An introduction to

Smart Dairy Farming

by Dr. Ir. Kees Lokhorst
professor Herd Management
and Smart Dairy Farming

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van hall larenstein
university of applied sciences

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"Individual care for cows will be the basis for future dairy farming."

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cow#016

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cow#034

Kees Lokhorst

*"I keep saying...
i am different..."*

Preface

Writing a book is a real challenge. The topic of this book 'Smart Dairy Farming' is something I have been engaged in from a research perspective already more than 30 years. The constant drive is to put developments in Information and Communication Technology into the perspective of farm practice innovations and farmers support. However, developments of concepts such as Smart Farming take time and should be approached from several insights. In my job as professor Herd Management and Smart Dairy Farming at Van Hall University of Applied Sciences I have experienced that training and education of the upcoming (and existing) generation of farmers and farm advisors needs extra attention. I want to share my insights and experience that I have developed in projects such as Lofar Agro, WASP, Smart Dairy Farming, BioBusiness, EU-PLF, 4D4F and in the ECPLF community.

I want to thank the funders of the Dairy Campus Education programme who made it possible to write this book. This book contains my personal view on Smart Dairy Farming, but it was impossible to write it without the received stimulation and comments. I want to express my thanks to my Wageningen University and Research colleagues Rudi de Mol, Pieter Hogewerf, Bert Ipema and Eddie Bokkers for their cooperation in projects and valuable comments on this book. Valuable discussions with Gelein Biewenga and Eric Schuiling, teachers at the Van Hall University of Applied Sciences, helped me to find the balance between detail and overview so that the book can be used by students. In the progress of writing and visualising I worked together with Dennis Luijer, Mike Jacobs and Jacky Rademacher. Especially, making the visualisations together with Dennis was inspiring. And last but not least I want to thank my wife Angelique Lokhorst and my youngest daughter Nynke Lokhorst who stimulated me to write this book and for reading and commenting chapter by chapter.

I hope the book will inspire everybody, especially the students of Universities (of applied science). And whomever is interested to learn about Smart Dairy Farming. And that it will be the basis of the development of education material and inspiring courses.

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Introduction

What to learn in chapter 1:

- **Why this book 'Introduction to Smart Dairy Farming is written.**
- **This book gives background information and an overview of relevant topics for students from universities of applied science and other interested people working in the field of dairy science and precision livestock farming.**
- **Introduction of the blocks:**
  - **the Objects of Interest in smart dairy farming,**
  - **techniques to work with digital data, data analytics and action based management support**
  - **organisational environment of smart dairy farming.**

1. Introduction

The objective of this book 'An introduction to Smart Dairy Farming' is to provide insight in the development of the Smart Dairy Farming (SDF) concept and advise as to how to apply this knowledge in the field of activities of students from universities of applied science. The information in this book includes background information and comprehensive insight in the concept of SDF.

The book will provide the reader with food for thought and give him inspiration for understanding dairy farming and Information and Communication Technology (ICT) related product/service development rather than providing him with an detailed overview of the recent developments. Although this book is mainly meant for students and staff from universities of applied sciences and other universities it also can be used by professionals already working on applications in research and development for this field of expertise, or people already active as dairy farmer of farmer advisor.

The SDF concept

The SDF concept has been developing for almost two decades, fuelled by research and the development of products that have reached the market. Farmers have already started working with these products, which leads to widespread knowledge. However, the concept hasn't yet reached the new generation of farmers. This is because training and education hasn't yet focussed on the SDF concept. In order to study why this concept hasn't been included in education the author of this book, Kees Lokhorst, started a professorship in Herd Management and Smart Dairy Farming at the Van Hall Larenstein University for Applied Sciences in 2014. During his professorship he set up a minor on this topic. While doing this it became clear that information

for students is fragmented. He experienced in several Dutch and European projects, except from the EU-PLF project, that there is hardly any decent education material available. The author finds that education is an important factor in transition and innovation adoption processes. Not only the early adopters and innovators (based on work of Rogers and the Diffusion of innovations[1]) should benefit from the SDF concept, but also the early and late majority should benefit from it. He believes that education is a very good internal motivator for free change of behaviour of students that wants to become farmers or other involved stakeholders.

Although including examples from other sectors such as poultry, pig and arable farming systems could make the theory even more challenging, this book specifically focusses on the dairy sector. Most of the examples origin from the Netherlands, but SDF can be applied worldwide. Elaboration on management of individual cows and calves that are part of a group, and management of location and time specific grass production in the dairy sector will be given. In order to fully comprehend this information, it is important to understand the challenges that the dairy sector faces and what the SDF concept contributes to tackle these challenges.

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Dairy sector challenges

Worldwide the dairy sector is faced with big challenges. According to many reports the main challenge is an expected increase in production of protein produced by dairy cows. To be able to produce these milk based products dairy markets are confronted with e.g. the following global and local requirements for the production of milk based products:

- Resource efficient production with a low impact on the environment, climate and health.
- Contribute to good farming practices with maximum care for animal welfare and social and economic entrepreneurship.

It is expected that developments in genomics and nano-technology will come up with disruptive changes and that developments in Information and Communication Technology (ICT) will provide a continuous stream of improvements for dairy farming systems. The ICT developments form the basis for the concept of Smart Dairy Farming (SDF), that will be explained in chapter 2 in more detail. However, the SDF concept, is seen as an important aspect that contributes to the development of dairy farming systems. These systems are able to tackle the challenges for the dairy sector that are mentioned above.

The SDF concept is developing autonomously already for almost two decades and it has had mainly contributions from research and development. Products have come to the market and farmers start working with it. However, training and education of the new generation farmers has not yet focused on the SDF concept.

Book overview

The book is build up according three main blocks. The first block deals with the specific domain of dairy farming and the choices for relevant objects of interest. In chapter two the history and definition of Smart Dairy Farming is given. Since SDF is focused on dairy production and the key stakeholders are the dairy farmer and his cows in chapter three the critical periods and processes for supporting the farmers management are identified. To support dairy farmers in their choices for supporting tools, either sensors, models and/or advisors, the longevity matrix is introduced in chapter three.

The second block is dedicated to techniques to handle the full cycle of plan, do and act. In chapter four the theory to transform digital data into information, interpret it with using context into knowledge, decide on this knowledge and transform it in dedicated work instructions. This cycle is goal driven and iterative. Collection of digital data by using sensor technology, being aware of the variables that are measured and examples of sensor technology are worked out in chapter five. The background, techniques and principles of data analytics and validation is depicted in chapter six. Chapter seven is dedicated to the use and writing procedures for Standard Operating Procedures.

The third block is focused on the organisational environment of smart dairy farming. In chapter eight insight is given in the involvement of different stakeholders. Chapter nine is dedicated to innovation in the context of smart dairy farming. Examples are given and also driving forces behind innovations are given. In chapter ten social, economic and business values are discussed with the goal to make farmers more aware of innovations. Chapter eleven is dedicated to awareness of trends in ICT. Chapter 12 deals with some future developments with the power to stimulate the further uptake of smart dairy farming.

individual

cow#034

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cow#233

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Group

What to learn in chapter 2:

- **SDF finds its scientific origin in Precision Agriculture and Precision Livestock Farming and is specifically dedicated to dairy farming systems.**
- **SDF is a management concept.**
- **SDF is capable to make use of time (temporal) and location specific (spatial) intra- and inter-variability in the Objects of Interest.**
- **Object of Interest is the smallest unit to manage/ monitor. For animals it can be an individual calve/cow, a group, a herd or a farm level. For grass production realistic objects of interest can be sub-parcel, parcel or farm level.**
- **SDF management improves (re)production and health of animals, crops and fields.**

2. What is Smart Dairy Farming?

2.1. Short history

In order to explain the concept of Smart Dairy Farming (SDF), it is necessary to introduce some definitions and key elements. To be able to do that some insight into the history is needed.

Historically we should be aware that SDF finds its origin in Precision Agriculture[i]. This form of agriculture came from the USA in the seventies and eighties of the last century. Precision Agriculture was focused on using information from satellites for arable farming. These satellites were not specifically developed for agriculture. However, it appeared that the location information (Global Position Signal) could also be used to know where the tractor was within a field. Satellites also used cameras and these cameras could be used to observe the vegetation of plants and some basic soil characteristics. This stimulated remote sensing techniques quite a lot. Having large fields of corn and soy in the USA, these new satellite and camera techniques made it possible for farmers to identify management zones within a field and to act according to differences between these management zones instead of treating the whole field as uniform. This led to more uniform fields. Variable rate application of fertilizer was seen as the key application for a new generation of decision support systems for the farmers. Until now these remote plant and soil observation, location information, data analytics and techniques to treat management zones more precise are the basics of current developments in precision agriculture for arable farming systems.

Precision agriculture (PA) or satellite farming or site specific crop management (SSCM) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. The goal of precision agriculture research is to define a decision support system (DSS) for whole farm management with the goal of optimizing returns on inputs while preserving resources[ii].

In the eighties and nineties of the last century this Precision Agriculture development was also adopted in Europe. The scientific developments in arable farming stimulated scientists from five universities and research institutes (Christopher Wathes from Silsoe research institute, Daniel Berckmans from KU Leuven, Jos Metz from Wageningen research, Ephraim Maltz from Volcani research institute and Marcella Guarino form University of Milan) to work on the new concept of Precision Livestock Farming (PLF). Stimulated by the potential new engineering concepts in sensing, data management, decision support, control theory and the concept of precision agriculture, they aspired to creating new applications in order to support management of livestock farmers. Where the satellite was the key in the development of precision agriculture, the development and large scale introduction of electronic identification systems (Radio Frequency IDentification tags RFID) was the key for the development of PLF. Suddenly farmers were able to identify individual cows that were part of a group and we could also treat them individually by giving

them concentrates. Together with the ability to measure the milk yield of individual cows, automatically the basic elements of PLF were introduced. These elements stimulated developments in sensor technology, decision support and in milking, feeding and housing systems. Group housing of sows and aviary systems for laying hens could be developed with the knowledge that data about the livestock in the barn was available and could be used to treat individuals or smaller groups (on pen level instead of compartment level). In conclusion we could say that PLF was focused on the support of the management of production animals. On individual level for dairy cows and breeding sows and on subgroup level for finishing pigs and all sort of poultry production (broilers, laying hens). This last group can also be seen as management zones as applied to zones of a field in precision agriculture.

The European scientific community started organising specific bi-annual conferences for precision agriculture (ECPA). After a few conferences these ECPA conferences were expanded with the European Conference for Precision Livestock Farming (ECPLF). The ECPLF conferences organised together with ECPA were in Berlin (2003), Uppsala (2005), Skiathos (2007), Wageningen (2009) and Prague (2011). From 2013 onwards the ECPLF conferences were organised separately in Leuven (2013), Milan (2015 and Nantes (2017). Within the PLF community regular discussions were held about the name. Precision Livestock Farming is an abstract concept. Even now the name is still under discussion which leads to alternative names popping up. Development and differentiation of the definition can be seen. For example, around the term **'precision'** we see differentiations such as 'precision feeding', 'precision breeding', 'precision health' and 'precision grassland management'. The term precision then means

'more precise actions that are based on high resolution data that can enhance the processes on the farm.' Another development can be seen around the term **'SMART'**. Smart Farming and Smart Dairy Farming are examples where decisions of stakeholders that are related to a farmer are influenced by the general management of the farm processes. So when using the term 'Smart' the farm is also seen as a part of a complex and dynamic production chain. It is interesting to see that the acronym of the SMART-principle is hardly used. The letters are used for:

Specific - Is there a clear target variable and decision to support?
Measurable - Can the input- or output variable be measured (automatically)?
Acceptable – Are the used target variables and references acceptable for the decision makers?
Realistic - Is it realistic for the context where it will be applied and can the target be reached?
Time related – What is the time frame of measurements, process and expected results?

In time we see people using different terminology. For this book the terminology of Smart Dairy Farming is being used. Be aware that SDF in essence is a subset of Precision Livestock Farming and that it is based on the same principles as those of Precision Agriculture.

2.2. SDF definition(s)

Although there are quite some different definitions we see that the following two definitions fit to Smart Dairy Farming.
- Daniel Berckmans[iii] defines Precision Livestock Farming as *"Management of livestock farming by automatic real-time monitoring/ controlling of production, reproduction, health and welfare of livestock".*
- The EIP- focus group 'Mainstreaming Precision Farming' uses the definition: *"Precision Farming refers to a management concept focusing on (near-real time) observation, measurement and responses to inter- and intra-variability in crops, fields and animals."* [iv]

These definitions include a few important elements that should be taken into account when we talk about Smart Dairy Farming. These are:
- Dairy farming
- Management
- Inter- and intra-variability
- (Near) real time
- Automatic observation/monitoring/controlling
- (Re)production, welfare and health of animals, crops and fields

Dairy farming
This book focusses on professional farms that produce milk by using dairy cows, or products and services that facilitate this production of milk. This definition applies on all type of farms, organic or non-organic, small or big and family owned or otherwise funded farms. The dairy cow is the key production factor and the interest is her lifelong contribution to the production of milk. Therefore also management of calves, heifers and cows that are in transition are of interest for this book. The book will not focus on the cows that are kept for the production of meat. Although SDF also can be used in the professional production of milk from goats, sheep and water

buffalos only dairy cow examples are used. Focus on livestock farming addresses the paradigm of **'group versus individual animal'** and the position of the farm in the total production chain/network. Internationally there is a trend that dairy farms increase their size and become more complex to manage for the farmer. This complexity has two reasons. The first is the freedom for cows to walk 'freely' inside and outside the barn where different functional areas are created. The second is that dairy farms are becoming more connected in dynamic production chains. They do this by exchanging physical goods (e.g. milk and concentrates) and non-physical data and transactions. Because of this the availability of enough, affordable and qualitative good labour to manage a dairy farm becomes a critical factor. A natural reaction of management is to increase to work with production groups. Every group is then managed as one entity. This is done without taking the value of the animals itself into account. In very intensive production systems this is already common practice. Since every individual animal has its own intrinsic value we argue that for Western European livestock production systems there is a chance for farmers and the production chain if they really treat their livestock as individuals. This is also based on the perception that each individual animal is able to send out signals to show how she feels. E.g. if she can get enough rest, if she exercises enough or if she is healthy. Really understanding these signals offers the possibility to treat cows as individuals. This gives farmers a very good instrument for daily management. To be able to read these signals, the farmer needs tools to register, monitor and interpret them.

Management
Management can be seen as the planning and administration of an organization/business which includes the activities of setting out the strategy of an organization and coordinating the efforts of its employees, service providers or process computers (robots) to accomplish its objectives. Input resources are used and transformed by a process, to output that has a certain utility. For a dairy farm it is clear that the delivered milk and meat in general is the output of a farm. Output can thus be a physical product, such as milk, calves and meat, or a service. Henri Fayol[v] describes management as six aspects: 'to forecast and to plan, to organize, to command, to co-ordinate and to control.' He identifies them as:
Planning: Deciding what needs to happen in the future and generating plans for action (deciding in advance).
Organizing: Making sure the human and nonhuman resources are put into place.
Coordinating: Creating a structure through which an organization's goals can be accomplished.
Commanding: Determining what must be done in a situation and getting people to do it.
Controlling: Checking progress against plans. According to this definition management has to do with the continuous cycle of plan-do-act-control that has been implemented in all kinds of organizations, management systems and quality control systems.

Management of dairy farms has to do with making and implementing decisions on different levels. Distinction is made between **the strategic, the tactical and the operational level of management.** Strategic management concentrates on decisions that take place on farm level. They have an long term effect and sometimes require heavy investments. Examples are: the choice of building a new barn, replacing the milking parlour, changing from delivering milk into production of homemade cheese. Within this long term level of farm management, there is a second management level. Tactical management concentrates on a time horizon that is much shorter, e.g. a year or a couple of weeks or months, and on a specific process within a farm. Making a feeding or grazing plan are good examples of tactical management for feeding. The plan for using specific bulls for the inseminations for the upcoming season is also a good example of tactical planning. The third level is the operational management, which has a short time horizon from real-time to a couple of days or weeks. This operational management focuses on a specific process such as feeding, milking, cow observation, manure handling or climate control. The decisions and actions are e.g. giving a specific cow 1 kg more concentrates, or inseminate the cow that is in heat before 11:00 o'clock or perform a hoof trimming because that cow shows severe locomotion problems.

Inter- and intra-variability
For a long time dairy farmers have strived for as much uniformity as is possible. Uniform animals and parcels are easier to manage. Especially in the value adding chain, uniformity is still one of the driving forces of payment, despite product differentiation is coming up. Breeding and reallocation of land are known examples of striving for uniformity. Nevertheless, everybody (farmers, advisors, etc.) knows that there is still a large variation between animals, plants, soils, farmers, and so on. The differences between cows, farms etc. are called inter-variability. This inter-variability is a specific characteristic of biological and variation is the key for evolution. Inspired by the concept of precision agriculture one can become aware that this variation can also be addressed in the operational management of the livestock production chains. This can start with the efficient use of expensive production factors. Working with the indivi-

dual efficiency and behaviour of animals can save costs. In extreme, one can also think of creating more variation in the environment of the animals so that they can choose their production circumstances themselves. There is also a phenomenon that is called intra-variability. This is the effect that the same object of interest, in our case a cow, a farm or farmer, does not show the same changes in time. The reaction of a cow might depend on health, or on the phase it is in. It can be imagined that the same cow responds differently when it is in the dry phase then when it is in the last part of the lactation period. Even in the beginning of the milking period the cows respond differently than at the end of the lactation period. So farmers have to be aware that they will be confronted with different behavioural aspects of cows, depending on the time and place. Farmers have to deal with this intra-variability in their operational management.

(Near) real time
Besides the location, time is an important factor in smart dairy farming. The different time horizons of strategic, tactical and operational management support have already been discussed. Since smart farming focusses on the operational management and the involvement of the action part of the plan-do-act-check we should be aware that time on the operational management level can have different meanings. Units of time can vary from seconds, minutes, hours, day-night, day(s) or week(s) level. The choice for the unit depends on the process, the action and the object of interest. Feeding is an good example. You can determine the amount of feed you want to give to a cow per day. However, if you are able to specify the feed per time slot and you can deal with the diurnal rhythm of the cows, then you should also use the hour time level. If process computers and sensors for detailed animal behavioural measure-

ments are involved, real time or near real actions can be performed. Climate control is a good example that is supported by real time data. The definition of smart farming leads us to the level of near real-time which means that measurements and actions could also be part of the control mechanism of a process level. From farm perspective smart farming focusses on improving and controlling underlying processes.

Automatic observation and control
Key for smart farming is the principle that you need to measure the input and/or output of the process that you are trying to control or to improve. Without measurements no action and no control. Observation can be done in quite some different ways. If done by a human, eyes, nose, hands and ears are used to observe. With brain, skills and knowledge these observations can be transferred to a measurement. Good examples are the scoring of locomotion and the body condition of cows. In smart farming it is not intended to use only human based measurements, but to try to replace them by sensors and computer algorithms. If measurements can be automated then it is possible to observe 24 hours per day throughout the year. And measurements can be done within places humans have no access to, e.g. in the milk line, in the manure storage or in the soil. Within smart farming there is a lot of research and development focussed on the development of all kinds of sensors. These sensors and human measurements produce data that has to be interpreted and translated into actions. Every time, you have to be aware that sensor data is harvested with the goal of using it to support a decision process.

(Re)production and health of animals, crops and fields

This statement contains two different parts. The animals, crops and soil part can be seen as the object of interest for smart dairy farming. This is the unit that we want to observe and feel responsible for. Management in smart dairy farming tries to focus on the most appropriate level of control. In some farm situations this can be the individual cow level, in others the lowest level will be on group level. The same principle also applies for the crops and the fields level. For grassland management we still use parcel level as a unit for most of the time. But learning from open field crops gives us the possibility to identify sub fields, like the tracks of the tractor, the side alleys of the parcel, or other management zones. Ultimately each individual plant might be the unit fit for control, but for grassland production this is still unrealistic.

The other part of the statement is identifying WHY we apply smart farming. In general the argumentation comes from (re)production and health. The aspect of why the potential benefits may include increasing crop yields and animal performance, cost reduction and optimization of process input, all of which would increase profitability, is included. However, this will not be included in the definition. At the same time, smart farming shall reduce the environmental impacts and contribute to better welfare of animals in agriculture and farming practices. Another aspect that is not defined back in this argumentation, but that is nonetheless relevant for smart farming is the role of humans with respect for the quality of labour, labour time, the social aspects of labour, the costs of production and the developments in ICT solutions. The argument which stated that automated sensor technology contributes to the datafication and the transparency in the production chain is also not part of the definition.

So far an impression on the 'definition' of smart farming and the elaboration on some basic underlying principles. These will come back in more detail in the rest of this book.

'As a dairy farmer I will guarantee that every cow/calve gets the care it requires at the right moment, in the right place, and to the right extent, and I am transparent about this.'

Support the dairy farmer and his advisors/service providers in their operational management.

Smart farming involves continuous measurements with dedicated extra eyes, ears, noses, and hands as automatic sensors and data from the measurements are part of a system and control approach.

The object of interest in smart farming are the smallest units in processes that can be controlled in farm situation. For dairy farming this is cow level and a parcel into grassland management support.

To deal with an increasing amount of complex, individual dependent, time varying and dynamic systems (inter- and intra-variability) management tools should support daily management of the farmers and other partners in the production chain. Single argumentation only from (re)production, welfare and health for WHY smart farming is neglecting social, economic and technical aspects that influence the relation between humans, animals/crops/field and management of innovative farming systems.

Single argumentation only from (re)production, welfare and health for WHY smart farming is neglecting social, economic and technical aspects that influence the relation between humans, animals/crops/field and management of innovative farming systems.

Process

cow calf observation

feeding

milking

cleaning & climate control

reproduction

Period

after birth first half year

period to become pregnant

1st 100 days after calving

transition phase

farm related diseases

=Critical

Period

1st 100 days after calving

transition phase

**Object of interest
Berta #045**

2 calfs
current status : lactation

Longevity per cow
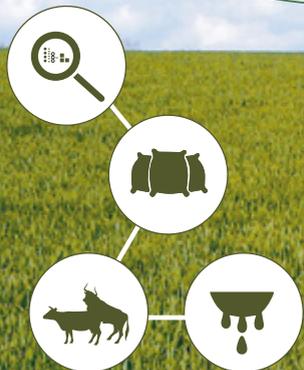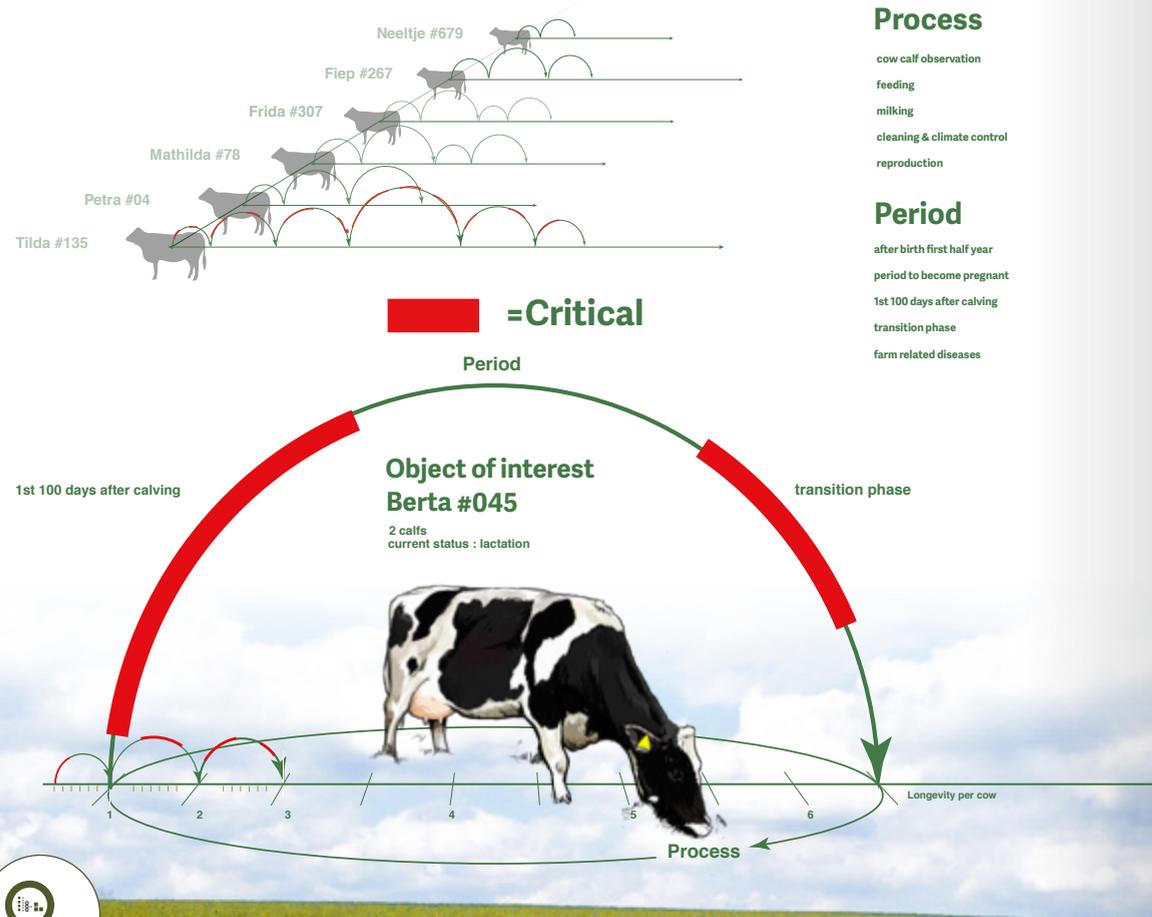
Process

What to learn in chapter 3:

- **During the whole life of a cow there are specific periods and processes where the calve/cow and the (re)production process is more vulnerable. The farmer should be extra alert in these periods and on these processes.**
- **Critical periods and processes of individual cows are not synchronised on herd level, which makes herd management a complex process.**
- **What the critical periods in cows life are.**
- **What the critical processes related to cow management are.**
- **Longevity matrix can be used to support farmers on decisions what, when and how to improve in his management and invest in SDF tools.**

3. Critical periods and processes in dairy farming

3.1 Critical periods

Dairy farming is in essence the production of milk by dairy cows. It is a natural and bio-logical process. For that, basic knowledge of how cows function is essential. Cows are extremely good in transforming grass or silage into valuable milk. To be able to develop tools for Smart Dairy Farming it is therefore necessary to understand some basic principles of grassland and dairy production.

