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Standardized Decision-Making for the Selection of Calf and Heifer Rearing Using a Digital Evaluation System

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Abstract: This study addresses the challenge of subjective remounting decisions in calf and heifer rearing, typically driven by the animal caretaker's feelings and experience, lacking a robust data foundation. Key factors such as developmental delays, diseases, or rearing problems often go unnoticed or are forgotten due to the number of animals. To address this gap, an established state-of-the-art sensor network captures behavioral data during rearing, which is supplemented by manually collected data. This facilitates a novel decision network providing well-founded recommendations to the animal owner regarding whether to retain or cull an animal. The approach focuses on four key areas: colostrum supply, milk intake, weight development, and disease history during the rearing time of each individual, offering a transparent decision path for the use of each future cow. Introducing a standardized decision-making approach, the proposed approach enables an efficient, transparent, and targeted management strategy, contributing to the sustainable enhancement of the health and performance of calves and heifers. Additionally, it allows for the comparison of the growth trajectories of different animals over time. Notably, individual and transparent decisions can be made at each growth stage, enhancing the overall decision-making process in calf and heifer rearing.

Keywords: calf rearing; animal husbandry; heifer management; standardization; farm management; advisor tool; dairy cattle

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1. Introduction

In animal husbandry, digital technologies such as feeding systems, automatic lameness or estrus detection, and automatic milking systems with milk analysis capabilities are increasingly making their way, especially in the context of modern dairy cattle management. Milk data, digital fertilization management, and monitoring of barn climate are widespread practices, as well as automatic disease detection [1]. These technologies are applied in the management of adult dairy cows. However, detailed data collection during the calf and heifer rearing period is either unavailable or limited, despite this time forming the basis for the later performance of dairy cows. To address this data gap, a state-of-the-art sensor network was established in the barn to continuously collect developmental data. These data are now intended to be used through standardization for the evaluation of animal rearing and to ultimately provide the animal caretaker with selection recommendations based on solid data. The resulting targeted management strategy aims to facilitate decisions for the animal caretaker and fill a gap in daily farm operations.

1.1. Current State of Art for Adult Dairy Cows

For adult dairy cows, large amounts of individual animal data are already being collected for various purposes, leading the way to precision dairy farming [2,3]. This includes the objective recording and utilization of feed and water intake [2,4–6], rumination activity [5,7], movement activity [8,9], evaluation of animal welfare [10,11], detecting general or specific changes in behavior [12,13], and indicating changes in the animal's health [2,14–16]. This data collection can be largely automated, such as during the milk test directly after milking [17], camera systems evaluating lameness [18,19] and body condition [20], or algorithms detecting behavioral changes. For milk testing, as an example, sensors are able to detect changes in milk conductivity, composition, or cell count and infer the onset of diseases such as mastitis [21]. However, this situation contrasts during the calf- and heifer-rearing periods.

1.2. Data Gap during the Calf- and Heifer-Rearing Periods

A largely different scenario unfolds during the calf-rearing period: only a few data points, such as birthweight or milk intake, are collected. The calves are usually observed when fed using a bucket, with a quick look over the herd. When an automatic feeding system, in combination with a feeding box, is used, regular or daily control is not guaranteed anymore, as the caretaker does not necessarily see the animals on a daily basis [22,23]. In calf rearing, there are already some approaches, but they are rarely found in widespread use on farms [24]. However, scientific testing of various technologies shows some promising approaches. These include, for example, acceleration sensors [25,26], which monitor animal activity and can distinguish between walking, standing, and lying down, or feeding stations [27], which detect milk intake and related factors and can infer diseases from changes in milk intake [28]. Additionally, the use of camera or acoustic systems is currently being investigated to infer changes in animal behavior and thus detect diseases early and automatically [24].

For the time heifers, it is even worse: on commercial farms, little to no data is collected or stored for later evaluation, and the animal control has to be entirely conducted manually by the caretaker [23]. There are also hardly any technologies practically implemented on farms. Among these, rumen boluses, which are also used for dairy cows, are being more precisely tested to analyze rumination activity, feed, and water intake [29]. Additionally, documentation of weight development is one of the few information points about the animal's progress during the heifer period, primarily used to determine if the animal has reached a certain target weight and is ready for the first insemination [30]. Modern approaches use 3D cameras to estimate the weight development of heifers on a daily basis, as they have been tested for weight estimation of dairy cows [31,32]. These cameras can provide reliable results without physical contact between the farmer and the animal, thus detecting the animal's development throughout the rearing process.

