for stress management in workplace and sporting scenarios. Given the emphasis afforded to energetic efficiency in livestock production, it is rather surprising that animal scientists have never (to my knowledge) considered stress as an addressable component of energy expenditure. From a technology point of view, there is no reason in principle why the Mindstretch mental energy approach could not be extended to dairy animals. The incentive to do so depends very much on personal perception: does one consider that animals expend very little energy on thought processes, or does one recognise that stress associated with competition for food (for example) may lead to total exhaustion?

All of the commercially available dairy animal sensor technologies are targeted at dairy cows, so a second aspect of '*Piggy-back tech*' is to transfer technologies into other dairy species, especially small ruminants. I do not need to expand on this topic, since it is covered in a companion paper in this Special Issue (Caja *et al.*, 2020). As regards the other future activities identified in Fig. 3, I have already described the use of large datasets and AI as a key part of the Clear Farming project (ClearFarm, 2020) and the principle of combining data from multiple sensors is well established, and will develop further, as discussed in Michie *et al.* (2020). Combining sensor data with biomarker data is less well advanced, and is an area that certainly needs attention. The use of biomarker technologies for wellbeing assessment was addressed by a multinational group of DairyCare participants in a recent comprehensive review (Almeida *et al.*, 2019). Decision support systems that incorporate data from activity sensors with concurrent biomarker data do not yet exist, but need not be far away provided that the will exists to create them. Given the recent reviews (Almeida *et al.*, 2019; Zachut *et al.*, 2020) I have chosen not to focus on biomarker technologies, although I consider them to be extremely important, and I would make two related observations:

Firstly, the traditional approach of taking a single blood sample to assess current status is rapidly becoming outdated. As a diagnostic measure of a specific disease the blood sample will quite likely remain the gold standard, but for evaluation of 'wellness' (welfare, wellbeing, psychological state, the terminology is fraught!) it has very limited value. Milk has already been

https://doi.org/10.1017/S0022029920000679 Published online by Cambridge University Press

mentioned, but it is now increasingly obvious that biomarkers can be assessed in a variety of different body tissue/fluids, examples being faeces, urine, breath, saliva, nasal fluid, sweat and hair. This was addressed in the First DairyCare Conference by David Eckersall, of Glasgow University (Eckersall, 2014). To my mind, the most exciting aspect of these different samples (and one that is still to be exploited) is the fact that they represent different chronological time windows, from the more-or-less instantaneous measure provided by saliva or breath through hours (milk, urine) to days (sweat, faeces) or weeks (hair).

Secondly, for the full power of biomarkers and sensors to be realised, it is important that we think beyond simply combining the data outputs. Technology can also, potentially, be the means through which the sample is obtained for biomarker analysis. Another colleague and contributor to the First DairyCare Conference was Ole Ravn, of the Technical University of Denmark, who considered the use of robots for taking biological samples (Ravn, 2014). Regrettably, our attempts to obtain research funding failed, and to the best of my knowledge, this combination of technology and biology has been completely ignored. More optimistically, it is quite certain that sensor technologies will develop and proliferate over the next few years, the real question is whether they will be applied to their full potential in commercial practice.

Barriers to implementation of sensor technologies

Figure 3 groups the main barriers into two categories, '*Disjointed activities*' and '*No economic clarity*'. This is a broad-brush analysis, and since the devil always resides in the detail there will be very many individual factors that will hinder the application of individual technologies. Nevertheless, I suggest that these two sets of barriers are where appropriate attention will generate most progress. Disjointed activities exist at several levels, from the researchers who fail to collaborate across disciplines through the commercial companies who can only focus on their own product to the governmental bodies who continue to operate on NIMBY (not in my back yard) principles. DairyCare was specifically set up to address the first of these, and was very successful at getting biologists and engineers face to face in the same venue. I am very happy that a number of successful collaborations emerged from this, but I am also conscious of the fact that creating a shared experience does not guarantee cross-disciplinarity. An internal mid-term evaluation of DairyCare concluded that 'silo-mentality' was a serious problem, which we addressed with the introduction of Incubator Groups. From my own experiences I do worry that biologists, from primary training through to career research, are becoming more and more specialised, and I suspect that the same is true of engineers. The pace of scientific advance over the last several decades has made specialisation inevitable, but this leaves us poorly equipped to tackle complex, multifactorial problems. There is a real need for individuals with broad skillsets; I can see no reason in principle why someone could not combine technological expertise with a fundamental understanding of how animals function (I know people who have managed it), and I would welcome educations that set out to achieve that.

The example of cross-disciplinarity used here (biologists and engineers) was appropriate at the time that DairyCare started, and remains an essential part of what will be needed in the future. However, it no longer represents the complete mix, in my opinion. This relates to the second set of barriers, and the need for economic clarity. If there were to be a second DairyCare (there will not be!) then I would wish it to include as many economists as scientists. Without much better knowledge of financial benefits to farmers and other stakeholders, the implementation of sensor technologies will either not happen, or be restricted to those elements (such as oestrous detection) where benefit can be assumed. The InfoConomy business model proposed in Fig. 1 and described fully in Knight (2020) is based on the accepted principle that data has value, but what is that value? Who stands to benefit most, is it farmers, veterinarians, feed companies or genetics suppliers? Could retailers obtain value from a generic welfare improvement strategy, or does their value reside in having their own scheme in place? When consumers state that they place value on good welfare, how much are they prepared to pay for it? When technology companies market their individual products in ways that prevent interaction with other related products, is it simply because they do not understand the added value that might otherwise be obtained? When countries insist on their own welfare standards, is it because they place value on welfare, or on the export potential that is created? Three years ago it was predicted (not by economists!) that the global value of animal biosensor technologies would, today, exceed $20 billion (Neethirajan *et al*., 2017). Has that figure been realised, and will the market continue to grow? I cannot answer these questions, but I can see that they do need to be answered.

Conclusions

I am under no illusions, CALM farming as a terminology will not succeed. From a marketeer's point of view it is not 'sexy', calm is passive and does not evoke the high-tech future that will persuade farmer's sons or daughters to continue the business. However, I am convinced that the principle is correct, and implementation would provide great benefit to dairy animals, farmers and stakeholders along the dairy foods chain. A large part of my earlier research was concerned with extended lactation, a management strategy that I believed (and still believe) could combine economic success for farmers with improved wellbeing for their animals (Knight, 1989). Rightly or wrongly (the economics have never been properly addressed) the great majority of dairy farmers still manage their cows for an annual calving cycle, so the experience has taught me how difficult it can be to introduce new approaches into dairy farming. My personal reason for helping to establish DairyCare was a strong desire to see dairy animals continue to be treated and managed as valued individuals, rather than becoming something akin to the unseen and unimportant bird or weaner within a huge poultry or pig unit. It is economics that is driving the move towards bigger and bigger dairy enterprises (tens of thousands of cows or more), and it is my hope that the power of economics can be recruited to ensure the widespread and successful introduction of technologies that will assist husbandry and thereby improve dairy animal welfare. Calmly!

Acknowledgements. I am extremely grateful to all of my DairyCare friends and colleagues, for it is they who were the inspiration behind these reflections. The article is based upon work from COST Action FA1308 DairyCare, supported by COST (European Cooperation in Science and Technology, https://www.cost.eu). COST is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

https://doi.org/10.1017/S0022029920000679 Published online by Cambridge University Press

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