In this chapter we try to indicate what the critical periods in the life of a cow and the growth of grass are. Of course a farmer must be aware that every day something might happen. But in some periods the chance that a cow needs extra care taking from the farmer is bigger than in other periods. These periods and their risks will be explained in the next paragraphs.

First half year after birth
By looking at the lifespan of a cow, from birth to death, it is commonly accepted that the first half year of a calves life is critical. In that period the calve has to deal with quite some transitions in feeding. It starts with colostrum, ideally from its own mother, for the first days because it is (unnaturally) taken away from the mother. Then the calve has to drink whole cow milk coming directly from the milking parlour or storage tank or with replacer milk made from powder bought from feed supplier. Within 2-3 weeks the calve also starts to drink water and to eat a little bit of hay or straw. Some concentrates will be integrated into the feeding. When a calve eats enough concentrates and roughage, the (powdered) milk will be finalized and the calve is weaned. During this whole period it is important to check feed

intake and growth of the calve, these checks are important because drops in feed intake and or growth can also be related to health problems. Most of the time, these feed changes coincide with change in housing. With regard to health climatic circumstances influence the risk of respiratory diseases. In the Nether-lands it usually starts with single housing in an Igloo and ends with group housing on slatted floors with laying beds.

Period to become pregnant
After the first 100 days in lactation we expect to have well balanced cows that are in a good condition so they can become pregnant again. This period is mainly driven by hormo-nal changes in the cow. In this period a farmer has to be alerted on oestrus signs, such as increased activity, changes in hormonal status, light change in body temperature, and lower feed intake. An oestrus period lasts approximately between 15 to 18 hours, but it can vary from 8 to 30 hours, depending on the cow. This shows that the farmer has to watch changes within a day and be alerted for opportunities to inseminate the cow. If he misses an oestrus period he has to wait for another three weeks. That is, if the cow is cyclic.

After insemination the farmer has to check if the cow is really pregnant. He can do that by observing that the cow is not showing oestrus again, or by performing a more formal pregnancy check. He can ask a veterinarian to perform a palpation test, or by checking it with an ultrasound or a blood test.

First 100 days after calving
In this period cows are expected to produce a lot of milk quickly. Beside this, they have to recover from calving. In this period we generally see that cows have difficulties with eating enough grass, roughage and concentrates to deliver the needed energy. Their energy balance becomes negative. Besides this, changes in hormone balance also make them really vulnerable for health disorders in this period. Most of the time these metabolic disorders are related to inappropriate feeding. With regard to feeding well known metabolic disorders are ketosis, acidosis and fatty liver. Feed intake, rumination, rumen pH and production should therefore be monitored carefully.

In this period a second type of disorders at risk are related to mastitis. Due to the high production, bacteria such as Escherichia coli, Klebsiella spp., Streptococcus uberis, Streptococcus dysgalactiae, Streptococcus agalactiae and Staph. aureus have a higher chance to come into the teat canal and cause an inflammation of the udder tissue. This is called mastitis and it can be recognised by redness of the skin of the udder, fever, a swelling of the mammary quarter(s), watery milk or clots in the milk. In practice it can be seen that milk production, milk composition, somatic cell counts and electric conductivity of the milk are used to check for mastitis. Sometimes a difference is made between clinical and sub-clinical mastitis. Clinical mastitis is mastitis in which an abnormality of the udder or secretion is observed. Sub-clinical mastitis is a form of mastitis in which the udder is normal. The milk also appears to be normal, but mastitis can be detected when microorganisms can be cultured from the milk or inflammatory changes in the milk can be detected by the somatic cell count. Although the milk appears normal, subclinical infected cows will produce less milk, and the quality of the milk will be reduced. In addition, infected cows can be a source of infection to other animals in the herd.

Since lameness of cows is sometimes related to inadequate feeding and presence of thin manure and urine we can expect that the risk to become lame is high in the first 100 days of lactation. The goal in this period is to get a cow into a good production mode and into a good balance as soon as possible. This way the health and condition of the cow can be guaranteed.

Transition phase
This is the period when a cow is dried off, prepares for calving, calves and start up production. So there is an overlap with the first 100 days of production. So let us focus on the last weeks of pregnancy preparing for calving. This transition period starts already a few weeks before drying off, e.g. cows that still have a relatively high milk production can be put on a diet to lower the milk production and to decrease the change of problems during the drying off period. In this period changes in feed composition and feed amount take place. On a day to day base it does not seem exciting, but in the long run it is important that the cows stay healthy and will be in a good condition for calving and the start of the production phase. Feed intake and activity should be monitored carefully. In this period, most critically within the calving process. If needed the farmer has to assist and therefore should be alerted in time.

Farm related diseases and recovery
There is always a risk that a cow or calve can become sick. In the previous described critical periods we have already seen that respiratory disorders for calves, digestive disorders for calves and cows, mastitis and locomotion disorders have a higher risk in a certain period. Nevertheless, they can occur at all times. When identified, the time period from identification up until full recovery can be seen as a critical period. Most of the time emphasis is put on early detection of diseases, but also attention to an adequate and fast recovery needs extra support from the farmer. During this period feeding and drinking behaviour, activity, body temperature and condition, and production might be relevant to look at.

Critical periods for grassland production
For production of grassland it is not yet common to identify critical periods. Briefly, the following periods can be seen as critical: Between sowing and the first time the parcel will be used for mowing or grazing the young plants are vulnerable for eradication. In periods with much rain or heavy draught grass is vulnerable. Growth is then almost stopped. When it rains a lot the carrying capacity of the soil will be too low for grazing cows or for heavy machines. After harvesting grass the length of the grass is low and the first week is needed to recover and start regrowth. In general we see that the critical periods occur during the entire growth season of the grass.

3.2 Critical processes
In paragraph 3.1 we identified critical periods in the life of a cow and that of grass. One can also look from the perspective of a process. Then question is: 'What are the critical processes that you should focus on?' In this paragraph we will describe some critical processes that you should take care of as a farmer.

Cow/calve observation
Understanding basic cow behaviour is essential to manage them. Within a specific farming system cows have a regular daily pattern of eating, resting, lying and walking. Depending on where the observation in the farm/barn takes place, different cow behaviour can be expected. You can look at the main activities on group level or on individual level. For a group you check e.g. how many cows are lying or standing at the feed alley and in the resting boxes. In general you are interested in the use of the facilities that are provided to the cows and the social interactions between cows. On individual level you have to check e.g. the activity, production, condition, weight, temperature, locomotion, cleanness or vocalisation. Every farmer decides what he would like to observe. In essence cow observation is the basis for early warning of diseases, becoming oestrus and the start of the birth process. Treatment of individual cows can be based on observing an individual cow in a group.

Feeding
Feeding is a complex critical process. In essence cows can eat and drink during the day, but diurnal patterns are present. There is a certain synchronisation of cow behaviour. The ration for a cow can be based on the following four components: fresh grass, roughage and maize silage, concentrates and feed additives. These basic components can be distributed to individual cows or to whole groups. Measuring feed intake is still quite a challenge. In most situations the concentrate intake can be measured quite accurate on an individual cow level. In practical situations roughage and maize intake can only be measured on group level. Grass intake is the unknown. We see that feed additives are becoming more popular and that farmers try to measure it on individual cow or group level. So determination of feed provision depends on the farmers choices and his farm characteristics.

For measuring water intake is seen as an important parameter for detecting digestion problems with the young stock, but in practise this is hardly used.

Looking to feed related individual cow behaviour it is important to look to the movement of the head and chewing of the mouth for

rumination activity, the stomach for the rumen pH and temperature, and the left side flank for the filling of the stomach.

Milking

The process of milking is the harvesting of the valuable product. Although different types of milking machines are used they have two things in common. Beside the harvesting of the physical product: milk, they also give the opportunity to harvest valuable information about the cow. Since payment of milk is not only based on quantity but also on quality and composition, it is important to determine fat and protein content. Furthermore milk represents some physiological information of the body and the udder. Alternative for milk samples would be blood or saliva samples, but invasive treatments would be needed to get these body fluids. Hormones in the milk are indicators for reproduction. Conductivity, cell count, blood particles and clutters are indicators for mastitis. Urea concentration of the milk is an indicator for the N efficiency and the composition of the ration. So the milking parlour can be seen as the place for harvesting important cow data. Knowing this you can also imagine that when a cow is in the dry period or when it is still a calve or heifer this information source cannot be used and you have to find alternatives. The milk quantities milking time, milking speed, milk temperature and difference between udder quarters can also be indicators of a specific cow. In conclusion the milking process delivers cow specific data.

Cleaning and climate control

A daily recurring process on group level is taking care of the environment of the cows. When we talk about the environment the following aspects are important. The ventilation should provide a good air distribution. Air flow, air temperature, humidity and the concentration of dust and greenhouse gasses

determine the quality of the air environment. In some countries and also in the Netherlands during some specific periods of the year the climate can lead to heat stress of cows, which should be prevented. This might also be the case when cows are outside. Then provision of shade should be provided.

Light intensity, quality, frequency and duration and the control of light can also be seen as an environmental factor that can influence the animal behaviour and animal production Another aspect of the environment is the availability and use of functional areas. Number of cows e.g. per water through, concentrate feeder, feed gate, laying bed, and parcel can be influenced by the farmer and has big consequences on group behaviour. Measuring this can provide us contextual information. There is a strong connection between these functional areas and the cow behaviour.

Cow health, quality of milk and air control can benefit from a clean environment and clean cows. Observing the cleanness of lying, walking and milking areas, or the cleanness of the milking systems might need some quantification. At the moment this quantification is hardly done in practice, while on the other hand daily activities can be seen to create a clean environment.

Reproduction

The process of oestrus detection and calving guidance can be seen as part of the daily cow observation. Depending of the size and the calving pattern of the herd the process of insemination will be a more irregular process. Both insemination and calving provide important data be taken into account while making decisions on insemination.

Growth grass and conservation of roughage

For dairy farming the recurring processes of fertilizing, grazing, and harvesting of grassland are most critical. In general fertilizing is done on parcel level. However, looking to the concept of precision agriculture it would be beneficial to look at variable rate applications within a parcel. This means that the amount of manure (whether it is manure or fertilizer) and the distribution of it within a parcel will be based on site specific soil and vegetation observations.

Another process is making the choice of which parcel of grass you should use for grazing of the cows. Based on original planning and according to the chosen grazing strategy this decision has to be made quite regularly. It can be based on the actual amount and quality of the grass (and sometimes soil), amount of cows and their need for food, and the expected weather.

Grazing is one way of harvesting the grass, but mowing is another one that occurs a few times per parcel per year. This depends on the grazing strategy. Mowing is done when there is enough grass and when the time frame for drying and for ensilaging is big enough. The weather is a very unsecure factor in the harvesting of good quality of roughage.

3.3 Critical choices in the decision process

In chapter 4 the steps from data gathering towards actions will be explained in detail. More simplified there is always a form of measurement and data gathering, a step of interpreting and analysing the information, and a step of action. The action can be based on an action list or a work instruction for a human or a machine. If these basic steps are placed in a context such as a critical period or a critical process it can be imagined that the tools supporting a farmer can differ quite a

lot. Observing cow behaviour might also differ when it is needed for different periods such as in the transition phase, or in the first half year of the life of a calve 100 days of lactation. The message is that it is important to be aware of these periods, processes and steps to turn measurements into actions. Every time this background should be kept in mind, since information determines the context of the information exhumed from the measurements. In essence a farmer has the knowledge to do this. However it becomes complex when the amount of cows grows and when grazing has to be integrated and cows are housed on several locations.

Dairy farms have an important role in data collection of cows. Farms are connected to the Internet and data between different organisations, applications and databases has to be exchanged. Platforms for data exchange are full in development. To contribute to a better understanding of the data forms of standardisation and agreements have to be made. I nice way to structure these arrangement is using the FAIR principle. The F stands for findability of the data. The A stands for Accessibility. Data providers (e.g. farmers) and data user have to agree who is allowed to use data. The I stands for Interoperable, which provides the user to choose freely for a specific system. A farmer can e.g. choose between companies to measure cows activity. All these system should be easily integrated in his farm management system and deliver data according to an agreed format to the cloud. The R stands for Reliability of the data. Users should trust on the quality, secureness and timeliness of the data. The FAIR principle will be very useful in the further development of data exchange in the dairy chain and the value creation of sensor data.

3.4 Using longevity matrix to select a smart farming strategy

In the previous chapters and paragraphs the concept of smart dairy farming and the relevance of measuring systems were introduced. However, for an individual farmer it still might be difficult to choose a specific strategy to implement sensors, decision support tools and standard operating procedures to support him in improving his daily management. In this paragraph we elaborate on these choices.

On a more strategic level the choices for farming system, barn design, type of breed and type of milking barn are made. Of course these strategic choices have consequences for the integration of the smart farming concept on the short term. On a more tactical level there are also choices to be made. It is expected that a farmer has the skills to analyse the development of his farm and that he is able to identify the strong and the weak points in the running business. Most of the time a human cannot handle many different processes at the same time. So, the challenge is to pick a few weak or strong points to focus on during a certain period of time, e.g. a year. The farmer can make a plan to improve himself. For this you have to choose what kind of support you need. You can e.g. decide to start measuring key indicators of certain processes. You can then set a target and a set of rules on how to handle these processes. Then you have to stick to this plan for a longer period so that you can experience change. After a while you have learned and improved this strong or weak point and you are open for a new round of plan-do-act.

To support this process Van Hall Larenstein university of Applied Sciences and Dutch dairy farmer Jan van Weperen developed a longevity matrix (Figure 3.1). For Dutch dairy farming systems longevity of the herd is a good iceberg indicator in which a lot of important farm parameters are incorporated. In the longevity matrix the farm is checked in a structured manner. The existing longevity of the herd is used to set a target value. The matrix is looking at ten different aspects. These aspects look like the critical periods and processes that were introduced in chapter 3.1 and 3.2 in this book. Per aspect the following items have to be discussed. The farmer can be supported in this process by a trainer.

At first it has to be identified what the key indicators are to evaluate the specific dairy farm. If needed some additional checks can be added. Then try to identify what you would like to quantify so that you can measure it. Then in the next column you can give your preferred reference value. These two are the key to success, since they force you to be aware of what you are looking at and what your target or references are for the thing that you see. This can be very farm specific. When you have identified what is important for you to measure, you have to discover if that is possible. You have to be aware of potential measuring devices that fit to your farm situation. However if you are not able to measure parameters then it will become very difficult to improve yourself. Beside measuring devices you can also decide which experts, decision support models and/or standard operating procedures can help you. These should also fit to your farm situation. In the next chapters information can be found on these measuring devices, models and standard operating procedures. The longevity matrix is dedicated to the cow and herd management part of a farm. There is no version yet for the grassland and roughage management.

Figure 3.1 *Example of the longevity matrix to support farmer in choosing appropriate indicators and supporting sensors and tools.*

> Regular proper farm specific plans are needed to know what and how to improve and which measuring devices and expert tools fit to that farm. (get inspiration from the longevity matrix)

DATA COLLECTION
Gathering / aggregation of data

PROCESS GOAL
Health / improve

Object of interest

INFORMATION
Data processing -
making information

ACTION
Decision on execution
SOP

KNOWLEDGE
Individual information
Analysis & context
interpretation

What to learn in chapter 4:

- **Importance of knowing that goal to achieve is part of a cyclic process to base actions on proper data collection, information analysis and knowledge based interpretation in a specific context.**
- **Learn difference between data, information and knowledge.**

4. From data to action

In this chapter we will explain the route from data to action. Data collection will always be done to support a specific process or targeted goal. Even just observation can be such a process. The concept is illustrated in figure 4.1. It is important to be aware of the difference between data, information, knowledge and action. They are strongly related, but in terms of decision support they vary quite a lot.
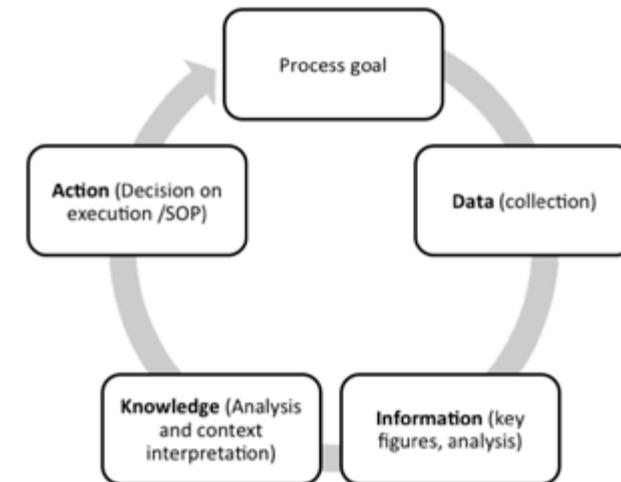
Figure 4.1 *Scheme from data to action*

The best way to show the different steps is to use an example form dairy farming. We build up our example from the basic data on just noting dates when something is happening with a cow.

4.1 Data
For a specific cow the following dates can be noted:
- insemination moment
- identified as pregnant
- when it calves.

In essence DATA are presentations of basic quantified raw measures. These measurements can be quantitative, e.g. in our example as date. In this case it is important that you

are clear in the format you use. Date formats can vary between countries, and per application. If you use an application originating from a European country together with an application from the USA and you use a windows computer with Dutch language then you need to check whether all date formats will be used in the same way. According to Wikipedia[vi] in a Gregorian date format the Y generally stands for year, the M for month and the D for day. However it is good to be aware that these basic components can be used in different order and numbers. A year can be expressed by YY or by YYYY. If you use historical dates from more than one century it is advised to use the YYYY format. The

month can be explained by MM for numbers 1 .. 12, MMM for three letter abbreviations Jan, Feb, .. , Nov, Dec, or MM..MM if you would like to spell the month name in full. For the day's most of the times DD is used, since the numbers of days per month vary from 28 till 31. As separators the characters stroke "/", dots ".", hyphens "-" or spaces " " can be used. The order in which Y, M and D are used differ per country. In the Netherlands we prefer DD-MM-YYYY, but in the UK MM-DD-YYYY is preferred.

The example of the date shows the importance of being aware of the format that is being used and of the unit in which the data is expressed. For numerical data there is an option to express data as a single integer, or as a real number with a limited number of decimals behind the comma (or point in some notations). Also the + or the – sign before a number can be important. With regard to the unit it is important to be aware of the object that is measured. In the example of the unit it is date for the cow. But if we measure e.g. the milk production of morning milking of that same cow on a certain day we can express it as kg milk/cow or as l milk/cow. The litre is the term used by farmers in practice. According to SI-units dm3 or kg is the official term. ICAR certifies milk meters based on the recording in kg milk. There is a slight difference between 1 kg and 1 dm3 of milk. The density (kg/dm3) of milk is on average 1.03 (can vary between 1.01 and 1.04).

As in other sectors, measurement systems can be supplied by different suppliers in dairy farming. This is a good development for the sector because competition in most cases has a positive impact on the price development and the quality of the systems. For data processing, however, it is important to know to what extent the type data obtained from systems can be characterised. Here, in principle, there are 3 situations:

• *An absolute measurement:* a measurement provides an S.I. standardized measured value (weight, temperature, pH). These measured values are comparable, but the accuracy with which something is measured may depend on the measuring system. It is therefore desirable that the measurement accuracy of the sensor is known in addition to the measured value. Measuring accuracy may depend on the conditions under which a sensor is used, for example a weighing unit that is used in a static situation (for example in combination with a unit in which animals receive concentrate and where the animals are more or less stationary for a longer period of time) can weigh more accurately than the application in a dynamic situation (for example, animals walk when leaving the milking parlour on the weighing unit and are only stationary for a very short time or not at all).

• *An indicative measurement:* a measurement yields a value that is not completely comparable because there is a certain degree of interpretation sensitivity. If agreements are made, which are respected by everyone, about the interpretation of the measurements, then there is no longer an indicative measurement, but it then became an absolute measurement. An example of an indicative measurement is a sensor that counts the number of steps an animal takes per unit of time. The definition of what a step is can influence the measurement. For example, a particular sensor may classify the animal's leg lifting an animal without classifying a forward motion as standing while another system classifies it as a step. Possible indicative measurements can be corrected for the differences in interpretation, resulting in a reasonable degree of comparability. It is therefore important that it is known according to which method a measurement has been carried out in order to be able to apply the correction.

• *A relative measurement:* a measurement yields a value that is not comparable in principle because, for example, a completely different measurement method is used or because the measurement is performed on another part of the body of the animal. An example of this is cow activity measurement. Sensors types can respond differently to the movement frequency and movement intensity. In addition, the measurement can be strongly influenced whether the sensor is attached, for example, to the leg (front or hind leg), the ear or the neck of the cow. The sensors can all aim to register the same deviation and although the measurements are completely different, there may still be a certain degree of similarity as a result of which the information is comparable at a more global level of deviation. Therefore, it is desirable for the data to know which type of sensor has been used in a given measurement and how it has been applied.

4.2 Information

If we would like to give meaning to data we have to add value by transforming data into information. Calculation, correction, aggregation and clustering are well known strategies to create information. In the example of a cow where we can note the day of oestrus, the day of insemination and the day of calving and/or birth we can suddenly calculate the age at first calving, the calving interval between successive parities, the number of open days for a specific parity, and so on. If you have already more parities for a specific cow you can calculate the average calving interval, the average open days, average number of inseminations before that cow becomes pregnant. These are examples for a single cow. You can do the same type of calculations for a specific group of cows on your farm or for the whole herd. In the management information systems there are numerous indices, ratios and parameters calculated. You can even calculate this information for different time periods. For a day, per month, per year, per lactation, etc. If we take the example of the data of the milk production per milking, we can see that this can also be used to calculate the milk production for a specific day for that cow. We can calculate the average production of a group for a certain day. If we take into account parity and days in milk we can even calculate average milk production per parity or per month. In the past even more complex indices have been constructed to be able to quickly compare production of cows that differ in age and part in the lactation. The index 305DMP (corrected milk production for a 305 days lactation period) is such an example. Also the FCMP (fat corrected milk production) is such an index.

In principle 'unlimited' information can be generated from a dairy farm. As discussed already in the DATA part the unit and the format of expression of the INFORMATION is important. When you generate information you should be aware of the type of decisions that will be supported, the object of interest (whether it is an individual cow, a group, a parcel, a farm, a sector in a specific country or on a breed type), the time horizon (real time, within day, day(s), week(s), month(s), year(s) or lactations) and the location. The other side is that someone who has to decide on a specific issue is also capable of generating all kinds of information that suit him. For farm specific decisions this might be challenging. However, if you would like to compare cows and parcels from different farms there is a need for standardised information. In the Netherlands Agroconnect[vii] coordinates such standardisation activities. On international level ISO and ICAR[viii] are important organisations that contribute to standardisation of information in the dairy sector.

4.3 Knowledge

After giving meaning to data it is needed to interpret the information and put it in the right context. By using the context of the information we can compare the information to what we expect, or what is normal for that context. If we know the context we can also reason with the information. The context can be build up from different sources. If we take the example of the average calving interval, the result can be 402 days. This means that the interval between two successive calves is 402 days if we look at an individual cow. The interpretation whether this 402 days is good or not depends on the context and the expectation of the farmer. If it is for a tenth lactation cow it might be very good, but for a second lactation cow it might be rather poor. You can have the same reasoning when you look at herd or farm level. On that level the average calving interval can also be 402 days. This might be good for an Italian farm, but not okay for an Irish farm. So it is important that when you interpret information to be aware of the context. In this case the context was the lactation number of the cow or the country where the farm was located. You can imagine that there are many potential contextual factors.