Fundamentally, technologies developed so far are mostly available for adult dairy cows [33], while on commercial farms, digital monitoring of calves is still limited, and monitoring of heifers does not take place at all, even though some fundamental research is available and certain approaches seem to be marketable. Considering that the period of calves and heifers forms the basis for later productivity and profitability as a mature dairy cow, improved health at a young age has a significant impact on the animal's development [34,35]. During these periods, a healthy milk supply, gradual weaning, a healthy intake of water and feed [36], as well as the absence of diseases, are crucial aspects that the caretaker must ensure. Not only is the appropriate milk and later solid feed supply important for healthy growth, but through regular checks of the animals, it can be ensured that diseases are avoided, and there is no developmental disorder or delay in the animals. Good professional practice requires conducting regular animal inspections with a certain level of attention to ensure the optimal health and development of calves and heifers and treating the animals in a sympathetic way regarding the standards of animal welfare [37,38].

As Figure 1 shows, through specially developed sensors and adaptation of the sensor technology used for adult dairy cows, a state-of-the-art sensor network is established in the stable, and the development of calves and heifers can be documented entirely, closing this existing data gap [39].

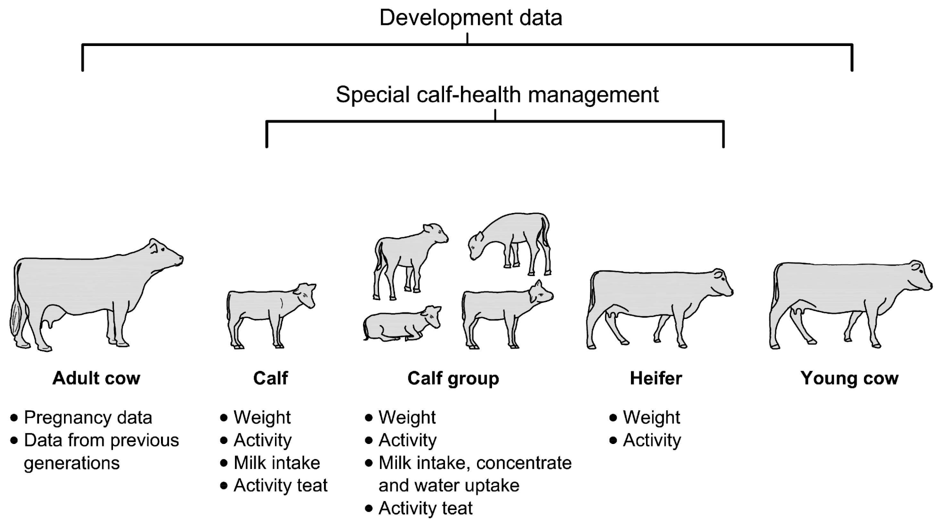


Figure 1. Presentation of data collection during the calf and heifer period to close the previously existing data gap using a state-of-the-art sensor network [own graphic].

1.3. Decision-Making for Selection

Selection decisions on farms are traditionally made by the livestock owner. This can involve a proven scheme where records of growth are used. Typically, decisions are made without the use of extensive data, as would be available through sensors. This leads to uncertainty, making decisions based on intuition rather than objective criteria for optimizing farm operations. A more advanced technology is breeding using genetic evaluation and breeding programs, which enhances desirable traits such as milk production, milk quality, reproductive efficiency, longevity, and disease resistance. Through these programs, the aim is to produce a more efficient, productive, and sustainable herd that meets the needs of the dairy industry while ensuring animal welfare [40].

Especially for small farms and on-farm breeding, a novel decision-making network can provide a solution, issuing decision recommendations based on defined algorithms using the established data foundation. Here, the data collected through the state-of-the-art sensor network provide an opportunity to assess the raised animals based on their growth and development using a newly developed algorithm. Ultimately, this offers a data-based recommendation to the user about the retention or culling of an animal.

2. Materials and Methods

The first prototype for a digital decision support system for the selection of calves and heifers was created using the online low-code platform bubble.io [41], marking progress in the integration of digital technologies in dairy cattle rearing. When using bubble.io, a system is employed that allows programming without deep knowledge of computer science, simultaneously providing a user-friendly interface. This helps create an appealing interface for the first prototype without further time requirements. For the programming of the envisioned decision support system, it is necessary to store collected farm data, benchmark values, and numerous individual animal data related to the individual farm and animal if there is no integration with existing cloud services (e.g., CalfCloud [42]). For the development of a prototype, the paid 'Starter Plan' subscription of bubble.io is chosen, providing features such as file import in CSV format, the ability to create API interfaces, an online version of the app for remote access from various devices, and automatic storage of an online backup in case of server issues.