The example of the daily milk production per cow also has several contextual factors that can be taken into account. It is known that lactation, type of breed, and days in milk are good contextual indicators that can be determined quite easily. However, actual weather, introduction of new cows in a group, change from one parcel to another or change in grass silage are examples of less predictable context information that might be needed to interpret the information in relation to the context. Most of the time the contextual information is not as structured as expected and decisions have to be made in an uncertain environment.

4.4 Action

The next step in the cycle of figure 4.1 is to make a decision (based on information and context) and execute that action. Execution of an action needs identification of who has to do what, when and where. The action must be concrete in such a way that a human or a system can perform a specific task. This task is dedicated to a specific object of interest. This can be a cow, a group, a parcel or a machine. In general there are many objects of interest possible. Depending on where the object is or when it has to take place, the instruction and action can differ.

In the example of the calving interval a farmer can decide to sell that specific cow, or to inseminate that cow the next time it is in oestrus. The example of the daily milk production can lead to quite some different actions. Doing nothing is always a possibility. Giving some extra concentrates, an hour extra in the parcel, skip milking if predicted milk is too low, or separating the cow are some examples. In the following chapters this phenomenon will be explained in more detail. At this stage it is important to know that decisions based on information and context should lead to a concrete action that can be allocated to a person or a machine. This decision making demands craftsmanship of the people involved. If they have enough trust they can fully automate the decision process and the following action, but most of the time the human (farmer) will be part of the decision process.

4.5 Result

When actions are performed it should result in expected behaviour. This can be measured (checked) and thus result in new data. In this sense the circle of figure 4.1 is not a straightforward line. In system thinking, as explained earlier in chapter 2, we have a continuous flow of plan-do-check. From this continuous flow we can learn and do a better job or

improvement of the process. We can learn to measure things more precise with less errors, we can learn to understand the context and we can learn from the generated effects of the actions. In theory this additional phase creates wisdom. At present times most of the systems in smart dairy farming have limited self-learning capabilities. Creation of wisdom is learning from each other in practice or bringing in new knowledge based on scientific experiments.

In general it can be stated that the investment in data gathering, information analysis and knowledge interpretation only pays off if it is followed by an action that can be executed. Then the result is harvested. Doing nothing is also an action if it is based on a proper decision.

> **Investing in quality of data and understanding the right context of information will lead to more beneficial actions.**

5. Automation of data collection and sensor technology

5.1 Basic phenomena to measure
To measure and quantify observations by sensors is becoming popular. Sensors are responsible for the conversion of the measured phenomena into a quantity, which can be stored in a data acquisition system or in the cloud. The output of a sensor can be e.g. an electric signal (in current, voltage or frequency) which is in the data acquisition system translated in a digital number.
In general the following phenomena can be detected by sensors: biological, chemical, electric, electromagnetic, heat/temperature, magnetic, mechanical motion (displacement, velocity, acceleration, etc.), optical and radioactivity. See table 5.1 for some measurements that can be based on the mentioned phenomena. Currently in dairy farming many activity

sensors are based on mechanical motion. In grass growth observation some remote sensors are using optical information. Sensors to measure milk quality are e.g. based on optical, mechanical, thermal or electrical information.

Measurement in a sensor of the basic phenomena most of the time result in a continuous flow of electrical signals. Triggers have to be built in, in order to determine which signals have to be used and how they should be interpreted to determine the output.
An example is the weighing of cows with a walkthrough weighing platform. Based on the measurement frequency, e.g. 10 weighing's per second can be harvested.

Phenomenon	Measurement
Mechanical	Length, area, volume, all time derivatives such as linear/angular velocity, linear/angular acceleration, mass flow, force, torque, pressure, ..
Thermal	Temperature, specific heat, entropy, heat flow, state of matter
Electrical	Voltage, current, charge, resistance, inductance, capacitance, dielectric constant, polarization, electric field, frequency, dipole moment
Magnetic	Field intensity, flux density, magnetic moment, permeability
Radiant	Intensity, phase, wavelength, polarization, reflectance, transmittance, refractive index
Chemical	(in fluid and gas environments) Composition, concentration, reaction rate, pH, oxidation/reduction potential
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity

Table 5.1 *Examples of measurements for different sensor phenomena* [ix]

What to learn in chapter 5:

- Humans can observe cows and context when they have time and are present, but this is not sufficient anymore.
- Sensors can measure 24/7, also in harsh environments.
- Sensors are extra senses (e.g. eyes, ears, nose and tactile sensation) and based on some basic mechanical, thermal, optical, electrical, magnetic, radiant, chemical and acoustic phenomena.
- Sensor systems deliver digital measured 'quantitative' data.
- Most of the time indirect variables are measured and for proper decision support more than one variables are needed.
- Measuring can be done inside-, on- or from a distance of an object of interest (cow, herd, parcel) and/or dedicated to measure the context of that object of interest.
- There is a variety in sensors available.
- It becomes common that sensors will be connected to the cloud and will be remotely accessible.

When no cow is on the plate the signals can be used to tare the device. This enables then compensation for manure or urine that is left on the plate. When a cow steps on the plate you have to wait before the whole cow is on the plate (also before her leaving the plate or another cow joining her on the plate). Then you should be aware of some dynamic effects of a walking cow and the whole measuring system. Besides there can also be more than one cow on the plate at the same time. This should also be taken into account. So, criteria are built in and an algorithm is used to determine the weight. Within the algorithm the amount of signals that have to be taken into account is known. It determines how these signals will be combined and aggregated and how to translate it in a digital value, in this case a weight in kg. This is all part of a sensor. Knowing this, it can be understood that sensors from different companies are not always comparable. The composition of the sensor system, the measuring process and the used algorithms will give companies many choices. The result is quite different products on the market and the challenge for farmers to pick the system that fits best to his situation. Another example is measurement of milk temperature in the liner of a milk claw. There temporary milk flow is also measured. In the end the sensor should indicate what the temperature in degrees Celsius was of that milking. A dedicated procedure and algorithm are integrated in the sensor.

5.2 Direct and indirect variables
After the introduction of some basic principles to measure phenomena and the translation into a digital number we should also be aware of another issue. In most of the cases it is not possible to measure the primary variable in dairy farming. This can be illustrated by an example. When a cow becomes in oestrus the primary change is in the hormone level of the cow. These changes in hormones make the

cow susceptible for insemination or mating. Hormone changes can be seen in the blood of the cow. Currently, there is no system that measures the hormonal changes in the blood of the cow in practical situations. One simple reason is that it is not allowed to have surgical operations for such measurements. Hormone changes can also be seen in the milk. So there are some sensors on the market that measure progesterone in the milk. By doing this you only have the possibility to measure this when cows are milked, so two to three times per day, instead of e.g. every hour. The process of becoming in oestrus is rather fast and can develop within hours, so for detection regular sensor data measurements are needed. Also while measuring in milk it is not possible to detect oestrus in heifers. It is known that a cow that is coming into oestrus also shows some others signs. De Mol[x] developed some detection models that are based on table 5.2. There we can see that a cow in oestrus can have a lower milk production, a higher temperature, an increased activity and a slightly lower concentrate intake. In practice all these second order signs could be used to see whether a cow is coming into oestrus. However we see that changes in milk yield and concentrate intake are not always shown by the cows and cannot be measured in heifers. This explains that measuring the activity of the cows seems to be the most favourite variable to measure oestrus (activity can also be measured for heifers).
In table 5.2 it can be seen that for diseases such as mastitis, metabolic diseases and lameness indirect variables are measured. In Smarty Dairy Farming the term golden standard is used for the method and variable(s) that are used as the preferred reference in practice. In chapter 6 it will be explained how to interpret and combine these variables in early warning models.

	Milk yield	Milk temperature	Electrical conductivity	Activity	Concentrate intake
Oestrus	-/0	+	0	+	-/0
Mastitis	-	+	+	0	-/0
Other infectious diseases	-	+	0	-	-/0
Metabolic diseases	-	0	0	-	-
Lameness	-	0	0	-	-/0

+ = increase, - = decrease, o= no change

Table 5.2 *Expected change in variables for oestrus and some diseases[x]*

5.3 Connecting a sensor to an object of interest, time and/or location
In itself a sensor is just measuring a phenomenon and delivering a quantitative value (e.g. voltage). The sensor is part of a measuring system. In that system it is in theory possible to connect the sensor (measuring signal) to three basic elements: an object of interest, a time and a location.
Most of the time the object of interest in dairy farming is an individual cow, a group or a parcel in the field. Identification of an individual cow is regulated by international ISO standards. The ICAR website[viii] gives a lot of background and actual information on identification and sensing issues. At birth every calve in Europe gets a unique ID number. This number of the calve is registered in a database and is put on the two yellow ear labels (one inserted in each ear) of the animal together with a barcode representing the number. An example is given in figure 5.1. It is comprised of the responsible organisation in a country (LNV in the Netherlands), the country code NL, the complete unique life number 68025082(9) in numbers and in barcode. The last four numbers are highlighted to be used as work number by the farmer. Additional there is a control number, in this case 9.

Figure 5.1 *Example of a Dutch ear tag for a cow [xi]*

Every cow has a unique number. There are companies that also link this unique number to an electronic number. They make a unique RFID (Radio Frequency Identification Device) transponder that can be used in combination with one of the yellow ear tags. A lot of farmers use RFID tags that are connected to the collar of the cow. The principle of these RFID tags is same as the RFID used for official

identification and registration schemes, but there is one important difference. The advantage is that this RFID can be electronically read, allowing the use in automatic systems. In such measuring systems each sensor identification will be allocated to an RFID of an unique cow. Most of the time these sensors have a unique code that has some logic meaning from the sensor perspective. In the ideal situation the sensor information is directly connected to the unique cow number. In most situations where this cannot be realized then a up to date and unambiguously administration is needed to know which sensor is connected to which cow at what moment in time. Beside cows there are other objects of interest. If we look to an automatic milking system, there are a lot of sensors incorporated that should be connected to a specific milking robot, which is then the object of interest.

The second important issue for measurements is to allocate it to a specific time. As discussed earlier in chapter 3 and 4, time plays an important role and several methods can be used to express time. In real time sensing systems time is also used to identify events. The time of an event is given in e.g. date-hour-minutes-seconds-milliseconds if it is within the technical sensor system very time critical, e.g. radar systems use timestamps to calculate the distance between sending and arrival of a signal. On another level the time of beginning and end of a visit to a concentrate feeder can be used to calculate meals. For this the level of seconds or even minutes is detailed enough.

The third part is knowing the location where the measured signal originates from. Outside in the grassland field this can be expressed as a field number (that belongs to a unique farm name/number) or when GPS are used as a GPS coordinate in latitude and longitude. Inside barns the location is not yet expressed as a standardised GPS coordinate. In some cases the barn or the pen is identified and given a name or number. Most of the time commercial systems to locate cows inside a barn use a relative position within a barn. The barn lay-out should then be a given in the system. So, in the area of location awareness there is hardly standardisation yet. Nevertheless, when it is important to know where something is measured it is necessary to think of how to express the location.

5.4 Examples of sensors

In practice and research there are numerous examples of sensor systems that are applied in dairy farming. It is very difficult to get an actual overview of sensors that can be bought by farmers and that are developed/used in research and industrial companies. Recently Gerardo Caja[xii] et al. published a table of existing sensors in dairy farming that are promoted by companies. A copy is shown in table (see table 5.3). In 2013 Rutten[xiii] et al. gave an overview of scientific based sensors in the invited review paper for Journal of Dairy Science. This survey shows the diversity of sensors.

Many sensors are used to support automatic systems, e.g. RFID to identify animals, sensor in concentrate dispensers to measure portion concentrates, optical sensor to detect the position of the teats of an cow in an automatic milking system, presence detection e.g. for the controlling of selection gates, a milk level detection in the vacuum separator for controlling the milk pomp. In this book is the focus on sensors that are used to monitor cow (and grassland) related aspects (e.g. cow health). In general we see that those sensors are mostly sensors are based on 3D axial accelerometers to measure activity. Besides this remote sensing techniques using cameras for NIR and 3D images are used. Thermistors and pH are used to measure the temperature and the pH inside the cow. Although there are a lot of potential meas-

uring principles it can be seen that currently accelerometers are preferred.

Throughout the past decades we can see some important steps in the development of these accelerometers. In the beginning activity was measured with 2D-accelerometers and it was expressed as a general activity g. The sensor data could be collected when a cable was connected or when the cows were near a reader. So, data were aggregated to one single value g that had no agronomic meaning and data were available only once or twice a day. Later on it became possible to acquire the data from the sensors by using wireless network technology. Also improvements in data handling and calculation power on the sensor itself made it possible to design accelerometers that used 3 axis, and could deliver data that were based on a two hours interval. Together with an improved battery life this resulted in activity meters that could be attached to a leg or on the neck. Currently these sensors are bought by many farmers to support them in their oestrus management. In the larger herds and the appropriate time interval, farmers started to rely on the signals coming from these activity meters. So, the current success is a consequence of technical improvements and fits to the current dairy farm practice. In current research and new products we see that the 3D accelerometers are also used to determine more specific information. It is e.g. possible to determine whether a cow is standing, lying or walking. When you cumulate this it is possible to get a time budget of a cow per day. Other manufacturers use additionally the 3D accelerometers to identify if a cow is eating or ruminating. This is possible thanks to improved calculation power, memory, sensor quality and almost continuously remote accessibility. It is expected that these developments will continue, and that gradually it will influence the products and services that will be accepted by dairy farmers.

Objective	Manufacturer (address[†])	Type & features	Technology used	Reference link
Milk composition	AfiLab (Afimilk, Kibbutz Afikim, IL)	In-line milk composition	Near-IR[‡]	www.afimilk.com/products/milking-parlor-automation/integrated-milking-point-analysiscontrol
Somatic cell count (SCC)	OCC, DeLaval (Tumba, SW)	Milk SCC by udder quarter	Analysis of cell ADN by u.v. fluorescence	www.delaval.com/en/-/Product-Information1/Milking/Products/Stallwork/VMS-station/DeLaval-online-cell-counter-OCC/
Body condition scoring (BCS)	DeLaval BCS (Tumba, SW)	Lower back image (loin, rump, hook, tailhead fatness)	3D imaging	www.delaval.com/en/-/Product-Information1/Management/Systems/DeLavalbody-condition-scoring-BCS/
Metabolic biomarkers	Herd navigator, Lattec I/S (Hillerod, DK)	Biomarkers in milk	Fourier transform mid-IR	www.herdnavigator.com/pages/id1.html

Objective	Manufacturer (address†)	Type & features	Technology used	Reference link
Activity behaviour (oestrous, feeding and health signs detection)	CowManager, SensOor, Agis Automatisering (Harmelen, NL)	Ear: activity, feeding, health	RF§, 3-axial accelero-meter	www.cowmanager.com/enus/
	Cow Alert, IceRobotics (Edinburgh, Scotland, UK)	Leg: activity, oestrous, health	RF, 3-axial accelero-meter	www.icerobotics.com/products/
	CowScout, GEA (Düsseldorf, DE)	Neck or leg: activity, eating time, oestrous	RF, 3-axial accelero-meter	www.gea.com/global/en/products/activity-detection-cowscout.jsp
	Qwes (Lely, NL)	Neck: activity, oestrous rumination	RF, 3-axial accelerom-eter	www.lely.com/en/milking/detection-system/qwes
	Activity meter, DeLaval (Tumba, SW)	Neck: activity, oestrous, health	RF, 3-axial accelero-meter	www.delaval.com/en/-/Product-Information1/Management/Systems/Activitymeter-system/
	Silent Herdsman	Neck or leg:	RF, 3-axial	www.afimilk.com/products
	Afimilk (Kibbutz Afikim, IL)	activity, oestrous, rumination	accelero-meter	products/cow-monitoring
	MooMonitor, DairyMaster (Tralee, IE)	Neck: activity, oestrous, health	RF, 3-axial accelero-meter, SMS¶	www.dairymaster.com/heat-detection/
	HeatPhone, Medria (Chateaubourg, FR)	Neck: oestrous, health	RF, 3-axial accelero-meter	www.medria.fr/en_GB/produits/heatphone.html
	Gyuho SaaS Fujitsu (Fukuoka, JP)	Leg: activity, oestrous, health	RF, 3-axial accelero-meter	www.fujitsu.com/jp/group/kyushu/en/solutions/indus-try/agriculture/gyuho/
	HeatWath II, CowChips (Manalapan, NJ, US)	Tailhead: oestrous	RF, pressure	www.cowchips.net/index.html

Objective	Manufacturer (address†)	Type & features	Technology used	Reference link
	Heatime, EFS (Westmeath, IE)	Neck: activity, oestrous, health	RF, 3-axial accelerom-eter	www.efsltd.ie/
	HeatSeeker, BouMatic (Madison, WI, USA)	Leg: activity, intake, oestrous, lameness	0	www.boumatic.com/us-en/products/heatseeker1
	RumiWatch, Itin+Hoch (Liestal, CH)	Nose and leg: activity, intake, drinking, rumination, lameness	RF and USB‡, 3-axial accelero-meter, thermistor, pressure	www.rumiwatch.ch/index.html
Lameness	StepMetrix, BouMatic (Madison, WI, USA)	Platform for gait consistency	Time and force sensor	www.boumatic.com/eu-en/products/view/stepmetrix
	Gaitwise, ILVO (Merelbeke, BE)	Mat for gait consistency	Time and force sensor	www.dairycareaction.org/uploads/2/4/2/6/24266896/4.2_van_nuffel.pdf
Mating alert	Celotor (Cali, CO)	Harness reader and tail inject	RF, SMS	www.celotor.com/celotor/partes-y-operacion
Calving alert	Vel'Phone, Medria (Châteaubourg, FR)	Vaginal temperature	Thermistor, SMS	www.birth-monitoring.com/home/birth-monitoring/
	iVET birth-monitoring (Papenburg, DE)	Vaginal temperature	Thermistor, SMS	www.birth-monitoring.com/home/birth-monitoring/
	Moocall (Dublin, IE)	Tail ring	Accelero-meter, SMS	www.moocall.com/
Rumen function	eCow Devon (Exeter, UK)	Rumen bolus: pH, tem-perature, drinking	RF, pH electrode, thermistor	www.ecow.co.uk/

Objective	Manufacturer (address†)	Type & features	Technology used	Reference link
	San'Phone, Medria (Chateaubourg, FR)	Rumen bolus: temperature, drinking	Thermistor, SMS	www.medria.fr/en_GB/produits/san-phone.html
	Well Cow (Roslin, Midlothian, UK)	Rumen bolus: pH, temperature	RF, pH electrode, thermistor	www.wellcow.co.uk/bolus/
	SmaXtec pH & Temp Sensor, SmaXtec Animal Care (Graz, AT)	Rumen bolus: pH, temperature, drinking	RF, pH electrode, thermistor	www.smaxtec-animalcare.com/en/products-services/smaxtec-ph-temp-sensor/
Integrated functions	SmaXtec Sensor, SmaXtec Animal Care (Graz, AT)	Rumen bolus: activity, temperature, drinking, oestrous	3-axial accelerometer, thermistor	www.smaxtec-animalcare.com/en/products-services/smaxtec-sensor/
Position location	WildCell, Lotek (Ontario, CA)	Neck	GPS, RF, temperature sensor, 2-axial accelerometer	www.lotek.com/wildcell.htm
	CattleWatch (Rehovot, IL)	Neck, ear	GPS, RF	www.cattle-watch.com/
	Ser. 500 Cluster Geolocation System, Omnisense (Cambridge, UK)	Neck	RF, mesh network indoors (200–400 m)	www.omnisense.co.uk/agriculture.html

† Officially assigned country codes: ISO 3166–1 alpha-2 codes
‡ Infrared spectroscopy
§ Radio frequency (ultrahigh frequency)
¶ Mobil-to-mobil short message service
♯ Universal serial bus connection

Table 5.3 *Currently available engineered devices for monitoring the performances and wellbeing of dairy cows after Caja et al.* xii

5.5 Packaging and accuracy

In general farmers and producers want to have cost efficient sensors that they can rely on for a long period, that can function in the dairy environment and that give accurate and useful information. During product development all these elements have to be taken into account. In dairy we see a lot of sensors integrated in the milking machine. Measuring the amount of milk and the milk quality does not require direct contact with the cow itself. Sensors have to be integrated in the milking units and milk transportation system and designs have to be based on minimal influence on the milk stream and maintaining milk quality.

Camera technique is used to observe attaching teat cups, but also to observe locomotion of walking cows. The casing of these cameras should"cow prove". Size of cameras and functionality is rapidly changing.

On the outside of the cow sensors are combined with the RFID. Sensors can be attached to a leg, on the neck, in an ear or on the tail. Depending on the location on the body the casing differs. On the neck they are generally bigger than on the leg or the tail, also the bands to connect the sensors differ. Attachment on the neck collar depends on the application. If rumination should be measured then the neck collar is fixed tighter then when only activity is measured. Some neck based activity meters require that they are positioned at a specific place. Then the collar should be designed in such a way that this can be guaranteed.

The last example is the use of boluses that are placed in the rumen and used to measure pH in the reticulum. Since they have to be inserted via the mouth and stay in the rumen the sensors should be small enough to be inserted and heavy enough to stay in the rumen. The material used for these boluses should also survive the acidic environment in the stomach of the cow. So, design of the sensors has to deal with different aspects. For this book we limit it to some general aspects. Accuracy, reliability and feasibility of the sensors and battery lifetime are important aspects in the design phase. When people are asked, they want the highest accuracy and a long lifetime of the sensor. In practice it is a result of choices made in the development process, the price of materials, the available technology and the marketing strategy of a company. At the moment there is no general requirement on accuracy, except official milk meters and RFID tags for I&R have to be certified by ICAR. The rest is based on what is possible and accepted by the market.

Be aware that most of the time sensing systems measure indirect variables and that these measurements should be connected to the right object of interest (cow, parcel, ..), at the right time and at the right location.

Adoption in practice of sensing systems is not at the same level as research and innovation.

Data analytics

Visualization, Models, Statistics, Artificial intelligence

Process

context

time

Period
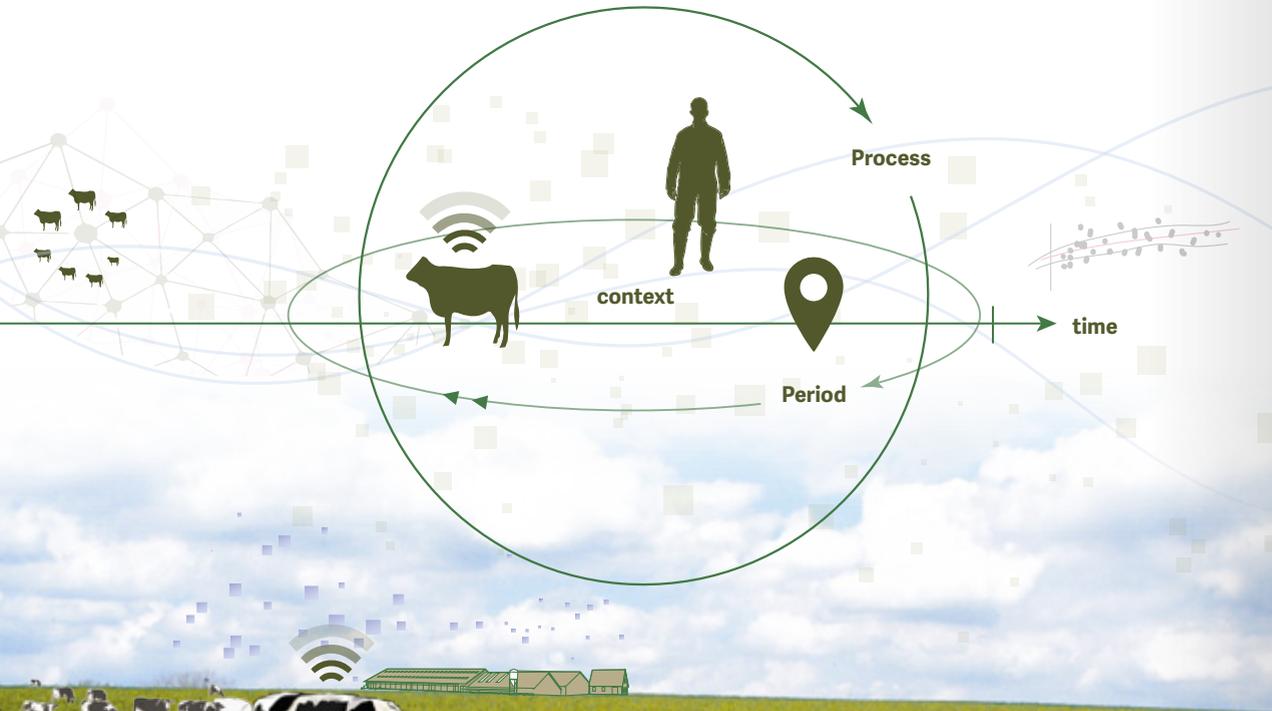
What to learn in chapter 6:

- **Select data that relate directly or indirectly to the process that needs to be managed.**
- **Most of the time more data (from different sensors) have to be analysed simultaneously.**
- **Some insight in difference between statistical methods and artificial intelligence.**
- **Awareness of quality and characteristics of references to be used.**
- **Interpretation of information depends on specific context (time, location and object of interest specific) and leads to knowledge and data based decisions.**
- **Performance of decision support depends on fine tuning of models (sensitivity and specificity) and accuracy and precision of sensing systems.**
- **Farmer as user should be aware of these possibilities.**

6. Data analysis to transform data into information and knowledge

6.1 Introduction and visualisation

The goal of data analysis is to give meaning to the data. Meaning in such a way that patterns, clusters can be seen and ideas of relationships can be formed and translated into a format so that the farmer can act on it. So, data analysis is key to Smart Dairy Farming. In chapter 4 'From data to action' the basic steps were already explained. In this chapter we introduce some basic insights on how to handle data.