2.1. Research Stables and Initial Data Aquisition

Three research stables located in different regions of Germany were equipped with a large sensor system for quantitative data acquisition. Stable 1 with 62 animals in the project, is located at an elevation of 259 m in southern Rhineland–Palatinate. Stable 2, with 270 animals in the project, is in Brandenburg at an elevation of 87 m. Stable 3 with 96 animals in the project, is in southern Baden–Württemberg at an elevation of 531 m. Data collection and analysis are planned until the end of the project, aiming to detect regional climate influences on calf health and development.

2.2. Evaluation of Animal Development

To evaluate the development of an animal, four key areas are essential for a healthy upbringing, and an individual index for each key area is established: sufficient colostrum intake as it is the initial supply of immunoglobulins to build up a proper immune system; further milk intake throughout the weaning period; weight development from the birth-weight until the first calving as an adult cow and beyond; the occurrence of diseases in every stage of life. Those four aspects are individually evaluated to generate a comprehensible rating of the animals' development and make it comparable to other animals on the farm.

2.2.1. Colostrum Intake

An adequately large and preferably early colostrum intake after birth is undisputedly one of the most crucial factors for the healthy basic immunization of a calf [43] and healthy growth of the gastrointestinal tract of the animal. The colostrum intake cannot be detected automatically and must, therefore, be recorded manually by the user of the system. This can be performed digitally directly in the decision support system's database, where the intake quantity in liters (L), intake time defined as hours after birth (h_{ab}), and quality of colostrum defined using percent Brix (%Brix) for the first colostrum are entered. The intake amount in liters is therefore measured using the feeding bucket or milk bottle and calculating the difference between the initial amount of milk in the bottle or bucket with a potential leftover amount. For the feeding time, the time difference between the birth of the calf and the beginning of the first colostrum intake is calculated and stored in 'hours after birth'. Finally, for a proper evaluation of the colostrum quality, a refractometer is used for proper estimation. These values are used for the evaluation of the first colostrum, which is most important for the initial immunization of the animal [44]. For an additional second colostrum feeding, quantity, timing, and quality can also be recorded for further evaluation using the same measures as the initial colostrum.

2.2.2. Milk Intake

Subsequently, the established sensor network automatically records the milk intake during the entire feeding period when the calves are stationed at an automatic feeder (feeding station VARIO, Förster-Technik GmbH) with automatic feeder for single-housed calves (CalfRail, Förster-Technik GmbH, Engen, Germany) or feeding box for group-housed calves (HygieneBox, Förster-Technik GmbH). Data can be directly accessed in real time through integration with the CalfCloud service [42]. Depending on the sensor configuration, in addition to milk quantity in milliliters (mL), additional factors such as feeding time in minutes (min), suckling speed in milliliters per minute (mL/min), visits without entitlement as a number (n), feeding interruptions as a number (n), and impact activity on the teat as acceleration per minute and visit (mG/min/visit) can be recorded and used for further and more precise evaluation.

2.2.3. Weight Development

Continuous weight assessments are conducted to evaluate the weight development of an animal. Besides the birth weight (kg), which is determined immediately after calving by the caretaker and recorded in the database, certain weights are essential throughout the rearing process. Weighing should be conducted during the transition from individual to group housing, at weaning, if possible, periodically, and at the first insemination at the latest. For every weighting, the date (dd.mm.yyyy) and the weight in kilograms (kg) are stored in the integrated database. This is necessary to track the animal's weight development throughout its life and calculate its daily weight gain. During the feeding period, a front hoof scale [45] built into the feeding box allows for periodical and automatic weight determination every time the calf suckles milk. If such a scale is not available on the farm, an alternative is to work with a (large) animal scale (Bosche animal scales "1-2-3 Einzeltierwaage ETW VA" for weights up to 300 kg and "RTW 2510" for weights up to 1500 kg) and manually add the necessary data to the integrated database through the input form. For proper evaluation of the weight factor, it is subsequently necessary to store the data in the database and ensure closed data chains.