In general the first step that always has to be taken is to visualize the acquired data. When visualizing data it is possible to get an impression on what the data looks like. Data can be visualized in all kinds of combinations. A well trained analyst already get an impression of the potential relations, outliers in the data and in the range and distribution of data. An example of a data visualisation is discussed on the basis of the weighing data of a calve presented and discussed in figure 6.1.

In Figure 6.1 the raw weight data are shown of 120 days automatic weighing data of a calve at Dairy Campus. In this visualisation of the raw data already different things can be seen. When looking at the range and the expression in the axes it can be seen on the x-axis that the data is presented as the days in a year. In the heading it is mentioned that the calve was born on December 25th 2014. So from this it can be expected that the presented days in the year are from 2015 and that it almost correspondents with the age of the calve. This helps in interpreting the data. On the y-axis the range of the weights can be seen. The axis is from 0 till 130 kg. It can be noticed that there is no data recorded during the first weeks of the life of the calve. This is probably because during that period the animal was housed in a calve box without weighing facilities. In the beginning of the year the data points range from ~10 kg till ~75 kg. When the calve becomes older, at the end of the 120 days of observation, data ranges from ~10 kg till 130 kg. Seeing that the minimum values for the whole period are ~10 kg raises some questions, since it cannot be expected that the calve stays at the same weight. So, it might be expected that this minimum value is a threshold in the software of the measuring system. The threshold does not include a mechanism adjusting on the bases of the age (or expected weight) of an animal. Values below the threshold are not
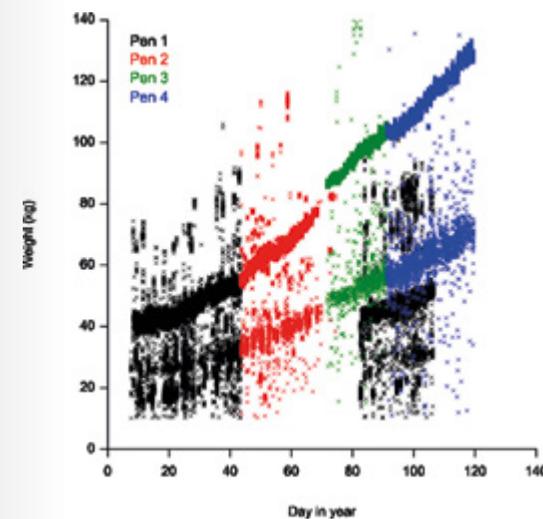
← **Figure 6.1** *Visualisation of raw data for one calve 4463 NL746644638 (born at 25-12-2014) at Dairy Campus (data from DeMol)*

reported, and the measuring system is not aware of the age or expected weight of the measured calve. The maximum measured weight grows from ~75 kg in the beginning of the year till an unknown value. The visualisation shows only data till 130 kg, but looking at the figure it can be expected that there are also weights that will be higher. In the visualisation four different colours can be seen. From the legend in the figure it can be seen that the calve was housed in 4 different pens. Each pen had a specific colour. Interesting to see that the black dots appear again later on when also blue prints for the same calve are present. It appeared that the colour used for this calve later on was used for a new calve in pen 1, but the connection between band and the valve name was changed. Then the question might also be whether the data came from four different weighing platforms and if each weighing platform might have its own characteristics (mechanical construction, accuracy, measuring mistake, tare possibility). Looking to the 'outliers' in the higher regions of the weight it seems that they are hardly presented in the blue and green spots and more in the red and black spots. Is this also an effect of the measuring system? In the figure there seem to be two prominent lines. One from ~40 kg till 130kg and the other from ~20kg till ~70kg. In interpreting this it is an advantage to have some dairy background knowledge and insight in the weighing system, how it is functioning and placed in the barn. It can be expected that a calve grows in the first three months from 20 till 75 kg. Then the upper line indicates that in quite some cases e.g. two calves were present at the same time in the weighing system and that it only could be attributed to one of the two. On the other hand if you can expect a calve to weigh around 40 kg at birth and it will grow in the first three months till ~130kg then the lower line might indicate that there are quite some measurements of a calve that

only stood on the weighing platform. Based on dairy expertize it is known that this should come from her front legs. From this it can be seen that robust dairy knowledge and being aware of the measuring system gives you a good hint in analysing the data properly and made it possible to come up with a good measurement. This visualisation shows the weights based on measurements per 5s. They are plotted in a figure with on the x-axis a day number as unit. Within one day more measurements could occur. Looking at the natural calve behaviour it would be nice to visualise the data with respect to the time of day. You can do this to see whether there is a diurnal pattern present that should be corrected. A recurring discussion is that weight differs during the day. A nice exercise in this case is to try to make a weight balance of a calve and to plot it on a 24 hours period. Input for increasing weight for young calves can come from milk, water, concentrate and roughage intake. Output is the amount of urine and faeces excreted. Then it can be estimated how frequent per day this happens and what the size of input and output is. This rhythm might have severe impact on the weight of the calve. In the data analysis this has to be discussed. Should there be a correction for time of measurement or is it just simpler in this case to taking all measurements and calculate the weight average for that day?

6.2 Statistics and Artificial Intelligence
Where visualisation is needed to get some basic insight into the measured data and getting hints to understand the measuring system in relation to the performance of a cow or calve (in essence the 'object of interest'). It is based on human interpretation and there is also a need for a more scientific proof. In delivering this proof several different tools are used. Depending on the character of the data and the decisions that need support, people can choose between a variety of data analysis

techniques. In general there are two main streams: statistics and artificial intelligence.

According to Wikipedia[xiv] statistics are mathematics dealing with the collection, analysis, interpretation, presentation, and organization of data. Statistics work with populations in mind or a statistical model. Statisticians collect data by developing specific experimental designs and survey samples. Representative sampling assures that inferences and conclusions can reasonably extend from the sample to the population as a whole. Two main statistical methods are used in data analysis: descriptive statistics, which summarize data from a sample using indexes such as the mean and standard deviation, and inferential statistics, which draw conclusions from data that are subject to random variation (e.g., observational errors, sampling variation). In statistics all kind of data can be handled. They have to be characterised on an appropriate scale. According to Wikipedia nominal measurements do not have a meaningful rank order between values. However, ordinal measurements have imprecise differences between consecutive values. Interval measurements e.g. have meaningful distances between measurements defined. Ratio measurements have both a meaningful zero value and the distances between different measurements are defined which permits any rescaling transformation. Because variables conforming only to nominal or ordinal measurements cannot be reasonably measured numerically, sometimes they are grouped together as categorical variables. Ratio and interval measurements are grouped together as quantitative variables, which can be either discrete or continuous, due to their numerical nature. In statistics there are numerous theories and examples for hypothesis formulation, error handling, estimation procedures and significance. The theory and background will not be discussed in this book.

Thus the nature of statistical based data analysis is that it has a focus on distributions and proof of relationships in well-defined experimental conditions. Extrapolation and application of these relationships in the real world require extra attention with regard to the conditions.

Artificial intelligence is another category in the field of data analytics. Artificial intelligence started to develop since the sixties of last century and coincided with the rise and development of computer technology. Therefore the term machine learning is often used. The term "artificial intelligence" is applied when a machine mimics "cognitive" functions that humans associate with other human skills, such as "learning" and "problem solving". According to Wikipedia[xv] traditional research in artificial intelligence focused on reasoning mechanisms, problem solving mechanisms, knowledge representation, planning, learning, natural language processing, social intelligence, creativity and the perception and the ability to move and manipulate objects. Although artificial intelligence can also include statistical methods, it is more often identified with techniques such as neural networks, case-based reasoning, expert systems and most recently the technique of deep learning.
In the perspective of Smart Dairy Farming the data analytical concept of artificial intelligence seems to address the learning and problem solving techniques in a 'real time' environment. We have to address the complex varying circumstances on animal and group level. So, the expectations from artificial intelligence are high. However, the complexity is still in the human factor. In order to adopt them, humans want to understand and explain the reasoning mechanisms, which is a paradigm, since this is not in the nature of artificial intelligence methods.
As an example a typical normal distribution

is shown as a representative of the statistical school in figure 6.2. In the same figure a neural network is shown as a representative of the artificial intelligence school. The normal distribution expects that measured data perform this behaviour. If this is true, you can then calculate the abnormality of a new measurements. When the new measurement is e.g. higher than the 'average + 3 ' then it is seen as a severe deviation. In the case of the neural network you have to depend on the training of the network. And when a new measurement is used as input it also delivers an output value. However, how to interpret this output is sometimes difficult to explain for humans. If a machine or control system is part of the system then it will be capable of interpreting this output and can connect it to an action.
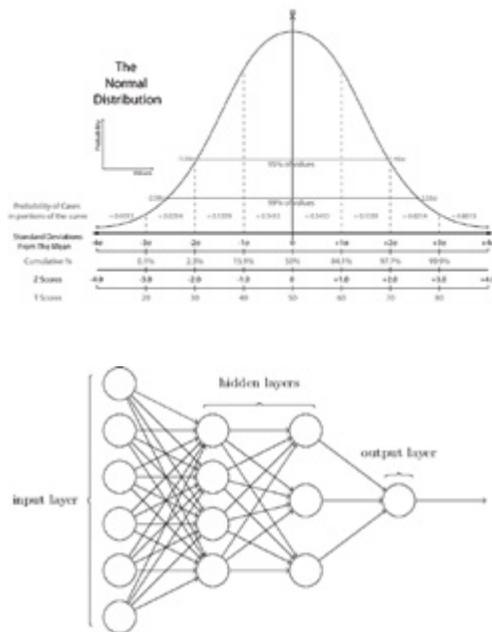

Figure 6.2 Typical examples from the statistical (normal distribution at the top) and the artificial intelligence (neural network at the bottom) schools.

In the actual world of smart dairy farming we see both schools represented. When the amount of data rises, the complexity of the relations between data becomes higher and the calculation power of computers grows. We see more and more applications being developed that are based on artificial intelligence. By nature they might fit better to the basic of smart dairy farming, but the difficulty to understand the underlying mechanisms and the need to involve humans in most of the decisions are main barriers for applications that are based on artificial intelligence.

6.3 Univariate and multivariate analysis

When analysing data it is important to be aware where you are looking at and if you are working with just one variable or with more than one variable at the same time. To explain some of the differences the basic insights comes from figure 6.3.

In the case of a univariate analysis we take the example of activity data that can come from a 3D accelerometer. From table 6.1 it can be derived that an increase in activity might be a good indicator that a cow is becoming in oestrus. However when activity is lower than expected it can be an indicator for an infectious disease, a metabolic disease or an upcoming lameness for that cow. If warning and sensing systems are based on measuring just one variable, one should be aware of the quality of the system. In this example the increased activity might be useful in oestrus detection. However, the quality of the warning then depends on the underlying quality of the data, the time interval used, the housing of the cows, the used reference method and the specific settings made at the farm for attentions. When the activity is lower than expected then there are still more options for potential causes. In this univariate approach the warning can be given to the farmer, but

	Milk yield	Milk temperature	Electrical conductivity	Activity	Concentrate intake
Oestrus	-/0	+	0	+	-/0
Mastitis	-	+	+	0	-/0
Other infectious diseases	-	+	0	-	-/0
Metabolic diseases	-	0	0	-	-
Lameness	-	0	0	-	-/0

+ = increase, - = decrease, o= no change

Table 6.1 Expected change in variables for oestrus and some diseases[x] (see also Table 5.2 in this book)

in his interpretation he should be aware that there might be different causes and that further observations might be needed.

To overcome this, multivariate analysis is used more often. In this multivariate approach the potential causes are the starting point. When checking whether a cow is in oestrus it is possible to check whether there are deviations in milk yield, milk temperature and concentrate intake at the same time. Combining these deviations increases the probability that the warning of a cow is becoming in oestrus is correct.

In research and during product development the challenge is tried to develop a warning system that is applicable on all farms. However, mostly the outcome is with the fact that in practice there are quite some different situations and that not all sensors (in the multivariate case) are present on a farm. A second experience was that not all cows or herds showed the same response. There might be other factors that can be relevant as well, but are not yet integrated (e.g. stall climate and stall lay out). To overcome this, it might be needed to make the systems more flexible, in such a way that it can be easily adapted to

a farm situation. On the other hand, farmers would be encouraged to be aware of how their cows and herds respond. In this sense the warning system might fit much better to the specific farm situation and the management of the farmer.

6.4 Use of references

In data analysis it is very important to know what is the accepted 'normal' situation. When knowing what is normal also abnormalities can be identified. To be able to do so references are used. A reference in this case is a value or a description for a variable that is seen as normal. Sometimes this is expressed as a single value and sometimes as a band around a value. In practice there are a lot of different references that can be used. In this section we want to show that the choice of a reference depends on the related process and decisions to be taken.

To get some insight, weight data of 10 calves from March 12th till April 18th 2103 are plotted in figure 6.3. The y-axis shows the weight in kg on a specific date. The x-axis shows the day number in 2013. When analysing this specific group and studying which calves underperform then a reference which shows

the expected weight at a specific age might be needed. For this purpose the growth curve or table from the breed could be used. This growth curve should then be integrated in figure 6.3. This is not always an easy job because growth curves and tables do not always use the same time axis, e.g. most growth curves have the age in months as x-axis. Another reference can come from a benchmark with growth results of calves from the same farm from the past or with a benchmark from a group of calves in the same age from a few other farms. The third method can be to calculate the group average and the standard deviation. Then from the comparison it can be learned which calves over-perform and which under-perform. Interesting fact in figure 6.3 is that it reflects quite well on what can be seen in the barn. Probably not all calves in the group are born on the same day. So the overview probably shows calves with different ages. If data are corrected according to that information, the x-axis should be transformed to age in days and then the figure might look different (less distance between the lines). In addition figure 6.3 shows that daily growth data can be used for early warning. It is clear that this early warning needs references on individual or group level. Although the references are not shown in figure 6.3, three different blocks indicate some potential issues. From left to right the first block shows that weights of all calves are increasing at the same time. This might find its cause in the measuring system itself or in a group issue. If they all have the same specific food adjustment and they respond in the same way this might be an explanation. The second block shows the weight of calve 5. In this block you see that from day 95 onwards there is a small change in growth and around day 105 there is a faster disturbance in the growth with more variation in consecutive days. Also in the third block for calve 9 it can be seen that around day 97 growth is lower than expected,

although this drop can also be seen for some of the other calves. So references and warning systems should be able to deal with these different circumstances. The choice for a reference can vary. Even on an individual calve level the farmer can choose for a fixed reference. However, for a proper early warning a more dynamic reference should be used. One reference method can be based on the statistical method. If you have single observations from a population you can calculate the average and standard deviation. Then you can decide that the lines with average plus minus 2 or 3 times the standard deviation are the references. If a measurements then falls outside this zone you have an attention. Be aware that this reference is based on the statistical philosophy.

An alternative method is to determine the reference that is used in theory from time series. Based on the assumption that the best predictor for a measurement is the previous measurement you can use time series, such as moving averages to determine the expected value. This is an alternative to the earlier mentioned calculation of the average. A new upcoming popular way to determine the reference value is the use of dynamic linear modelling. Based on statistical information every time a new measurement is added, a new confidence interval will be estimated. In this sense the references are following the observation of a specific object, in this case the weight of the calve. These methods are very helpful in identifying fast changes in behaviour of measurements. To catch the more slow changes a mix of reference values might be beneficial.

6.5 System requirements and testing
Nowadays physical (e.g sensors) and software (e.g data analytics) systems become more and more integrated. As an example an automatic milking system consists of many
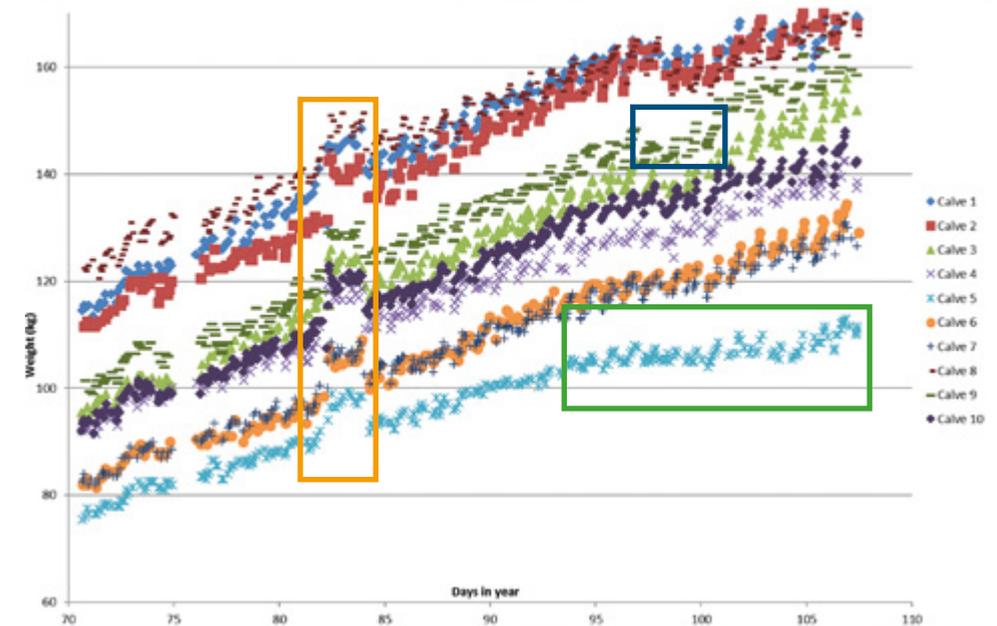
Figure 6.3 *Calve weights of 10 calves at Dairy Campus (period march 12th till April 18th 2013)*

hardware parts and a lot of software parts. So it is important to see that a 'system' can be divided into subsystems. Even subsystems can be divided until you come to the lowest level of functionality. In system development requirements should be defined. These requirements can have a variety of forms. For mechanical functions e.g. that it should function between -20 0C and + 50 0C, in a humid environment and at least battery life shall be 5 years. For software or models one can think of the early warning should detect more than 95% of the real cases. The farmer should not receive any false attention or the size of the buttons on a cell phone should not be smaller than 0.7 cm.
The function of having requirements is sometimes underestimated. However, it forces the developers to think on functionality of the (sub)system and what to expect from performance in advance. This is to challenge the developers in formulating requirements that can be achieved, and that are realistic. It also helps to streamline the discussion between

the developers and the users (e.g. dairy farmers). If in advance no expectations are set for proper functioning of a (sub)system then this will lead to disappointments. A big risk is that the system is not defined well enough and that the requirements are not realistic. Requirements should be formulated in a SMART way. They should be Specific, Measurable, Attainable (Achievable, Actionable, Appropriate), Realistic (Relevant) and Time Bound (Traceable, Timely). There are more variations in the SMART definition on requirements. Therefore between brackets some alternatives are given. In essence they all have the same direction.
If requirements are formulated SMART it is possible to do a proper test. Testing also comes back in all development methods. Testing is essentially trying to find out whether the requirements are fulfilled for a specific (sub)system. Testing can be done in quite some different ways. Therefore within a development process one has to agree not only on the requirements, but also on the

methods of testing. In practice more testing methods might be available most of the time. Each test method might have its specific (dis)advantages and costs. On each system or subsystem level requirements are formulated and a specific test can be allocated. These tests can focus e.g. on a specific unit and test whether a specific model or algorithm delivers the right output. Also integration aspects of different sub-systems in a larger system have to be tested. At the highest product level there also is an acceptance test. Testing will have its costs and is not always possible: because the system cannot be built yet or the circumstances to test are in a very harsh environment such as in a manure pit with toxic gasses are too hard. In those situations expected behaviour of the system can be simulated. So, besides logical and practical experiments simulated environments or games can also be used in the testing of systems.

6.6 Validation

While developing and testing systems (sensors or decision support models) one should be aware of some basic principles. Some of these will be introduced. Of course the different elements of the SMART requirements have to come back in the testing. Especially for the specific system, subsystem or unit that is tested. What is measured and how traceable and time related this measurement is.

Accuracy and Precision
Testers should be aware of the difference between accuracy and precision. Figure 6.4 gives a nice visualisation on the difference between accuracy and precision. Given a set of measurements, the set can be said to be precise if the values are close to the average value of the quantity being measured. While the set can be said to be accurate if the values are close to the true value of the quantity being measured. The true value comes from

the chosen reference value or golden standard. The two concepts are independent of each other, so a particular set of data can be said to be either accurate, or precise, or both, or neither. In practice testers most of the time want both: having a high precision and a high accuracy at the same time. It is clear that statistical theories form the background of these principles. Being able to repeat measurements on the system and concurrently measure the golden standard one is capable of calculating the accuracy and precision. Precision is sometimes introduced as repeatability. Accuracy is sometime introduced as agreement. Important is to be aware of what you are testing.
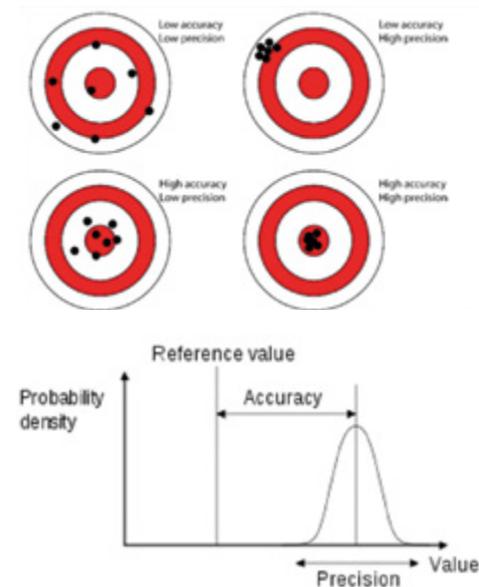

Figure 6.4 *Visualisation of difference between accuracy and precision*[xvi].

Beside accuracy and precision we should be aware of uncertainty. Uncertainty in the measurement can be a result in the measurement itself or in the stochastic environment itself.

Sensitivity and Specificity
A second basic principle of testing systems is the difference between sensitivity and specificity. Sensitivity and specificity are statistical measures of the performance of a classification test. Sensitivity (also called the true positive rate) is the extent to which true positives are not missed/overlooked and measures the proportion of positives that are correctly identified as such (e.g. the percentage of sick cows who are correctly identified as having the condition to be sick). Specificity (also called the true negative rate) is the extent to which negatives really represent the condition of interest and measures the proportion of negatives that are correctly identified as such. In practice there is a trade-off between sensitivity and specificity. In Smart Dairy Farming early warning systems should have a high sensitivity because you do not want to miss a cow that is coming to oestrus or that is becoming too late. On the other hand, in Smart Dairy Farming farmers want a high specificity because every time you get a warning that a cow is in oestrus or is sick you have to check it yourself. It is rather annoying to find out that the warning was a false attention. Then your trust in the system declines and the next time you might think that you do not have to react any more.
To calculate sensitivity and specificity a confusion matrix is constructed (see figure 6.5). In this confusion matrix it can be seen that testing is always based on an experiment where all measurements together form a population. In the confusion matrix some basic calculations are also shown. Besides the explained sensitivity, specificity, accuracy and precision also prevalence is highlighted. Prevalence is the number of positive conditions according to the golden standard related to the number of observations. As an example a prevalence of 25% of lame cows indicates that 25% of the cows in a specific herd were really lame according to the used golden

standard. This confusion matrix stresses the relevance of having a golden standard/reference that is close to the primary process even more, as discussed in Section 6.4.

In practice, it appears very difficult to have a high sensitivity and a high specificity at the same time. People have the possibility to influence the specificity and the sensitivity by altering the threshold or references. To express the trade-off between sensitivity and specificity Receiver Operating Characteristics (ROC) curves are used. In statistics a ROC curve is a graphical plot that illustrates the diagnostic ability of a classifier system as its discrimination threshold is varied. The ROC curve is created by plotting the true positive rate (TPR), also known as sensitivity, against the false positive rate (1- specificity) at various threshold settings.
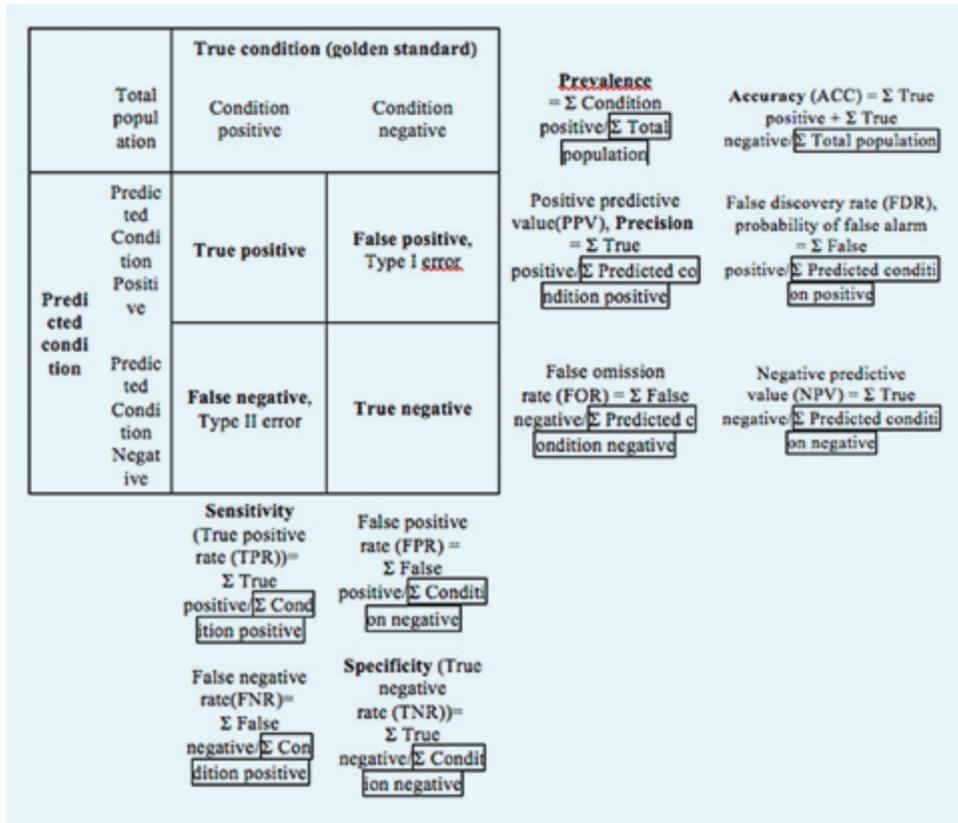
Figure 6.5 *Confusion matrix* [xvii]
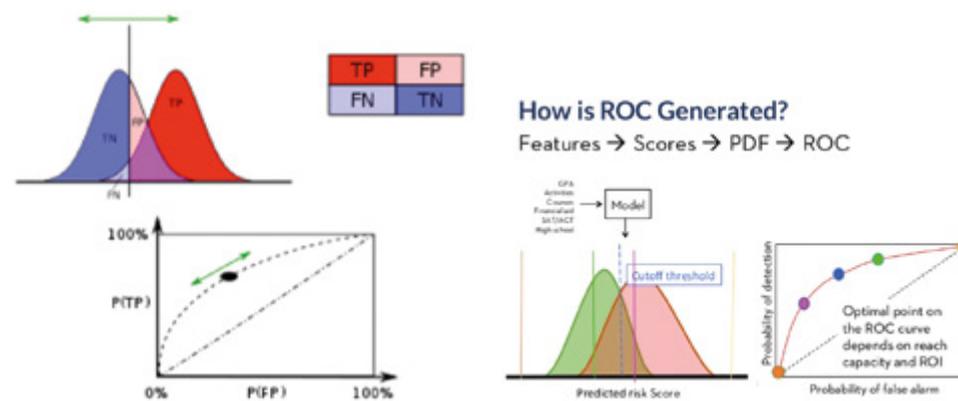
Figure 6.6 *shows an example of how an ROC curve is generated. It gives a graphical representation of the trade-off between sensitivity and specificity for different threshold settings. Example of how an ROC curve is generated* [xviii].

We have seen that testing is coming back in all phases of product and application development. Testing takes time, budget and energy and therefore there it is a big risk that proper testing will be discarded. For every test a proper experimental design has to be developed. The goal and expectations of the test have to be specified. And then material and methods have to be chosen in such a way that the outcome of the experiment can be analysed accordingly and can be used to learn from or to conclude whether the requirements are fulfilled or not. In Smart Dairy Farming several tests have to be performed. Specific attention is needed for model development and testing. In research it is not allowed to have the testing on the same data that were used for the model development and model calibration. When dealing with model development one has the possibility to split a dataset when data are already gathered. Two third of the data can be used for model development and the other one third randomly chosen data can be used for validation (testing) of the model. An alternative is that time series from a specific period are used for model development and model calibration and that a new time period will be used for model validation. Keeping track of the different steps in product and application development, the determined requirements and agreed test methods and test results will help to optimize product development.

Data analysis can have its origin in statistics or artificial intelligence, where the Smart Dairy Farming concept fits best to the learning capabilities of artificial intelligence. Crucial is the possibility to choose appropriate references that fit to the farm specific situation and that supports multi variate analysis.

Work instruction

SOP

What to learn in chapter 7:

- Formalization of work instructions in WHO should do WHAT, WHERE, WHEN and HOW.
- Farmer as user has a role in systematic process of writing and designing SOP's and to make them farm specific.
- A SOP is always directed to an Object of Interest.
- SOP users can be humans (owner, personnel, family), service providers or machines.

7. Action based on standard operating procedures (SOP)

7.1 Users of SOP's

In order to come from data to action as described in chapter 4 it is an important step to determine the advisable action. For this it is important to be aware of who will perform the real action and to which process it belongs. The action will be performed on a specific object of interest, at a certain moment in time, at a specific location, with a predefined method, with an 'amount' of action and by a certain actor. At a dairy farm the actor can be a human or a machine. Humans can have different backgrounds, characteristics and functions. It can be the farmer, a relative or his employee. Also a service provider, such as a hoof trimmer, can be a human actor. The form and the way these humans receive instructions might differ. Some can do with informal verbal instructions while others need a detailed description of what and how to work. Service providers do not need instructions on how to work, but they need a 'legal' and official commitment.

Process computers, as a representative of the 'robot' actors also need instructions. These instructions are in the form of settings in the computer, and in electronic commands. This can sometimes be done manually on a screen in the barn or milking parlour, in a central application on a computer in the office or nowadays on mobile phones. There is a user interface to connect a human to the computer, but internally the action is translated into computer instructions. To communicate these instructions and the data to the actuators, different techniques can be used. When working on Standard Operating Procedures (SOP's) one has to be aware of how it relates to other activities. The position of SOP's is shown in figure 7.1. There it can be seen that it is in the decision making phase that the data is translated into a concrete action or work instruction. In that sense it differs from an action list that is only summing up the type of actions without telling who has to do the job and telling where and how to do it. The idea might be that it is overregulated, but when we work with more workers, service providers or computers (including robots) it is worthwhile to standardise it and make a proper protocol for it.
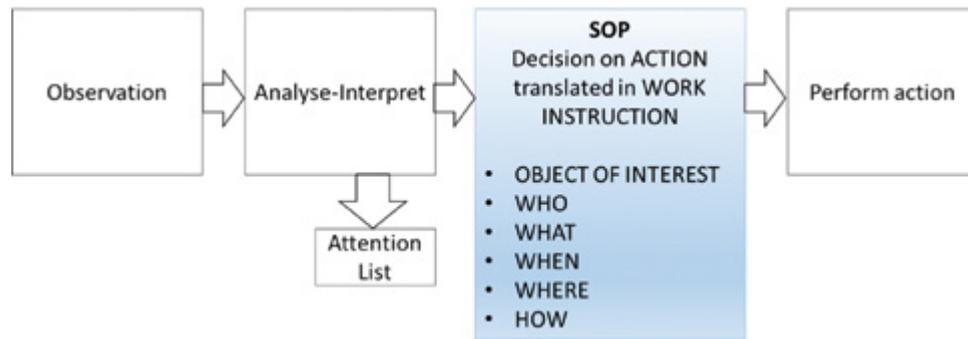
Figure 7.1 *Scheme for the position of SOP's*

Where in literature and practice SOP's are focused on written instructions for humans for all kind of types of organisations. In figure 7.1 we see the position of the SOP's between the data analysis, the knowledge based interpretation and the performing of the action. An SOP is more than the attention list, since it also describes the work instruction. For the object of interest it is exactly described who should do what, when, where and how. SOP's nowadays should not only be written instructions, but they should also be made available in electronic form. Both humans and machines can be targeted. SOP's can also be applied on dairy farms, especially to instruct the workers on a farm. This finds its origin in large scale dairy farms in the USA. The challenge is not to limit this to paper and humans, but to make it available in electronic forms and direct it to humans and machines. A balance should be found between making good and generic examples and make them available for individual farms (with farm specific situations). It shall be possible to make them quite easy to farm specific situations. Then it becomes a tool for the farmer to understand his processes better and to communicate with his advisors more efficient. So a uniform understanding of SOP's will be beneficial for more stakeholders working with the concept of Smart Dairy Farming.

7.2 Writing of SOP's
Smart Dairy Farming is a way to improve processes on a farm and make daily decisions more data driven and cow specific. A method to instruct humans is to create SOP's. In the H2020 thematic network 4D4F[xix] (Data Driven Dairy Decisions for Farmers) we adopted a method to create SOP's and produced some examples. This paragraph is based on that work.

SOP's will set out protocols how farmers should perform specific tasks in such a way that other people can do the same task according the protocol. We see that tasks and processes are supported and driven by data, these data come from sensors that are used for monitoring, advice systems and machines to perform actions. So for these situations SOP's are also needed.

But how can we make SOP's more applicable in dairy farming? Today's farms are getting more and more in touch with automatic systems, such as milking robots, sensor technology and more real-time applications that make work on a dairy farm more easy. SOP's can help to make a decision on what to do when a certain attention shows up when using sensors on cows. But farms also get bigger and bigger in size and amount of cows. This is where SOP's can also help managing a dairy farm.

How to create and write SOP's is well developed by PennState Extension and described in 'Standard Operating Procedures: A Writing Guide'[xx]. This Writing Guide contains 7 steps of developing and implementing SOP's. The seven steps are:

Step 1	Plan for results
Step 2	Create a first draft
Step 3	Internal review
Step 4	External review
Step 5	Testing
Step 6	Post
Step 7	Train

Step 1: Plan for Results
Plan which processes you want to support with an SOP with the business goal in mind. The goal of a milking SOP is e.g. not to standardize the milking characteristics of the cows, but the goal is to quickly and efficiently harvest high-quality milk and reduce the risk to the spread of mastitis organisms. Standard operating procedures work best when they are designed to achieve specific results. Decide what business goals will be achieved through better management with SOP's and how those goals will be measured. Then this information can be used to adjust procedures and provide feedback to workers about their performance. In the industry many benchmarks exist to help measure quality and efficiency in specific areas. Ask your advisers to assist in identifying benchmarks that will help you improve your business. In some cases, you might need to come up with measures on your own that will help track progress over time.

Step 2: Create a first draft
When the procedure consists of different steps and some decisions are included then it is advised to use the format of a flowchart.

Start with the most reasonable beginning point. Draw the decisions that a worker will need to make and the actions that follow each decision. Don't try to be perfect with the first draft, because it is very likely that you will need to make many revisions.
For making flowcharts of a process the next symbols are advised:

As an example the flowchart and the connected SOP's of the mastitis detection process using the LDH data from a Herd-Navigator is shown in Figure 7.2.
The process starts with a signal that comes from the Herd Navigator. The signal is that a specific cow might have mastitis. Then the action is how to check and interpret the information on the computer from the Herd Navigator. In the SOP description it can be seen that this has to be done by the farmer and takes place in the office where the screen of the Herd Navigator is located. Then the SOP on checking a cow on clinical mastitis is triggered and the someone has to perform a California Milk Test (CMT)[xxi]. The CMT is a simple procedure to determine the Somatic Cell Count (SCC) of milk. It works by using a reagent which disrupts the cell membrane of somatic cells present in the milk sample. The DNA in those cells react with the test reagent. It is a simple but very useful technique for detecting subclinical mastitis on-farm, providing an immediate result and can be used by any member of farm staff. The SOP

describes how to do it. Based on the outcome of this test the question 'Has the cow clinical mastitis?' can be answered with YES or NO. Depending on the answer two different actions can be taken. To treat or to call a veterinarian. Of course this is a very schematic description. It can be assumed that a farmer wants to make this flowchart and the SOP's

DeLaval Herd Navigator - LDH – Process detection mastitis
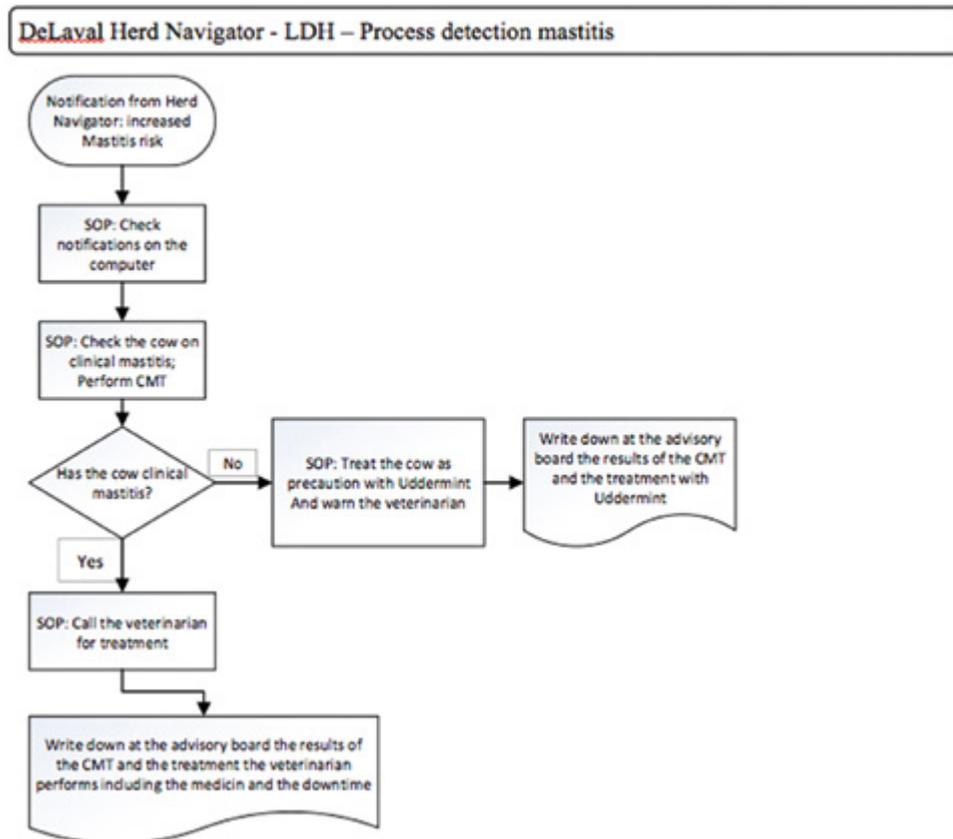
SOP – Check the notifications on the computer
Check which cows are on the attention list.

Object of interest:	Mastitis attention list
Who:	Farmer
What:	Check which cows (numbers) have an increased risk for mastitis
Where:	Office, phone (e.g.)
When:	Twice a day, in the morning and in the evening
How:	Click list of attentions

SOP – Perform the CMT test

Object of interest:	Milk of Cow #
Who:	The person who is responsible for the mastitis
What:	Perform the CMT test on all four quarters
Where:	In the milking parlour
When:	When you suspect mastitis
How:	See how to perform the CMT

How to perform the CMT
1. Clean the four-well plastic paddle exhaustively
2. Pre-milk every quarter
3. Put the four-well plastic paddle straight underneath the udder, keep around 5 cm space between the udder and the four-well plastic paddle. Milk every quarter twice in an separate cup of the four-well plastic paddle
4. Remove the four-well plastic paddle from the udder. Keep the four-well plastic paddle slantwise until the milk hits the marking lines.
5. Add CMT liquid to the milk. The amount of liquid has to be the same as the amount of milk.
6. Swerve the four-well plastic paddle for 10 seconds slowly until the milk and the CMT-liquid is mixed.
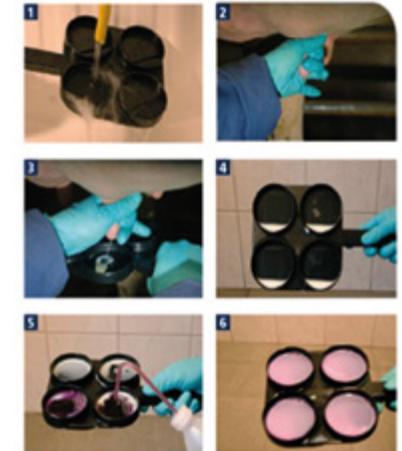
SOP – Treat the cow as precaution
If a cow has subclinical mastitis, it must be treated with care. This prevents clinical mastitis.

Object of interest:	Cow # with subclinical mastitis
Who:	The person who is responsible for udder health
What:	Treat cows with subclinical mastitis
Where:	E.g. Milking parlour or separation box when there is an AMS
When:	After milking the cow
How:	Massage the udder after milking and salve the udder with udder mint *(Before treatment check the package for instructions, follow these instructions)*

SOP – Call the veterinarian

Object of interest:	Cow #
Who:	The farmer
What:	Call the veterinarian
Where:	Wherever you are
When:	Between 11:00 and 12:00 on Wednesday
How:	Call number ... : ask veterinarian to come before 18:00 on the same day.

more specific to the situation on his farm. The structure of using a flowchart to identify the actions (SOP) that are worked out in the form of object of interest, who, what, when, where and how should be used consequently. If people are getting used to this structure then it supports the discussion on the content and it will be quite easy to adapt it to a specific situation.

Step 3: Internal Review
Provide each worker/person who performs the procedure with a copy of the draft SOP. Ask them to review and suggest changes that are easier to understand, more accurate, or will improve performances. Assure the workers that their input is important and will be used. People are much more likely to accept and use the SOP if they feel a sense of ownership. Workers will feel ownership and commitment to an SOP if they believe that management used, or at least fairly considered, their ideas during development. The chance of success is reduced when workers feel that management is imposing SOP's without regard to worker's input.
Another excellent reason to involve the workers is that they are likely to have good ideas. Highly successful managers actively engage their work teams and relations in a continual quest to become more efficient, increase cost effectiveness, and improve quality.

Step 4: External Review
Dairy managers increasingly rely on the advice of trusted advisers outside their own organization. The SOP writing process is an excellent way to tap into the expertise of your technical advisers such as the veterinarian, nutritionist, or extension agent. They can give you advice that is based on their scientific knowledge and broad experience with other dairy businesses.
Provide your advisors with a copy of the SOP draft. Ask them to suggest any changes that

will make it clearer and more effective. Dairy managers often see significant performance improvements after their technical advisers helped them with SOP's. In many cases, the procedure of the writing process takes communication with advisers to a much more productive level than ever before. Revise the procedure as necessary to incorporate input from your technical advisers.

Step 5: Testing
For procedures to be effective, they must perform in the workplace. There is only one way to be absolutely certain that a procedure is well written and performs as expected. Have someone test the procedure by performing each step exactly as it is described while the procedure writer observes. Have a person not familiar with the work follow the procedure. Any steps that cause confusion or hesitation for the test worker should be revised.

Step 6: Post
Make a final draft of the procedure and post it in the appropriate locations. The workplace is one essential location. A master SOP file should be kept in a central location so workers can review little-used SOP's when necessary. Another possibility is to include SOP's with employee handbook materials. In each case, it is essential to keep SOP's up to date. Preferably, the workplace copy of the procedure should be printed in text large enough for workers to review while completing their work. Many copy centres have the ability to make enlargements. In addition, it may be helpful to laminate the workplace copy so that it will hold up under difficult conditions.

Step 7: Train
The last step in the SOP writing process is often the most neglected. Train or retrain everyone as necessary to follow the procedure exactly. Even with very detailed steps, it is necessary to train all workers. Otherwise,

individuals will interpret the meaning of procedures in different ways, leading to inconsistency in work routines and performance. While training workers, share the reasons why procedures must be performed correctly - not just what to do or how to do it. People are much more likely to follow procedures exactly when they understand why they are important. In addition, sharing "why" demonstrates that you care about the worker and his or her success. It also helps to develop the worker's job knowledge and enhances his or her ability to contribute to future procedure improvements.
An effective SOP training program will first make the worker aware of what training activities will take place and what the trainer will be able to do when training is complete. The trainer will explain and demonstrate both why and how each step in the SOP is performed and then give the learner a chance to practice. The trainer will provide positive feedback as the learner masters parts of the procedure and patiently revisits those parts that need improvement.

Standard Operating Procedures (SOP's) are powerful tools to improve processes on a farm, to incorporate data awareness in decisions and to communicate better with family, workers, service providers and computers. It brings data to real action at the right time and place according to the expected procedure.

Media

Society

Consumer

the general public

Certification

Government

Policy

Retailer

Slaughterhouse

Bank

BANK

Research & education

Dairy processor

Accountancy

Breeding companies

Veterinarian

contractor

What to learn in chapter 8:

- **Beside the dairy farmer, a lot more stakeholders have interest in data from the cows/herds/farms (data is the new oil).**
- **The dairy farmer, together with his cows and his farm visiting advisors form the primary stakeholders for smart dairy farming. They are involved and support the operational management of the dairy farm.**
- **Learn to think in primary, secondary and tertiary stakeholders and their power, interest and influence.**

8. Stakeholder involvement

8.1 Stakeholder analysis theory

According to Wikipedia[xxii] a stakeholder analysis is the process of determining the impact of decisions, systems, concepts on relevant parties. This information is used to assess how the interests of stakeholder should be addressed. Stakeholders have also needs and expectations and they can influence other stakeholders and the product development and use. Therefore stakeholder analysis is frequently used during the preparation phase of a project, a product or a service in order to assess the attitudes of the stakeholders regarding the potential changes. Stakeholder analysis can be done once or on a regular basis to track changes of stakeholder attitudes over time. If the power and influence of a stakeholder is high and the interest of the stakeholder is also high then the stakeholder has to be managed closely. If their interest is low in this situation then you should keep them satisfied. If on the other hand the power and influence of the stakeholder is low and their interest is high then you should keep them informed. If in this situation their interest is low then you just have to monitor them.

The first step in building a stakeholder map is to develop a categorised list of members of the stakeholder community. Once the list is reasonably complete it is possible to assign priorities. Then the stakeholders with the 'highest priority' can be visualised into a table or a picture. The potential list of stakeholders will always exceed both the time available for analysis and the capability of the mapping tool to sensibly display the results. The challenge is to focus on the 'key stakeholders' who are currently important. The most common presentation styles use a matrix to represent two dimensions: interest, and power/influence. They can be scored high and low.

A way to categorise the stakeholders can be to identify:
- Primary stakeholders: are those ultimately and directly affected, either positively or negatively.
- Secondary stakeholders: are the 'intermediaries', that is, persons or organizations who are indirectly affected by an organization's actions.
- Tertiary stakeholders: are the companies that will not directly benefit from these products by an profit increase. These stakeholders benefit indirectly from data generating and management systems by enabling more efficient and/or accurate performance of their job.
- Key stakeholders: who can also belong to the first two groups, have a significant influence upon or an importance within an organization.

Sometimes it can be arbitrary to which category a stakeholders belongs.

8.2 Stakeholders in SDF

In dairy farming and SDF we can also categorize different stakeholders. Figure 8.1 shows the results of a generic stakeholder analysis for Smart Dairy Farming. It shows different circles that can be interpreted as primary, secondary and tertiary stakeholders. This figure clarifies that we start with the animal (cow/calve) and the dairy farmer as key stakeholders. Since the approach of SDF is animal and farmer centric, it is clear that the cows/calves also can be seen as stakeholders. This also applies for the crops, the grass, the subfields and fields. If we have a central role for the interactions on the farm between humans, animals, fields and on-farm advisors with delivering tools and services they all can be seen as primary stakeholders. Therefore the veterinarian, contractor and farm visiting

advisors form feed, dairy and breed companies are seen, together with the dairy farmer as primary stakeholders.

From figure 8.1 it can be seen that there are quite some organisations that might have a relation with and can be impacted by what happens on a dairy farm. Stakeholders in the circle with accountants, banks, slaughterhouses, dairy processors, feed companies and breeding companies can be seen as secondary stakeholders. Governmental, policy, certification, retailers, research and education organisations can be seen as

tertiary stakeholders. Even media, consumers and the general public might be 'connected'. The basic message is that what is happening on a dairy farm is part and of interest for a complex production network with all kind of expectations. Besides physical products they are connected through data, information and knowledge. A specific role can be seen for technology providers. They are able to provide all stakeholders in this complex network with adequate technology and techniques. That is the reason that they are also can be categorised as key stakeholders in SDF.

Figure 8.1 *Additional Smart Dairy Farming stakeholders to key stakeholders (farmers, cows, fields).*

As an example (see table 8.1) students from van Hall Larenstein University for Applied Sciences analysed the role of stakeholders with respect to data driven decision support systems and their influence on the farmers. The chain perspective of the Dutch Dairy

chain is coming back in their description. They focused on organization level and did not identify the animals and fields as stakeholders.

Table 8.1 *Example of an SDF oriented stakeholder analysis of the Dutch dairy chain (source student report [xxiii]).*

Stakeholders as influencers	Impact on farmer - how and how much?
Animal health companies - especially veterinarians (and claw trimmers)	**Short term impact** Veterinarians (and claw trimmers) are the stakeholders who visit the farm most regularly. Besides the farmer, they have the most influence on the (claw) health of the animals. Veterinarians also influence reproduction results of the animals by the performance of oestrus and pregnancy scans. These companies will have a lot of one-on-one contact with the farmer by which they can highly influence his decisions on investments in technology.
Feeding companies	**Short term impact** Feeding companies offer additional services performed by nutrition specialists visiting the farm to compose rations for the cows and heifers. These nutrition specialists visit the farmer at least every season, so 4 times a year. The nutrition specialists will also visit the farm in case there are problems with feeding or production. They can also give the farmer advice on land management. By being such an important factor for the results of the farmer and having a lot of one-on-one contact, feed companies can easily influence a farmer's decision on investments in new technology.
Reproduction (Breeding) companies	**Long term impact** Reproduction companies deliver the semen for insemination of the cows. They will visit the farmer less often, but still a couple of times a year. These companies might also give the farmer advice on reproduction choices. Although of less influence than the two stakeholder groups above. Still, these companies have one-on-one contact with the farmer by which they can influence his decisions on investing in new technology.

Stakeholders as influencers	Impact on farmer - how and how much?
Advisory companies	**Medium and long term impact** Advisory companies will visit the farm when they are asked to do so by the farmer. These stakeholder companies might differ a lot and will offer services in different forms (advice on for instance ICT/animal health problems/laws & regulations/land management et cetera). However, to be able to give proper advice, it needs to be based on practical, specific facts and results. For this it is needed to visit the farm and go through the generated data or management systems. But besides needing the data, these companies also influence the farmer's decisions on investments in new technology by visiting the farm and having one-on-one contact with the farmer.
Dairy industries	**Long term impact** Dairy product companies are currently very powerful stakeholders in the production chain. The farmers are dependent on these companies for their income and since the sector is very unstable lately, these companies can force farmers to implement certain technologies. This makes them one of the most influencing, if not the most influencing stakeholder in the decision of a farmer to invest in new technology.
Bank/accountant	**Long term impact** Although the accountant may not visit the farm very often, financial services are a big part of the decision making process a farmer goes through. To be able to invest, money is needed, and if it is a large investment, this will require a loan from the bank. Therefore the bank or the accountant can influence the farmer's decision a lot.
Equipment + software suppliers	**Medium term impact** Technical companies deliver and install the technical innovations referred to. These stakeholders will change into secondary stakeholders once the farmer has invested in one of their products. From that moment on they will be regular visitors in terms of machine maintenance and they will be able to directly influence the farmer's decision to invest in other new technologies. But beforehand, they will only reach the farmer by adverts, brochures and events and they will not be visiting his farm. Thus they won't have knowledge of the situation on the farm. Although they sell the devices and earn profits, they won't influence the decision of the farmer to invest in new technology much.

Stakeholders as influencers	Impact on farmer - how and how much?
Animal welfare companies	**Long term impact** Animal welfare companies strive for optimized conditions and care for all animals in the country. They try to achieve this by food labels for products with higher welfare standards, having campaigns, performing checks on livestock farms and more. These companies most likely do not visit the farm or influence the decision of the farmer to invest in new technology. Farmers may choose to be part of a certain label, but they cannot be forced to do so by these companies.
Researchers/ research institutes	**Long term impact** Researchers/research institutes are highly involved in the development of rules and guidelines and new technology and although data collection is crucial for them to be able to perform studies, they will not have much direct one-on-one contact with the farmer, the products are most often not implemented by the researchers in the end. Therefore researchers or research institutes do not influence the decision of a farmer to invest in new technology a lot.
Housing companies	**Long term impact** Housing companies sell and install housing systems and supplies for livestock (in this case). Although these companies might offer some technology amongst their products, they won't have much direct contact with the farmers, except for when a farmer is visiting them on a trade fair or contacts the company after seeing an advert or hearing about a certain product. These companies may become secondary influencers once a farmer has purchased a certain product that needs maintenance regularly, but beforehand these companies do not influence a farmer's decision to invest in new technology.

It can be seen in table 8.1 that there are a lot of stakeholders that might influence the farmers in adopting the SDF concept. However, it also works the other way around. Data coming from dairy farms are also of interest for these companies. They use them for developing new services and products for their own business. Based on farm data they can develop new services and add value to the data. Remote access and connectivity are now possible and it can be seen that the dairy farms are part of a complex production network. New business models for chain partners will be developed based on the SDF concept.

Data from key stakeholders (farmers, animals, fields) will also have value for all kind of other primary, secondary and tertiary stakeholders in the complex dairy production network. Data is seen as the new oil.
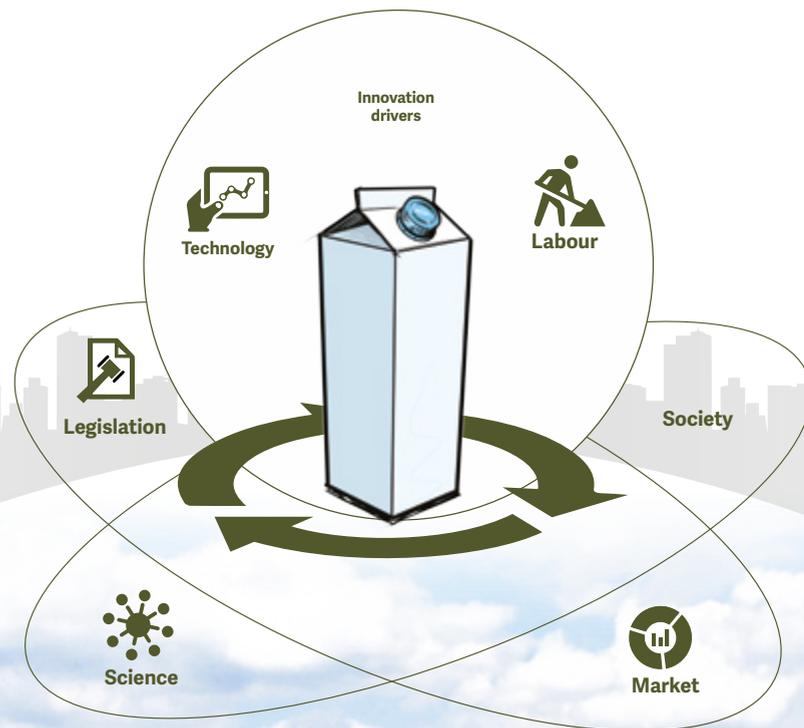
9. Innovation in smart dairy farming

9.1 Innovation background

According to the business dictionary[xxiv], innovation is the process of translating an idea or invention into a good or service that creates value for which customers will pay. To be called an innovation, an idea must be replicable at an economical cost and must satisfy a specific need. Innovation involves deliberate application of information, imagination and initiative in deriving greater or different values from resources, and includes all processes by which new ideas are generated and converted into useful products. In business, innovation often results from ideas that are applied by the company in order to further satisfy the needs and expectations of the customers. In a social context, innovation helps create new methods for alliance creation, joint venturing, flexible work hours, and creation of buyers' purchasing power.

Looking at innovations, it is important to be aware that there are several types of innovation. For Smart Dairy Farming we think it is essential to look at the following four types of Product, Service, Process, and System innovation (PSPS):

Product Innovation
A product is a physical good that is produced by a company and sold to another company or a consumer. A dairy farmer produces milk, which is a physical good, that is sold to the dairy company. A feeding company produces concentrates or fertilizers, which are physical goods that are sold to the dairy farmers. So there are different levels for product innovation, if a farmer introduces a new types of milk (e.g. milk with extern high percentages of minerals), a feeding company introduces

a new type of concentrates or grassland fertilizers (for grassland) in the market it can be seen as product innovation (although some of the product innovations might be market concept innovations (same product with a different story)).

Service Innovation
A service is action, e.g. labour or making a software module available, done for the benefit of others. Services are provided to others. When providing services, the work performed by a company does not result in a product that can then be delivered to companies or consumers. A contractor delivers a specific service to the dairy farmer. Sometimes because the contractor is more flexible and can deliver specific competences together with specific machines. Harvesting grass and maize are examples of services of contractors that are sold to dairy farmers. Specific employment agencies are also examples of services that are delivered to dairy farmers. Another example is the service that is delivered by an accountancy company. They also have specific expertise that is beneficial for dairy farmers to hire.

Process Innovation
A process is a set of coherent activities to convert input into output. A process is started by a clear trigger and ends with a clear result. Processes can be seen at different system levels. On farm level the whole process of producing milk can be seen as one singular process. However, within a dairy farm also the processes of milking, feeding, cow monitoring, climate control and grazing can be seen as processes.

What to learn in chapter 9:

- **Innovations can be on the level of Products, Services, Processes and Systems (PSPS).**
- **A company can be successful in innovations if they create either a new market or a new PSPS, or a new PSPS for a new market.**
- **Examples from the past can be inspirational for new innovations.**
- **Developments that influence labour and technology are key drivers for innovations.**
- **Developments in markets, society, legislation and science can also drive innovations.**
- **Innovation is not only based on creativity, but can also be incorporated in business development. COCD box can support decisions on innovation selection.**

System Innovation

A system is an assembly of mutually tuned but otherwise independent parts, each of which has a function in achieving a common purpose. A cow can be seen as a system. But a production group of cows, a dairy farm or even a total production chain can also be seen as systems. Looking at system innovations it is important to notice that it consists of a (complex) system where different parts have specific functions that contributes to the result of a whole system. Changes in one part of the system will affect also other parts of the system. A good example was the development of automatic milking. Although it primarily changed the process of milking of the cows, it had consequences for the cow control, the barn layout and the gazing of the cows. So the introduction of the automatic milking systems can be seen as a system innovation. Also the introduction of the Artificial Insemination had big consequences for the cooperation in the production chain and thus can also be seen as an example of system innovation. On the long term it is expected that system innovations have a much higher impact than product-, service and process innovations.

Critical note: the concept of smart dairy farming so far has been positioned as process, product and service innovation. There is no common insight in the optimal dairy production system that benefits on the long term with large effect from the smart farming concept. The system innovation projects so far focused on the design of barns with emphasis on environment, welfare, health, labour and economic benefit.

Beside the different types of innovation it is essential that there is also a market component addressed. Innovation is all about change and successful introduction and application of the product, service, process or system (PSPS) in the market. Innovations are directed to an existing or a new market. Figure 9.1 shows the expected change to occur when we talk about innovation. From this scheme three different situations can occur. The first situation is that in an existing market a totally new PSPS or a totally new version of a PSPS will be introduced. When the company Nedap, who is already active in the dairy market, introduced their new product which is able to locate cows within a barn, it can be seen as a new product for the existing market (new product in existing market).
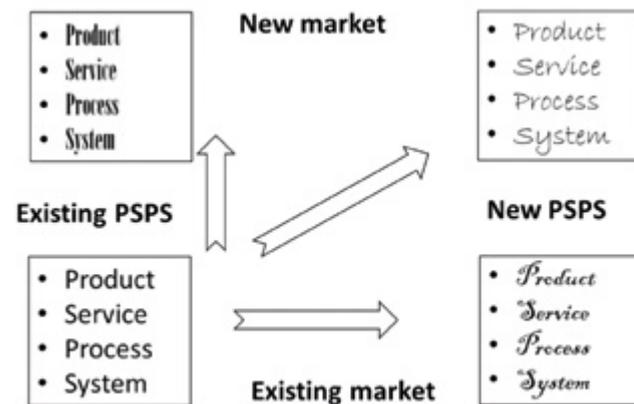

Figure 9.1 Innovation scheme with expected changes in market and/or PSPS.

The second situation can be that a company has a proven product that they want to apply in a totally different market. If we take Nedap's product as an example, the following will occur. If the company TomTom who has a product that locates a vehicle or a person introduces this product in the dairy market it can be seen as an innovation (existing product in a new market). The third situation is when a company decides to do both, create a new or strongly adapted PSPS and introduce that in a new market for them (new product in a new market).

Of course there are disputes of what is new or strongly adapted and what is a market. Also the phrase 'successfully introduced in a market' can be interpreted differently. So there is no strict definition or regulation that can be used to say that we are dealing with an innovation. Nevertheless it is good to see that both type and market should be directed towards change and success.

9.2 Innovation examples relevant for smart dairy farming

To be able to work on innovation it is good to look back in history and identify some crucial technical innovations that influenced dairy farming. These examples still form the basis for smart dairy farming, but are hardly recognised anymore as being relevant. They have become normal and are accepted as they are.

The first example is the development of the **electronic identification** of cows (RFID = Radio Frequency IDentification). Passive transponders were developed and put on the neck or in the ear of a cow. When electronic identification was possible it, together with the development of slatted concrete floors, stimulated the development of new housing and feeding systems. Concentrates rations could even be given to cows that were not

tied up any more, but part of a group. The free stall barn system became possible. This identification of the cows is the basis for the actual Identification & Registration system and has internationally become the standard. This is guided by the International Committee for Animal Recording (ICARviii) and the ISO organisation. ICAR also focuses on the standardisation of automatic and reliable milk recording. In the same period the automatic measurement of the individual milk production of a cow was developed. Being able to quantify and measure the individual milk production of a cow that was part of a group or a farm stimulated breeding programmes. Nowadays, when we talk about smart dairy farming measuring milk production and being able to identify a cow is commonly accepted technology.

Another example is the development of **management information systems**. In earlier days records of cow administration were noted on a cow card. The cow was identified based on the sketch made by certified person. On the card important dates were noted. The farm administration was based on these cow cards and a financial logbook. When personal computers came on the market also new companies came into the market that developed management information systems for dairy farmers. The cow administration was automated and later on new functionalities were added. Connection between the management information systems and the process computer for milking and concentrate feeding are good examples. Nowadays, at least in the Netherlands, all professional dairy farmers are using a farm management information system. So, for the concept of smart dairy farming there is a good administration available on key cow and calve data. In the last 50 years a tremendous change took place in the **milking of cows** and handling the milk on a dairy farm. Milking by hand

in the barn or in de field and collection of milk in buckets and bushes has gradually been replaced by machine milking with using pipe lines and cooled milk tanks for the milk storage. For smart dairy farming the real breakthrough was when milking parlours became common. In these milking parlours cows were identified and milk production was measured automatically on cow level. An alternative for this automatic measurement was the ability to work with the Milk Production Recording (MPR) programme. As a service once per three weeks the milk production was measured. This MPR resulted in standardization of indexes so that benchmarking between farms became possible. This is common practice in the Netherlands. Later on even the process of milking has been automated and fully automatic milking became possible. Nowadays in the Netherlands 20% of the dairy farmers are using an automatic milking system. These automatic milking systems are ideal in measuring performance of individual cows. Doing so, beside harvesting the milk production data are also harvested in the milking parlour.

Tie stall
feeding: farmer has to go to cow to feed her individually several times a day
milking: farmer has to go to every cow twice a day for milking her

Free barn stall
feeding: farmer has to go to the barn to feed group of cows several times a day
milking: farmer takes group of cows to milking parlour twice a day for individual milking

Automatic milking system
feeding: farmer has to go to the barn to feed group of cows several times a day
milking   cows go milking robot several times a day for individual milking

Electronic identification, milk production recording, farm management information systems and machine milking (including automatic milking) have become common practice during the last couple of generations. The concept of smart dairy farming is built on being able to measure and quantify animal, crop, field, machine and human behaviour. However, implementation of automated sensors is not common practice yet. Integrated in the process computers for feeding, milking, climate control and tractor based implements a lot of sensors are in use. However in the field of sensor development there are still big differences. Sensors integrated in process control are accepted more than independent sensor systems. From these independent sensor systems the activity meters or pedometers are the ones that are accepted. In chapter 5 'Automation of data collection and sensor technology' the variety of different sensing techniques have been explained.

9.3. Driving forces for Innovations
In order to be able to innovate it is important to see what drives innovations. Based on experience and looking at important innovations in the past the following insight *(~formula)* was developed:

$$\text{Innovation drivers} \quad \sum L * T$$

The **L** in the formula stands for Labour. One way or the other we see that labour is an important driving mechanism. Reduction of

labour is directly connected to saving money. Most of the time reduction of labour does not mean that humans will work less, but that the labour efficiency is improved so that they can handle more in the same available time. This makes living and working easier, more fun and important. This makes the labour strongly related to the human aspect.

The **T** in the *formula* stand for Technology. Developments in technology are huge and can have a big impact. Chapter 11 of this book will elaborate more on current developments. The developments in ICT are predicted on a regular basis by Gartner[xxv]. These predictions are used by many organisations for strategic investments. On LinkedIn Aiden Conolly[xxvi] indicates that the following developments in ICT have the capacity to change the agricultural sector. Drones, robots, sensors, 3D printing, Internet of Things, Artificial Intelligence, Virtual Reality, Augmented Reality and Blockchain will find their way in the smart dairy farming domain. Professionals in the dairy sector must be aware of these upcoming technologies and judge them on usability in order for these innovations to be successful in the dairy sector.

The ∑ sign can have different interpretations. The first is the SUM of the combinations in Labour and Technological developments. However if you rotate the ∑ it becomes a M. In the Dutch language the M is the starting letter of 'Maatschappij' which means Society. Discussions in society on e.g. having cows grazing outside, or on size of mega-farms can drive innovations. The M is also the starting letter of Market. The market mainly drives innovations. Customers expect new products that are based on innovations. If we rotate the ∑ the other way around we get a W. In Dutch the W is the first letter of 'Wetgeving', which means legislation. We have seen e.g. that legislation is used to limit uncontrolled

and undesired product growth or emission of greenhouse gasses. In itself this drives innovations, since people try to be smart and find ways to seek for the limits or try to work around legislation. Another Dutch word that starts with a W is 'Wetenschap', which means Science. Finding explanations how and why things works, creating new concepts and studying behaviour lead to new insights that can be in itself a drive for innovation. In conclusion there are many potential aspects that stimulate innovations in smart farming.

It is interesting to see that a specific topics can be seen from all these different perspectives. As an example we look to the trendwish that cows should also graze outside during the summer in the Netherlands. We see that this wish is initiated by discussion within Society. Another factor is that the Market gives a premium to pasture milk. Nevertheless there is a movement that Legislation will also be involved. On the other hand we see that Science is now working on the topic. So, almost all driving mechanisms are at stake and you can expect quite some innovations in this field the coming years.

9.4. Tools to support innovation processes
Innovation in itself is a process and therefore there are quite some tools available to support people and organisations. Ramon Vullings and Marc Heleven[xxvii] give a nice overview of tools that can be used in the innovation process. In general some basic elements come back. Whether it is a group or an individual process, it has to deal with stimulating creativity in thinking and imagination. Diverge and think (in a systematic way) outside the box. Techniques such as classical, imaginary and reverse brainstorming are well known. Recently biomimicry is becoming popular, especially examples from nature for smart farming might be inspiring. Other tech-

niques such as attribute listing, brain writing, challenge assumptions and the Osborn checklist are not well known in innovation for smart dairy farming or for innovation in general.

After divergence there is always a form of convergence needed. Try to categorise the ideas and give them weight so that selection of the best option(s) become possible. For this convergence phase several techniques are available. Well known procedures are clustering and prioritising by giving members of the group a limited number of stickers or euros to distribute amongst the potential topics for innovation. In the convergence tools selected by Vullings and Heleven *the hundred euro test*, and the *weighted selection* fall in these categories. Selection can also be based on negativity. The idea advocate and the *negative selection tools* are based on the quality of people to criticise solutions. More creative and structured tools are the COCD[xxviii], or the six thinking hats[xxix]. These tools help to categorise solutions. In Figure 9.2 some examples of the creativity tools are shown.
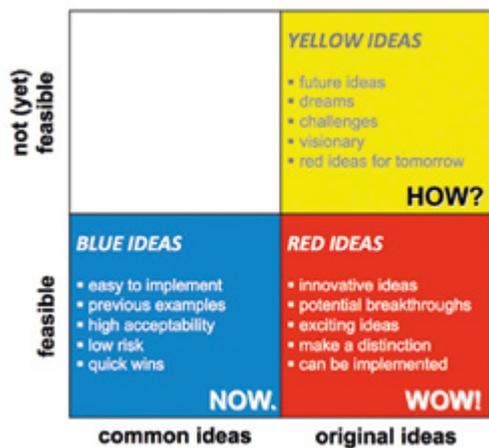
Figure 9.2 *Examples for convergence in creativity by using COCD (top) or Six Thinking hats (next column).*

After the creative work on diverging and converging ideas, the process of research and development starts. The road from an initial idea to a concrete and marketable product or service takes time and energy. In figure 9.3 a nice infographic on the stages of product development from Tobias Larsson[xxx] is shown. For the sake of this book we will not elaborate on all stages and different methods companies use to organise their research and development work.
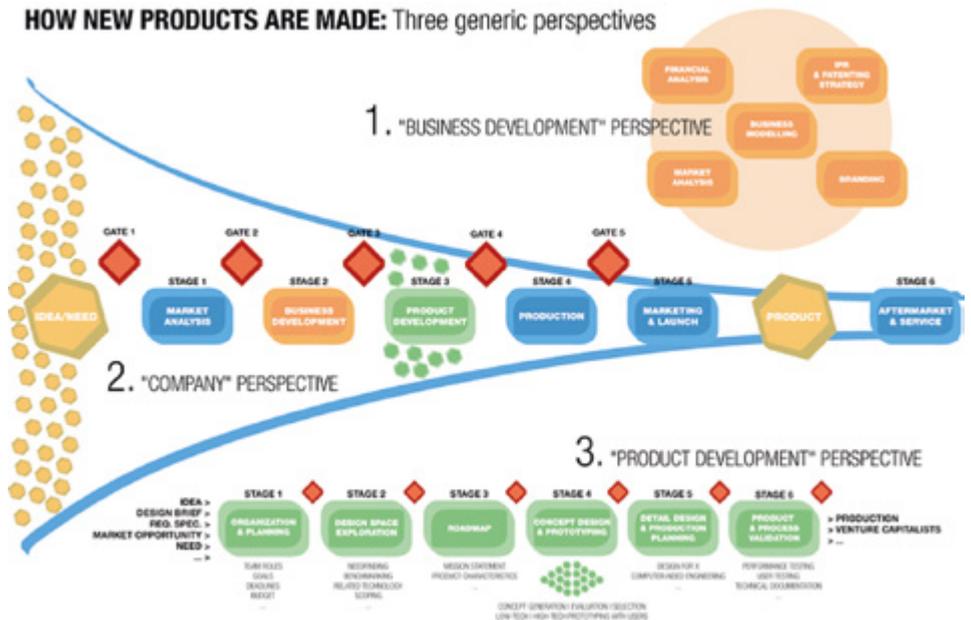
Figure 9.3 *Infographic product development stages from Larsson[xxx].*

Larson also shows that in the R&D different perspectives should be addressed. Looking from the business, company and product perspective guides you through the whole process and will lead to successful market implementation with innovative products, services, processes and systems.

Innovation is not only based on inspiration and creativity only but also on hard and systematic work in research and development and smart balanced choices in the whole process.

Driving forces behind Innovations are Labour, Technology and the ∑ of Society, Market, Legislation and Science.

Economic
[My investment]

Social
[My Family]

VALUE

Dairy Chain
[My Position]

What to learn in chapter 10:

- **The farmer is involved in many decisions. All these decisions should fit to his personal preferences and the way he would like to organise his farm.**
- **Insight in relevant social factors.**
- **Insight in some economic factors and see economic difference on incident and farm level.**
- **Data can be used to create value for farmer and other stakeholders.**
- **Value creation, social factors and economic factors will be perceived differently in regions that differ in labour efficiency and capital intensity.**

10. Farmers awareness

10.1 Social aspects

In the EU-PLF [xxxi] project there have been some attempts to get initial insights on social and economic value and backgrounds of Smart Farming. Although no hard conclusions could be drawn, it gave some 'lessons learned'. Technical production results and cost and benefit relations form the basis for economic indicators. Definitions and price mechanisms often differ per sector and region and are therefore sometimes difficult to compare. On the other hand, social indicators can be directly connected to Smart Farming products and services and it seems that they are less vulnerable to sector and regional effects.

One of the advises from the EU-PLF project was to try to imagine how a market in a specific region will look like. Overall a distinction can be made between capital and labour as shown in figure 10.1. These are still driving forces behind market developments. In capital intensive regions there are high investments in buildings, machines and computers. In labour intensive countries there is a high production per hour of labour. For instance, the Netherlands is a country which is intensive in capital as well as labour. Romania is a country were capital and labour are still extensive. The idea is that when developing SDF products that you want then to sell on a specific market, you have to take care of these differences.

|	**Labour efficient** *Large number of animal per fte* *Personnel at work* *Low costs for customer work*	
Capital extensive *Tied stall* *Feed manually* *No computerized management system for animal control*	SCENARIO 1: *Country/Region:* *Northern Europe (e.g. Ireland)*	SCENARIO 2: *Country/Region:* *Northern Europe (e.g. The Netherlands*	**Capital intensive** *AMS/advanced parlour* *Highly mechanical (TMR)* *Computerized management system for animal control*
	SCENARIO 3: *Country/Region:* *Eastern Europe (e.g. Hungary)*	SCENARIO 4: *Country/Region:* *e.g. Israel*	
	Labour inefficient *Low number of animal per fte* *No personnel at work* *High costs for customer work*	

***Figure 10.1** Scheme to differentiate between labour and capital intensity for SDF product and service development (From EU-PLF project [xxxi])*

In the EU-PLF questionnaire on social en economic indicators it seemed that social factors were as important as economic factors. However, social factors are very difficult to quantify and describe. The five most important social key indicators were:

- **Labour conditions:** the physical environment to work in is sometimes not so human friendly. Situations with dust, bad air quality (ammonia, humidity, temperature) should be prevented as much as possible. So SDF products that support the farmer in preventing him to work a lot of hours in these circumstances might be beneficial. Another physical aspect is the walking distance. Farm lay-out and routing can be designed in the strategic decisions, but in daily routine benefit can come from SDF products. If you only have to walk to specific cows and can find them more easily helps to prevent excessive walking. However, this can also work the other way around. SDF based early warning system also generate false alarms. If you have to check these, you can be confronted with extra walking and annoyance.
- **Number of labour hours:** This is still a main driver. Besides its economic relevance the number of labour hours and the type of work has a strong social aspect. Dairy farming is very dynamic and consists of a lot of variety in actions throughout the day, week and year. This is very challenging. On the other hand there are also quite some activities that come back every day. It can be seen as boring. If you have to milk, feed and take care of the cow every day. In that sense the development of automatic milking and feeders was stimulated by have more freedom in time. Another thing related to the working hours is that farmers have limited time. An example is the routinely control of the locomotion of the cows. In principle the farmer is capable of doing that, but it takes time to observe the cows. Most of the times he is not willing to spend these extra hours.

When a product is developed to support the farming in doing these locomotion observations for him, then the developer should be aware that he is making a product that is bringing new functionality to the farmer and (in most case is) not replacing existing labour. The easiest and most successful SDF products are still those that replace human labour to prevent the farmer from working extra hours.

- **Pride/motivation to talk about and show animal and production facilities:** In essence all farmers are proud of their farm. However there are different categories of farmers. In a study of Dirksen and Rudolf [xxxii] four different styles are described that are currently present in the Dutch dairy sector. These styles are 1) cost reductionist, 2) growers by intensification, 3) cow farmers (fine regulators of animal production) and 4) labour reductionists. Every style has its own reason to be proud on a specific part and they are all intrinsically motivated to improve themselves within that style. There are no studies yet to find out how SDF can influence farmers in these different styles.
- **Availability of advisory systems:** The farmer is open for advice and there are a lot of advisers that come to the farm. Advises come from breed, feed and food companies. Advisers from service providers such as contractors, accountants, banks and veterinarians. And more indirectly advisers from media and research and education. In most cases these advisers are humans who will interact with the farmer. Thus communication and social interaction are very important. These advisers can make or break a new SDF product or service that comes on the market. A new development is that websites, social media and app stores also will be used as advisors. However, the impact of this development is still hard to predict.
- **Successor for farm business to continue the farm:** An important factor in dairy

farming is the continuity of the farm. This is a long-term process, but being aware that a farm can be in different stages is very important to know whether they are susceptible (perception, preferences, education, interest) to integrate SDF products and services in their farm. It makes a difference if you are a fresh young starter, having a partnership between a child as successor and parents that have some years to go to retirement, or a farmer without successor in his last decade before retirement. They have a different mind-set, long term ambition and willingness for capital investment.

Beside these top five social factors, other social factors such as job satisfaction, participation in a study group, risk awareness, attractiveness of the farm to external investors and social recognition for a job well done, are important.

There is an issue on how to give value to social factors. Since social factors are very difficult to quantify they cannot be translated into systems sensitivity, specificity, accuracy and precision. Since measuring system, models and decision support systems all deal with errors (of different kinds) and uncertainty this might give problems in the social context. This phenomenon needs a special place in the communication on SDF products and services.

When social issues are seen as important factors in the market, then they already have to be incorporated in the development phase. Try to identify them and translate them into requirements for the system. If possible you can use choice experiments, questionnaires, interviews or conjoint analysis techniques to find out preferences of specific social aspects. In the EU-PLF project these social factors were seen as intangible. Conjoint analysis was proposed to get an idea of

preferences and proof of intangible effect. Although there is limited experience with these methods. This in contrast to pure economic reasoning, which will be discussed in the next paragraph.

10.2 Economic aspects

In the same EU-PLF questionnaire mentioned in the previous paragraph important economic aspects were also identified. It is quite clear that economic aspects deal with costs and benefits that can be directly related to production factors. The following top five economic indicators were identified for Precision Livestock Farming: feed conversion, growth, health costs, delivery weight and energy costs. They all focus on cost reduction and factors that increase revenues were not identified. If we try to translate this to the dairy production then the following arguments come up.

- **Feed conversion:** This is also a very important driver and cost factor in Smart Dairy Farming. Feed is a key element in production. In essence cows have the unique capability to transform grass into milk. Besides ruminants, there are hardly other species that can do the same. Grass is the basis and, other feed types such as maize, concentrates and additives are used to optimize the transformation from grass to milk. So, being able to control in time and location all these feed types for herds or individual cows will have its costs and benefits. Quite some Smart Dairy Farming products can be found that try to deal with monitoring and controlling feed conversion. The difficulty with feeding costs is that measuring feed intake is very difficult in practice. For concentrates it can be done on cow level or time within a day. For grass, roughage and feed additives it is still impossible to measure at cow level. Then you have to try to measure or predict it on group level and find some ways to

allocate it to individual cows. So, there are quite some different calculations possible to 'determine' individual feed efficiency.

- **Growth --> milk production:** Where in beef, poultry and pig production systems the primary goal is on growth of the animal to produce meat, in dairy farming the primary goal is on producing milk. The delivered milk is the main source of income for a dairy farmer. Depending on the pricing mechanism both milk quantity and milk quality aspects are important. In the Netherlands the milk is paid based on quantity and fat and protein content. Sometimes additional premiums can be based on the farming system such as 'grazing premium', or fines based on quality of the milk (presence of water, antibiotics, high cell count). Where milk production is key for cows, growth is key for calves and heifers.
- **Health costs:** These are also important for dairy production. In the Netherlands two out of the three main reasons to replace a cow are related to health. Milk production related diseases (e.g. mastitis) and locomotion problems have direct effect on growth and (re)production. These direct effects on production when a cow is sick can be used in a cost benefit analysis. This seems to be a straightforward economic calculation. It becomes more difficult when talking about prevention or early warning. Some Smart Dairy Farming products and services try to prevent a cow of becoming sick. Then the costs will be made, but the benefit is sometimes hard to find. The benefit is then an estimation of the 'what –if' question, what would have happened with (re)production, feed intake, growth when no early warning was given. In this situation a break even analysis might be more useful, or a scenario analysis. Be aware that for calves and heifers respiratory diseases cause most of the problems. In some life stages gastrointestinal diseases might occur.

- **Fertility management:** The third main reason in dairy farming to replace cows is caused by fertility problems. Fertility has to deal with becoming in oestrus and pregnant on time and have a smooth calving process. There are quite some estimations of the costs when an oestrus period is missed. This can be translated in direct production loss and therefore the insemination decision is directly related to economics. This is part of the success of Smart Dairy Farming products and services that are dedicated to a timely and accurate oestrus detection.
- **Energy costs:** The topic of energy costs is not addressed in smart dairy farming yet. However, use of solar panels, cooling milk and manure treatment might need specific control that will use variation. Also the control of the indoor climate is not addressed yet in Smart Dairy Farming. In countries where dairy farmers have to deal with heat stress this might pop up first.

Based on these cost - benefit aspects we see different types of calculations and reasoning mechanisms. One very popular one is focusing on an incident or a single process. An incident can be a specific case of lameness, mastitis or oestrus. In general figure 10.2 shows the generic aspects of an incident. First is that an incident starts at a certain moment (T-start). Then it will have an effect on the variable of interest. In the figure it is assumed to be linear, but it can also have other patterns. Then it takes some time until T-Max when the maximum deviation (D-Max) occurs. From that moment on it also takes some time until one can say that the cow (if that is the object of interest) is recovered (T-recovered). Then there might be a total recovery, which means that the expected predicted curve is reached again, or that there will be left a permanent effect of the incident. In both cases there will be a permanent effect (D-permanent). If e.g. the influenced variable

is the milk production of a cow in kg/milk per day and the incident is cow is becoming lame the area between the two black lines is the missed milk production which can be seen as missed income.
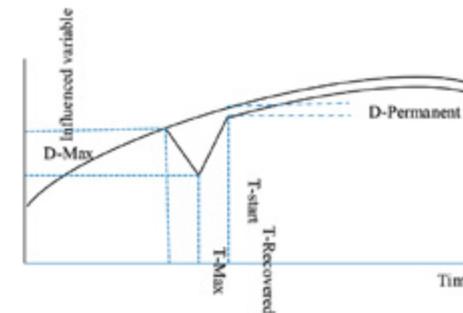

Figure 10.2 *Scheme for modelling a single incident.*

This generic model is very simple, but in practice not always easy to construct. Most of the time more than one variable will be influenced at the same time and it is hard to quantify the exact timing of start, maximum and recovery. Nevertheless it is simple in its reasoning and used a lot to sell smart dairy farming products.

It might be better to account for the prevalence and incidence. In the presented incident model it makes quite a difference when the incident takes place and how many incidents there will be. A locomotion or mastitis problem in the beginning of a lactation has much more economic impact than in the last part of the lactation. This is due to the higher production in the beginning and to a longer remaining period for the permanent effect. So, to be able to determine a more realistic cost-benefit analysis one should be aware how often incidents will happen, this is the prevalence of a disease, which variables will be influenced (in timing and severeness) and what the investments will be. Therefore

it is advised to base the cost-benefit for a smart dairy farming product on a farm level. For the EU-PLFXXV project the dairy farm model shown in figure 10.3 was developed. This model describes input and output characters for a whole dairy farm (in the box of labour and capital intensive in figure 10.1). Two situations are compared. One without the investment in PLF and the other with the PLF (the equivalent of Smart Dairy Farming) investment. It can be seen that the initial investment, maintenance and depreciation of the PLF investment should be estimated. Also the effect on farm level on other input factors has to be estimated. This exercise has been tried for a few SDF products. The experience is that people have much problems with estimating these effects of the products on farm level. Nevertheless this approach seems to be more realistic for big investments than the single calculation on incident level. However be aware that even different farm economic might be used. We only showed the one that was used in the EU-PLF project that included some basic data from Dutch Dairy farms.

Input	No SDF	With SDF	unit
Technical parameters			
Labour	1	1	full time equivalent (fte)
Hours of labour	2,300	2,300	hours / year
Farm size	100	120	dairy cows
Replacement ratio (calves)	40%	35%	of the number of dairy cows
Mortality of replacement calves (1 year)	10%	10%	of the number of replacement calves
Land	49	49	ha
Milk production	8,000	8,200	kg of milk / cow / year
Buildings and inventory (in €)			
Value of land	30,000	30,000	per ha
Interest rate land	2.0%	2.0%	
Interest rate	5.0%	5.0%	
Replacement value barn (including milking parlor)	800,000	800,000	
Depreciation period building	30	30	years
Depreciation buildings	3.3%	3.3%	of the investment
Maintenance buildings	1.5%	1.5%	of the investment
Replacement value machinery and equipment	100,000	100,000	
Depreciation period machinery and equipment	10	10	years
Depreciation machinery and equipment	10.0%	10.0%	of the investment
Maintenance machinery and equipment	5.0%	5.0%	of the investment
Replacement value SDF technology	0	14,000	
Depreciation period SDF technology		5	years
Depreciation SDF technology		20%	of the investment
Maintenance SDF technology	5.0%	5.0%	of the investment
Prices (in €)			
Dairy cow	1,200	1,200	/ dairy cow
Heifer (1-2 yrs)	690	690	/ heifer
Calf	150	150	/ calf
Milk	0.36	0.36	/ kg (4.40% fat; 3.50% crude protein)
Labour	18.00	18.00	/ hour
Other revenues (in €)			
Livestock revenues	272.00	272.00	/ dairy cow
Miscellaneous revenues	18.00	18.00	/ dairy cow
Other costs (in €)			
Concentrates, milk products, minerals	600	600	/ dairy cow
Roughage	135	135	/ dairy cow
Land lease	0	0	/ ha
Fertilizer and pesticides	250	250	/ ha
Customer work	200	200	/ dairy cow
Health care preventive (e.g., hoof trimming)	50	50	/ dairy cow
Health care curative	150	150	/ dairy cow
AI and Breeding	80	80	/ dairy cow
Miscellaneous costs	200	200	/ dairy cow
Other variable costs for using SDF technology	0	0	/ dairy cow

Output (in €)	No SDF	With SDF
Average investment per dairy cow		
Buildings and inventory	8,000	8,000
machinery and equipment	1,000	1,000
Land	14,700	14,700
Cattle	1506	1466
Average revenues per dairy cow		
Milk	2,880	2,952
Livestock revenues	272	272
Other revenues	18	18
Total revenues	3,170	3,242
Average costs per dairy cow		
Buildings and inventory	587	587
PLF technology	0	39
Machinery and equipment	175	175
Land	294	294
Feed	735	735
Interest cattle	75	73
Customer work	200	200
Fertilizer and pesticides	123	123
Health care (preventive)	50	50
Health care (curative)	150	150
AI and Breeding	80	80
Miscellaneous costs	200	200
Total costs (excl. labour)	2,669	2,705
Labour	414	414
Total costs (incl. labour)	3,083	3,119
Net farm income per dairy cow	87	123
Net farm income	8,741	12,301
Labour income	56,141	53,701

Figure 10.3 Farm level SDF - investment model from EU-PLF[xxxi] project, with a dairy example calculation.

10.3 Business Value Proposition

In the previous paragraphs we stressed the importance of social and economic impact for farmers. If you are able to quantify the effects of a Smart Dairy Farming product or service on the production then a proper cost-benefit analysis on farm level might be advised. To deal more with social effects then a proper conjoint analysis might be used.

However, nowadays it is not only about costs and benefits, but more on how to create value. There has to be dealt with the concept of value. A value proposition is a business or marketing statement that a company uses to summarize why a customer should use (buy or hire) a product or a service. This statement convinces potential consumers that one par-ticular product or service will add more value or better solve a problem than other similar offerings. The concept of value is more than just cost and pricing. It also has to deal with willingness to pay and perceived value. Value in itself is the result of perception, belief, pref-erences and interaction between producer and customer.

There has to be dealt with two different per-spectives. On one hand the farm and farmer are the customers of products and services that he is willing to buy or use to improve his farming system. He has to be convinced that this SDF product will be valuable for him in the sense that he expects that some social and economic aspects will improve. The sec-ond perspective is that the farm(er) is part of a complex and dynamic production network. By changing his farming system by integrating smart-dairy-farming tools he is able to deliver more value to partners in his production network. Data and information from his farm might have value for advisers from feed, breed and food companies, and also for advisers from service providers such as accountants, banks, contractors, veterinarians and also for knowledge institutes and governmental organisations. This is the consequence that the farm is not stand alone anymore, but part of a complex dynamic production network. The data and information then have value, but how much? This is very difficult to answer. This value will evolve in time and will be deter-mined in the development of the market that the production network is operating. Those who expect that data from a farm will directly deliver money will probably be disappointed. The added value will most likely come back to the farmers through another mechanism. It might be invested in new products and services, new ways of cooperation and/or just giving a licence to produce.

Thinking of value also brings us more to the development of a company, e.g. a dairy farm. According to Michael Skok[xxxiii] a value proposition is a **positioning statement that explains what benefit you provide for who and how you do it uniquely well**. It describes your target buyer, the problem you solve, and why you're distinctly better than the alter-natives. In creating this value proposition you can follow four steps: define, evaluate, measure and build. Define the problem to help whether it's a problem worth solving. A problem well stated is a problem half solved and many entrepreneurs make the mistake of diving into the solution before really understanding the problem they're looking to solve. Evaluate whether your breakthrough is unique and compelling. Measure the poten-tial customer adoption by using the gain/pain ratio. Build the value proposition according to the following positioning statement: It is FOR (target customers) WHO are dissatisfied with (the current alternative). OUR product/ser-vice is a (new product/service) THAT provides (key problem-solving capability), UNLIKE (the product alternative).

Of course this is one method to think and work on value. Another interesting method is provided by the CANVAS model. According Wikipedia the Business Model Canvas is a strategic management and lean start-up template for developing new or documenting existing business models. It is a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances. It assists firms in aligning their activities by illustrating potential trade-offs. Defining the value proposition is an integral part of the CANVAS model and therefore can be used to think of the value of Smart Dairy Farming products and services.
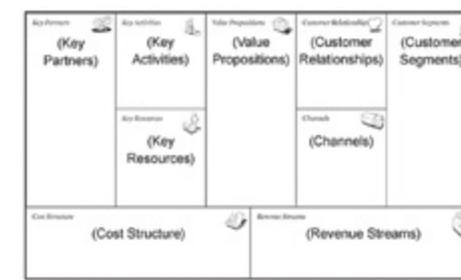

Figure 10.4 Scheme of Business Model CANVAS[xxxiv]

In Figure 10.4 the characteristic blocks of a CANVAS model are shown. Most of the time the business modelling starts with defining a value proposition. In the block customer relationship it is defined what kind of relation you envisage and in the block channels you identify how you will reach the customers. Try to identify what kind of customers you will

have. At this side of the scheme you try to estimate the potential revenues. On the left side of the value propositions in the blocks key activities and key resources identify what is needed to create and produce the product or service, It might be needed that you have to work together with key partners. So, on the left side of the scheme you can estimate the expected costs structure. In this schematic way you can work out your idea, see whether it will be beneficial, how you will envisage to work and who will be your partners and customers.

Value creation is more than adding social factors to economic factors. It also creates awareness of the position of the farm(er) in the production network and the relation between costs and benefits of incidental cases and the yearly farm budgeting.

Value = ∑ social + economic + technologic innovation(s)

Reality

Virtual   Augmented
Robots   Wireless

Drones   Big data

Connectivity

sensors

Interoperability

Blockchain

Location

APPS

AI

What to learn in chapter 11:

- **Emerging technology follows most of the time a 'predictable' curve of technology trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment and plateau of productivity (Gartners hype cycle).**
- **Insight in expected technology drivers that will influence Smart Dairy Farming, such as hyperspectral 3D cameras, Internet connectivity, location awareness and BigData based data analytics.**
- **That it is predicted that robots, drones, sensors, 3D printing, Internet of Things, Artificial Intelligence, Blockchain, virtual reality and augmented realty will have the power to transform agriculture.**
- **That all these developments will influence the practical implementation of integrated farm and herd management that will make use of smart dairy farming insights.**

# 11. Awareness of upcoming ICT developments

11.1 Gartner emerging technology hype cycle

The relevance of technology developments have already been stressed in previous chapters. But what are new developments, how to identify them and how to judge them? In this chapter we focus on the upcoming developments within the ICT domain. Then we of course neglect the important developments in e.g. material technology for creating new building structures, nano- and bio system technology for creating nanobots or –omics technology for 'creating' and improvement of livestock breeds. These will also influence the way we manage and keep our cows.

Looking at developments in Information and Communication Technology (ICT) the predictions of Gartner are used a lot. Figure 11.1 shows such a prediction. Regularly these predictions are updated. The structure of these figures is always the same.
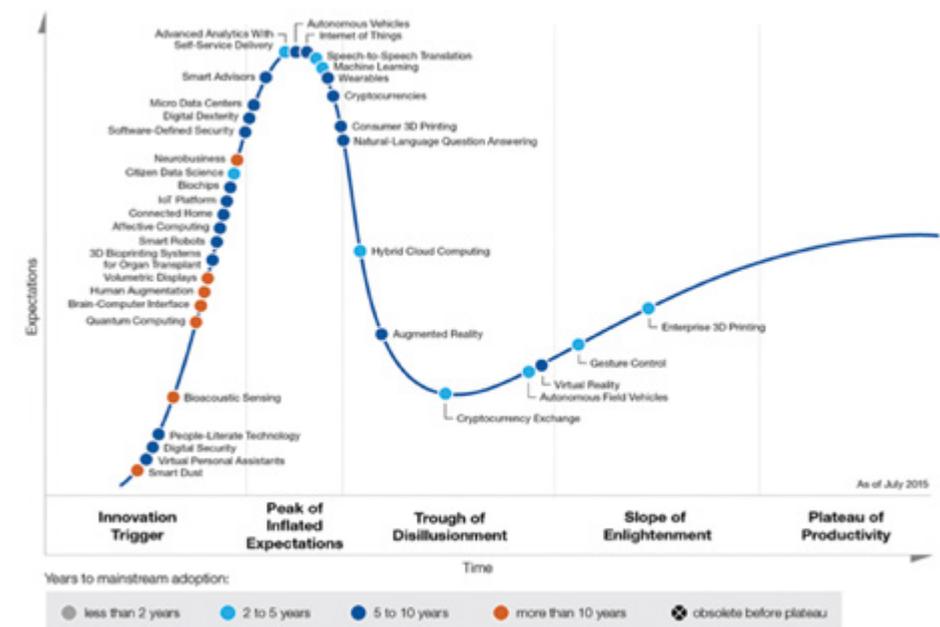
Figure 11.1 *Gartner's emerging technology hype cycle of 2015* [xxxv].

On the Y-axis the expectations are expressed. Expectations in the sense that this technology will be used and will add to solving issues in all kind of domains. The flow of the curve follows a natural order. It starts with an Innovation trigger. A new method to measure, to calculate or to handle data becomes possible. After a while this becomes so 'successful' that more and more people think that this new technology will also help them to solve their problem. This is the Peak of inflated expectations, also called the hype phase. By making people aware of what works and in which circumstances the technology can be beneficial. In this phase there will also be a lot of disillusions. Therefore this phase is called the Trough of disillusionment. After this phase people have learned how to use the new technology and they will see that really adds value to their challenges. Trust and expectations grow again in this phase of Slope of enlightenment. The last phase of this natural flow of expectations is the Plateau of productivity.

Each upcoming technology is positioned on the curve, but an expected time period before the technology is 'mainstream adopted' is also indicated. Periods of less than 2 year, periods between 2 and 5 years and between 5 and 10 years and longer than 10 years are indicated. This shows that every technology might have its own dynamics and speed towards mainstream market.

11.2 Technology drivers for Smart Dairy Farming

In chapter 9 on innovations we have already seen quite some technology that resulted in new products and services that are used in modern dairy farming. A few basic technologies have to be mentioned, since they are driving Smart Dairy Farming technology.

In pure sensing technology there are still a lot of systems based on traditional accelerometer technology. Developments will be triggered mainly in combination with chip development to perform already complicated calculations in the sensor itself, and in battery development. In the vision area we see the breakthrough of 3D cameras and in hyperspectral cameras. 3D to be able to position actuators more precise, but also to deal with different body shapes. The body condition sensor is such an example. Hyperspectral cameras enable much more detailed insight into quality aspects of products. They will be used in measuring quality and composition of milk, manure and grass.

The last decade a big development took place in wireless networks. This also influenced Smart Dairy Farming. Since wiring is costly and sometimes difficult to achieve in the barn, the wireless communication made it possible to obtain data from sensors that were attached to a cow 24-7. The increased success of the activity meters is also for a big part based on this development. Currently we see that the area that can be covered with wireless networks is growing. Where originally wireless networks had limited range of less than 50 m, we now see low range wireless network such as LORA and Sigfox that cover up to 5 km. The result will be e.g. that the sensors attached to the cows also work outside the barn. This will stimulate developments that include grazing.

Another technology that is gradually reaching in the area of Smart Dairy Farming is the technology to determine location. Knowing the location of a cow or an activity can tell much of the context of the cows environment. Location was the basis for precision agriculture. Satellites were used to determine the Global Position. The GPS coordinate in Latitude and Longitude is standardised world-wide. For

a long time the disadvantage was that GPS could not be used inside buildings. Therefore we had to wait for wireless networks inside to determine location inside a barn. We now see the first commercial products that measure the actual location of a cow coming on the Smart Dairy Farming market. In the coming years satellite based GPS and wireless network based location will have to work together to come up with one method to indicate the location of a cow.

Internet of Things (IoT) is now in the peak of inflated expectations. Internet of Things can be seen as an extension of the Internet, where mainly people are connected to people. Internet of Things makes it possible for physical systems to become connected through the Internet. So, automatic milking machines or manure scraping robots can be seen as 'things' that can be connected through the Internet. An IoT system embeds a few functionalities. It is a more or less independent system, has intelligence, electronics, software and actuators in it to perform actions and is connected to Internet so that remote control and data exchange becomes possible. The current challenge on Internet of Things are connectivity, interoperability and security. With connectivity we mean that it is not so common that in all (rural) areas where cows live Internet connectivity is supported. Developments in network technology such as the 5G mobile network will make streaming of image and sound possible. The other issue is interoperability. Interoperability means that if we have more systems that can perform the same task or functionality. So, when systems are plug and play then it should not matter whether the locomotion is measured with a system of company A or with a system from company B. They should both deliver the same outcome. If this interoperability becomes reality then farmers can choose between different systems that perform the

same action. In practice it is still difficult for farmers to select. Information to support their decision come from the companies, advisors or from media. There is no independent test yet on these smart farming IoT based sensor system. In the area of IoT security of data and systems will become crucial in the coming years.

Big Data is also in the peak of inflated expectations. In the area of Smart Dairy Farming this is coming back in projects. BigData has its focus on some basic elements. Developments in data analytics make it possible to handle data that can be characterised with 6V's (according to Sonka [xxxv]). **V**olume is the first characteristic of the data sets. Especially when vision and audio based sensors will be used, for the volume increases. **V**ariety of data is linked to the variety of incompatible formats, non-aligned structures, and inconsistent semantics. So, not only looking at the signals of an accelerometer, but also looking at the milk production, feed intake, and weather prediction at the same time can be an example. The data can also have a variety of sources. **V**elocity addresses the time aspect. Time is becoming more and more crucial and the response is quicker, sometimes even real time. This is needed on changes in measured data. Speed of data availability and needed response time are part of BigData issues. **V**eracity is the need to trust the data. So, quality checks of data streams and their context should be incorporated in a BigData project. **V**ariability is dealing with variation in the meaning of the data. This refers to chapter 4 where we talked about the importance of the context when transforming data into knowledge or action. **V**isualization is number six of the V's and deals with the power of visualizing data. Interpreting BigData sets brings people from different backgrounds together. Domain experts have to work together with data analytic experts

and data handling experts. Visualization can support this cooperation. BigData is looking for patterns and classification issues. BigData will have its added value in issues where data from more farms, cows, or parts of the production chain have to be used to come up with better advises for farmers. Benchmarking and learning from each other in more regional or production chain environments will drive BigData. Maybe developments in social media will also be incorporated, but that is not clear yet.

For the coming years we can predict that developments in the field of a 'Lab on a chip' and Blockchain will influence smart dairy farming. Lab-on-a-chip supports the development of does analysis of milk, manure, soil and grass that are currently carried out in specific laboratories. This takes up time and energy for the logistics, the analysis and feedback of the results. If you can already do the same kind of measurements on the farm you can reduce time and logistic costs. In the milking systems we see the first lab on a chip products that measure e.g. milk fat and milk protein. Furthermore, a prototype is ready for measuring the somatic cell count of the farm. This development will continue and

benefit from the same trend in human health applications. Blockchain is of a different order, but is growing rapidly. Blockchain is used to safeguard transactions so that they become secure and trusted. If the lab on a chip and Blockchain technology will be combined then information on cows, and milk will be trusted and can be the basis for new business interactions.

11.3 Technologies with power to change agriculture

In the media you can see a lot of predictions on upcoming and promising technologies. One intriguing is from Aiden Connolly from Alltech[xxxvi]. On his LinkedIn account he presented an overview of disruptive ICT technologies that have the power to change agriculture. Figure 11.2 shows these disruptive technologies. It is interesting to see whether these already influence Smart Dairy Farming.

From the previous chapters it is clear that the developments in Artificial Intelligence, Sensors, Drones, Robots and Internet of Things are directly related to Smart Dairy Farming already. Drones are expected to be used in grassland management. Although not
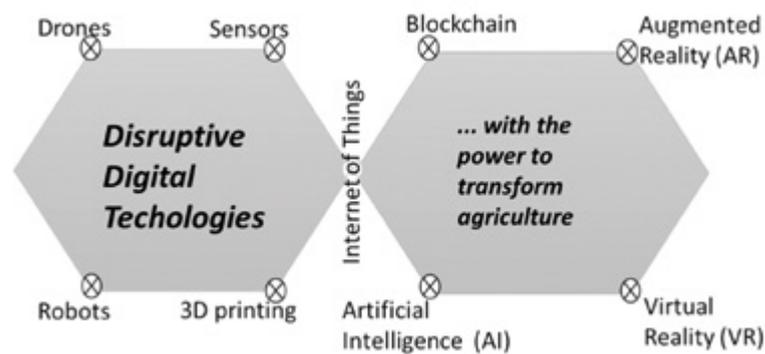
Figure 11.2 *Disruptive technologies with the power to transform Agriculture (After Aiden Connolly[xxxvii]).*

worked out in detail in this book we see that beside herd and individual cow management also grassland management becomes more important for farmers. In grassland management precision agriculture and smart dairy farming come together. Drones can be used to measure grass characteristics, but they can also be used to observe cows in remote areas or to manage grazing. Robots are already accepted technology in the milking process and also cleaning the barn and supporting the feeding. New robot technology will become available for dairy farming. Beside replacing a heavy and tedious recurring task, robots can also be beneficial in observing processes and guiding cows in a herd.

In the upcoming years it can be expected that the blockchain technology will be tried in the context of smart dairy farming. It will be less clear what 3D printing, Virtual reality and Augmented reality can bring. Currently there are no developments in this area with regard to smart dairy farming. With some imagination it can be expected that virtual reality and augmented reality might bring some extra features that can support dairy farmers. When remote assistance is needed, stimulated by the development of servitisation, also more complex issues can be solved in direct cooperation. Virtual and augmented reality can then be used to understand the complex situation, and even practice on solving the issue. Training and support of the farmer will then become more real-time.

The last prediction on ICT related developments is comes from the Animal Task Force[xxxviii]. In 2017 they wrote a white paper on the topic of precision livestock farming. Figure 11.3 depicts the scheme they introduced. This scheme positions several developments in a perspective. In the centre is the integrated support of herd and farm management. This is what SDF is about. So,

how to empower farmers and support farmers in their management of farms and herds while taking into account the care of the needs of individual cows (see chapter 2).

On top of the figure we see the changed position of the dairy farm. The farm has become part of a production chain where tracing and tracking (T&T) of quality and sustainable products is the basis for interactions. Data, information and knowledge about the production process has become a valuable asset of modern dairy farming. Therefore, a challenge is to address the concept of Smart Dairy Farming and its underlying tools for sensing, analysis and perform timely actions, into innovations that can be integrated into farm practices. This book shows that each farm and farmer will have its own challenges and therefore the knowledge of the SDF concept is needed to come to farm specific integration. These farm practice innovations is typically a field where universities of applied sciences can play an important role.
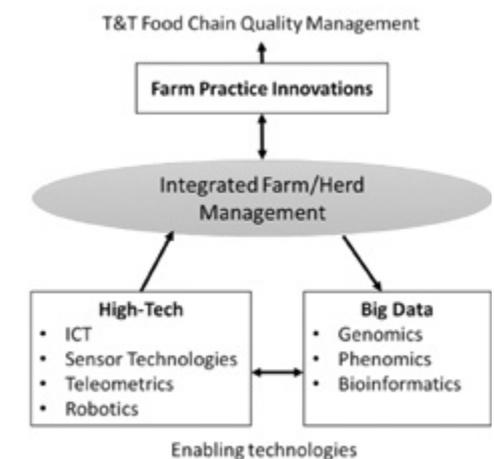
Figure 11.3 *Animal Task Force's scheme for Precision Livestock Farming[xxxviii].*

In the lower part of figure 11.3 we see the main developments in enabling technologies. The High tech and BigData developments are seen as driving forces for the Smart Dairy Farming in the coming years. In essence it will be the success of working on all these elements and to seek the interactions. In this book we presented these developments with the expectation that it will stimulate people to work on different topics of Smart Dairy Farming.

To check developments in ICT have a regular look at the predictions of Gartner. Smart Dairy Farming will also contribute to changes in farming systems and ICT developments will make farm specific integration and solutions possible.

"Cow centric huh... I wonder what that feels like..."

"Cow centric thinking...hmmm"

smart dairy farming

Cow centric, flexible, responsive milk production network

Technological development

Societal development

SDG

Flexible dynamic responsive product chaos

PLF

precision marketing

Rural organisations

IoT

What to learn in chapter 12:

- Dairy farm will play its role in a responsive dynamic production network.
- Dairy farmer can play a role as co-developer of SDF products and services.
- Datafication will be a main activity.

12. Future in Smart Dairy Farming

12.1 Complexity of the position of the dairy farm

This Introduction to Smart Dairy Farming has its main focus on herd and cow management aspects of a dairy farmer. Besides this there might be a future need to elaborate on the plant side of a dairy farm. Examples and theories from precision agriculture will then be integrated and highlighted. Two reasons lead to this insight. The first is that the basic principle is that cows are very good to transform grass into high valued milk. In the Netherlands, as in other parts of Europe, the quota system is abandoned. But new regulation mechanisms come into place. It can be predicted that a dairy farming will be regulated along the line of land and grass (plant) production. Then the integrated farming process of soil, grass, conservation and animal production has to managed. This increased complexity and objective to reduce inefficiency can be challenged by use of smart dairy farming. The second reason for more soil and plant integration is the up come of nature inclusiveness. Care for environmental aspect of dairy farms will also stimulate new farming systems with a mix of intensive and extensive management of plant and animals. This development of integration of smart dairy farming and precision agriculture will show regional differences. The place and dynamics of the society where the farm is located play an important role in future smart dairy farming developments.

A more market oriented approach shows that the relative position of dairy farms is changing rapidly. Digitalisation and smart dairy farming techniques can contribute to increased value creation in the dairy sector. Where in earlier days the dairy farm was a single entity where value was created, it is expected that dynamics and responsiveness of dairy production networks will make the difference in the future. Core in this is that farmers and all kind of other stakeholders will feel the need to work together. Cooperation will be based on transparent and digital data and new business models. This will also lead to more complexity for the dairy farmer. In this future perspective the current state of the art of smart dairy farming and its integration in practices is a step in the 'right' direction. The advice is to step in, experience with smart dairy farming and make your own choices. This introduction to smart dairy farming does not address the more intensive livestock sectors such as pig, poultry, goats, sheep, fish and insect production systems. These might have their own specific challenges in applying the concept of precision livestock farming. One is that they deal with groups on a more regular basis. The individual animal in these production systems is also present. On the long term the individual care for an animal should also become possible, when technology and farmers will evolve.

12.2 Role of farmer in system development

A dairy farmer can play different roles in the further development of smart dairy farming. Of course he can buy products and use services to integrate it in his specific farming system. This is encouraged to do, and he should discuss this also with his colleague farmers and farm advisors. Another involvement can

be that farmers take part of the development process of innovations. To become a co-developer he needs some basic insights in recent developments in project management.

For Smart Dairy Farming we have to be aware that products and services have to be developed before they can be used in practice. The development process in general is a process that encompasses several stages. Some think that the development of a service, a software product or a physical product will differ. But in general they all more or less follow the same steps. However, they will differ in detail and duration. For simplicity it will be called it a system or application that will be developed. Figure 12.1 shows some basic steps in the development of such a system. It always starts with knowing why and what kind of system shall be developed. Therefore requirements are setup and a thorough analysis of the problem has to be done. When you understand the problem well and know where and how the system should be able to function, you are able to translate that into solutions. In the design phase the system or a prototype is designed and build. An important step is that this design will be tested and implemented in a 'real life' situation before it is introduced in the market. In research projects most of the time the phase of deployment, hosting and support are not addressed. In the whole process of development a lot of decisions have to be made. To support this, most of the time systematic approaches are used.

Figure 12.1 is presented as an old fashioned hierarchical process. A new phase can only start if full consensus is reached over the previous part. From the begin of the process one should have a clear view of how the system will look like and in what kind of environment is has to function. However the last decade new developments in project management occurred. In practice there are several

systematic approaches [xxxix]. A system development methodology refers to the framework that is used to structure, plan, and control the process of developing an information system. A wide variety of such frameworks have evolved over the years, each with its own recognized strengths and weaknesses. One system development methodology is not necessarily suitable for all projects. Each of the available methodologies is best suited to specific kinds of projects, based on various technical, organizational, project and team considerations.
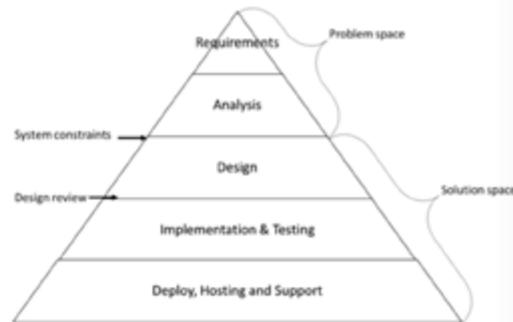
Figure 12.1 *General steps in the development of a system*

In general it can be seen that the character changed. Instead of a hierarchical process it has become iterative, prototype based and learning by doing. Also the involvement of user has increased. In the course of time we see more involvement of end users, less stress on detailed initial requirements and less detailed analysis. Speed in the process and showing intermediate products has become more prominent in modern software development tools.

Without being complete, some of the methods that were used were: the waterfall model, prototyping, the spiral model, and the rapid application development method. Currently Agile working and user-centric design are

popular methods. Figure 12.2 represents the Agile method.

Agile software development describes a set of values and principles for software development under which requirements and solutions evolve through the collaborative effort of self-organizing cross-functional teams. It advocates adaptive planning, evolutionary development, early delivery, and continuous improvement, and it encourages rapid and flexible response to change. These principles support the definition and continuing evolution of many software development methods. Agile software development frameworks continue to evolve, two of the most widely used being Scrum and Kanban.

Basic principles of the Agile model:
• Customer satisfaction by early and continuous delivery of valuable software.
• Welcome changing requirements, even in late development.

• Working software is delivered frequently (weeks rather than months).
• Close, daily cooperation between business people and developers.
• Projects are built around motivated individuals, who should be trusted.
• Face-to-face conversation is the best form of communication (co-location).
• Working software is the primary measure of progress.
• Sustainable development, able to maintain a constant pace.
• Continuous attention to technical excellence and good design.
• Simplicity—the art of maximizing the amount of work not done—is essential.
• Best architectures, requirements, and designs emerge from self-organizing teams.
• Regularly, the team reflects on how to become more effective, and adjusts accordingly.

Figure 12.2 *Agile software development model*

It can be seen that there are a lot of different methods available to support application and product development. In general it starts with having an idea for a potential application. Then a mix of defining requirements, analysis, design and construction is performed in a linear or iterative way. In all methods there is an important role for testing. This testing will be elaborated in the next paragraph.

12.3 System requirements and testing
In the previous paragraph some development methods were introduced. Although there might be some differences, they can be applied for the development of physical and software systems. Nowadays physical and software systems become more and more integrated. As an example an automatic milking system consists of many hardware parts and a lot of software parts. So it is important to see that a 'system' can be divided into subsystems. Even subsystems can be divided until you come to the lowest level of functionality. In all mentioned methods it became clear that in the 'beginning' of the development process, or at the beginning of an iteration, requirements should be defined. These requirements can have a variety of forms. For mechanical functions e.g. that it should function between -20 0C and + 50 0C, in a humid environment and at least battery life shall be 5 years. For software or models one can think of the early warning should detect more than 95% of the real cases. The farmer should not receive any false attention or the size of the buttons on a cell phone should not be smaller than 0.7 cm.

The function of having requirements is sometimes underestimated. However, it forces the developers to think on functionality of the (sub)system and what to expect from performance in advance. This is to challenge the developers in formulating requirements that can be achieved, and that are realistic.

It also helps to streamline the discussion between the developers and the customers. If in advance no expectations are set for proper functioning of a (sub)system then this will lead to disappointments. A big risk is that the system is not defined well enough and that the requirements are not realistic.

Requirements should be formulated in a SMART way. They should be Specific, Measurable, Attainable (Achievable, Actionable, Appropriate), Realistic (Relevant) and Time Bound (Traceable, Timely). There are more variations in the SMART definition on requirements. Therefore between brackets some alternatives are given. In essence they all have the same direction. If requirements are formulated SMART it is possible to do a proper test. Testing also comes back in all development methods. Testing is essentially trying to find out whether the requirements are fulfilled for a specific (sub)system. Testing can be done in quite some different ways. Therefore within a development process one has to agree not only on the requirements, but also on the methods of testing. In practice more testing methods might be available most of the time. Each test method might have its specific (dis)advantages and costs. In Figure 12.3 it is shown the relation between requirements and test for a software development process. It can be seen that on each system or subsystem level requirements are formulated and that a specific test can be allocated. These tests can focus e.g. on a specific unit and test whether a specific model or algorithm delivers the right output. In Figure 12.3 it is shown that when subsystems are integrated, extra tests are needed to test that integrated functionality. At the highest product level there also is an acceptance test. Testing will have its costs and is not always possible: because the system cannot be built yet or the circumstances to test are in a very harsh environment such as

in a manure pit with toxic gasses are too hard. In those situations expected behaviour of the system can be simulated. So, besides logical and practical experiments simulated environments or games can also be used in the testing of systems.
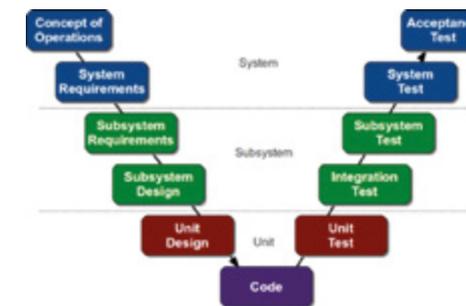

Figure 12.8 *Relation between requirements and tests.*

Farmers can play as co-designer and user in a complex environment a specific role in product development. Efficient development of applications and systems need a systematic approach in which predetermined goals and SMART requirements are translated in a creative product design that is thoroughly tested on all integrated system levels.
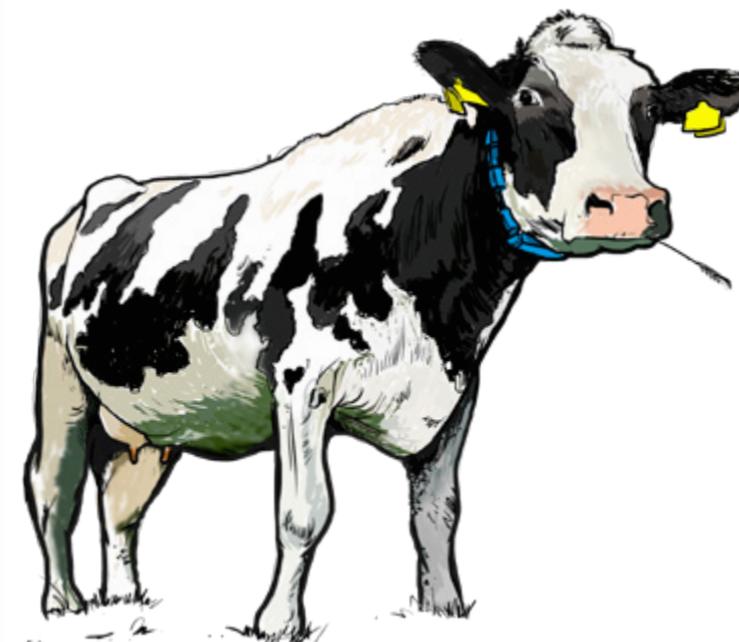
Reference

i   https://en.wikipedia.org/wiki/Diffusion_of_innovations

ii   https://en.wikipedia.org/wiki/Precision_agriculture

iii   Berckmans, D. (2008). Precision livestock farming (PLF). Computers and Electronics in Agriculture 62(1): 1-1.

iv   EIP AGRI Focus Group Precision Farming (2015). EIP-AGRI Focus Group Precision Farming Final report.

v   https://en.wikipedia.org/wiki/Henri_Fayol

vi   https://en.wikipedia.org/wiki/Date_format_by_country

vii   www.agroconnect.nl

viii www.icar.org/

ix   https://www.nap.edu/read/4782/chapter/4#11 and http://engineering.nyu.edu/gk12/amps-cbri/pdf/Intro%20to%20Sensors.pdf

x   Mol, R.M. de (2000) Automated detection of oestrus and mastitis in dairy cows Agricultural University. Promotor(en): A.J. Udink ten Cate; A.A. Dijkhuizen; C.E. van 't Klooster. - S.l. : s.n.], - 177 p.

xi   https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/dieren/dieren-registreren/runderen/oormerken-voor-runderen

xii   Gerardo Caja, Andreia Castro-Costa and Christopher H. Knight (2016) Engineering to support wellbeing of dairy animals, Journal of Dairy Research (2016) 83 136–147.

xiii C.J. Rutten, A.G.J. Velthuis, W. Steeneveld and H. Hogeveen (2013) Invited review: Sensors to support health management on dairy farms, J. Dairy Science 96:1928-1952. http://dx.doi.org/10.3168/jds.2012-6107

xiv https://en.wikipedia.org/wiki/Statistics

xv   https://en.wikipedia.org/wiki/Artificial_intelligence

xvi https://en.wikipedia.org/wiki/Accuracy_and_precision

xvii https://en.wikipedia.org/wiki/Sensitivity_and_specificity)

xviii https://en.wikipedia.org/wiki/Receiver_operating_characteristic

xix www.4d4f.eu/

xx   http://extension.psu.edu/animals/dairy/hr/personnel/ud011

xxi   https://dairy.ahdb.org.uk/technical-information/animal-health-welfare/mastitis/recordstools/test-kits/cmt-california-milk-test/#.WoFQEiXOXX4

xxii https://en.wikipedia.org/wiki/Stakeholder_analysis

xxiii Pornthip Boonmawong, Shonn de Cuba, Britt Engelsman, Shalin Jacobs, Ben Jespers, Julius Klein Bramel, Josanne Rutte and Jikke Snelders, 2016. Adoption of Innovations in the Dutch Dairy Sector. VHL student thesis, 74pp.

xxiv www.businessdictionary.com/definition/innovation.html

xxv www.gartner.com

xxvi www.linkedin.com/pulse/disruptive-digital-technologies-power-transform-aidan-connolly

xxvii www.slideshare.net/ramonvullings/27-creativity-innovation-tools-final

xxviii www.creapedia.com/wiki/COCD-Box   (http://workshopbank.com/wp-content/uploads/2015/05/COCD-Box.jpg)

xxix https://en.wikipedia.org/wiki/Six_Thinking_Hats

xxx www.tobiasclarsson.com/courses/masters-and-bachelors-courses/product-development-processes/

xxxi www.eu-plf.eu : Deliverable 4.1 List of socio-economic measures related to selected key indicators on farm.

xxxii Hans Dirksen Marije Klever Rudolf van Broekhuizen Jan Douwe van der Ploeg Henk Oostindie, 2013. Bouwen aan een betere balans: Een analyse van bedrijfsstijlen in de melkveehouderij, Wageningen UR and Dirksen Management Support publication.

xxxiii https://www.forbes.com/sites/michaelskok/2013/06/14/4-steps-to-building-a-compelling-value-proposition/#b162a1f46958

xxxiv https://en.wikipedia.org/wiki/Business_Model_Canvas

xxxv Sonka, S. 2015a. Big Data: From Hype to Agricultural Tool. Farm Policy Journal, 12, 1-9.

xxxvi https://www.linkedin.com/pulse/disruptive-digital-technologies-power-transform-aidan-connolly-7k-

xxxvii http://www.e-agriculture.org/content/8-disruptive-digital-technologies-power-transform-agriculture-0

xxxviii http://www.animaltaskforce.eu/Portals/0/ATF/Downloads/ATF%20General%20Presentation%20Animal%20Task%20Force_September2015%20V2.pdf

xxxix www.cms.gov/Research-Statistics-Data-and-Systems/CMS-Information-Technology/XLC/Downloads/SelectingDevelopmentApproach.pdf

Notes