2.2.4. Disease History

Disease assessment can be semi-automated, depending on the evaluated factor. The daily movement activity is detected via a neck-collar sensor that measures the acceleration in hourly units. Additionally, a manual health check based on a four-stage scale comparable to the Wisconsin calf scoring system [23] via the CalfApp-VITAL [46] allows the recording of changes in the nostrils, eyes, ear position, feces consistency, and breathing when there is suspicion of illness. This generates a numerical between 0 and 20 for every day, evaluating the animals' condition, which can be used for analysis. If no evaluation via the CalfApp-VITAL [46] is carried out, it is assumed that the overall condition of the animal is good, no abnormality is detected by the caretaker, and a score of zero is established for the certain day without evaluation. Additionally, long-term connections with herd management programs aim to infer veterinary treatments in a standardized manner for inclusion in the evaluation, but this will be processed in a later stage of the project. At this point, the inclusion of free text inputs and notes is not possible and needs to be established. For further detection of the animals' feed and water uptake, a SmartWaterstation (Förster-Technik GmbH) and a SmartConcentratefeeder (Förster-Technik GmbH) are used.

2.2.5. Data Storage and Transfer

Depending on the data collection area, the data are either directly retrieved from the linked cloud (milk intake data) or stored locally in the prototype's database (colostrum data and weight data). Figure 2 shows the connection of the sensors with the cloud service. The data transfer can take place without restrictions when an internet connection is available.

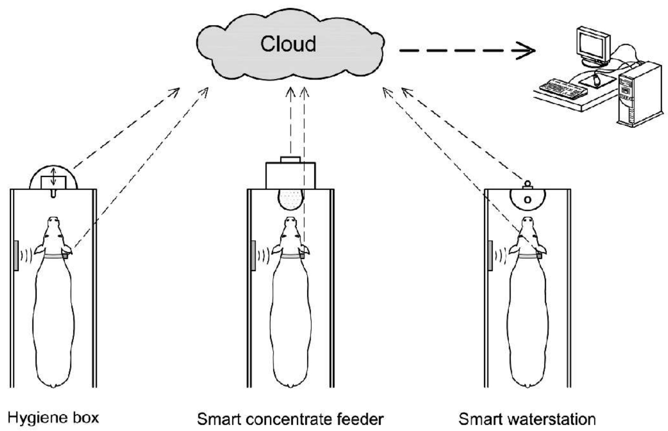


Figure 2. Positioning of the applied sensors: **left**—Hygiene box, **middle**—Smart concentrate feeder, and **right**—Smart water station. All calves are equipped with the Smart Neckband. All sensors are connected to a cloud for data storage and transferred to a computer for further evaluation [own graphic].

2.3. Selection Recommendation for the Livestock Owner/Caretaker

Based on the previously described collected data, a comparison with predefined target values can be conducted. The used target values align with current research findings as well as the experiences of our cooperating research facilities and stables. Standardization eventually enables the independent evaluation and comparison of animals regardless of external factors such as the daily fluctuation of the person evaluating the animals or changes in outdoor and indoor climate. In the long run, farm-specific factors will be considered and incorporated into the selection recommendation system, establishing a farm-specific recommendation. An autonomous update of comparative data within the system and manual adjustment of target values by the user should make it possible to optimize the evaluation system on an animal- and farm-specific basis.

3. Results and Discussion

Replacement decisions are made differently on each farm and are usually not subject to a fixed scheme. Often, farmers make decisions based on intuition and rarely rely on a solid data foundation. In their decision-making process, farmers are often influenced by a variety of complex factors that lead to an assessment of an animal [47]. This highlights the clear need for a standardized system that supports farmers in their decision-making and provides them with a well-founded and transparent recommendation based on a solid data foundation. With this goal, a decision support system is being developed as part of the described research project. Although some other approaches can be found in the literature, none of them has reached market maturity or broad application. Early attempts at standardizing decisions were made [48,49], with two management guidelines generally recommended: profit after conception for insemination decisions and future profitability for immediate replacement and veterinary treatment decisions. Early decisions should be made based on profitability to simplify herd replacement. It was recommended to include individual animal data, but the authors did not provide details on what these are and how they should be evaluated. A modern decision system specifically developed for Slovak conditions provides an economic recommendation for the herd to assist farmers in their replacement decisions [50]. The system also considers individual farm-specific characteristics, strengths, and weaknesses. It performs an individual calculation of the needed animals for breeding, issuing corresponding herd measures to the farmer. In comparison, the system developed within the project uses individual animal data not only to calculate herd replacement but also to provide targeted recommendations for the use of specific calves. This leads to higher practicality, as farmers can recommend which animals are particularly suitable for breeding based on their individual growth. Another decision support system based on economic factors purely calculates the monetary value of an animal and models farm-specific replacement decisions [51]. In this case, the entire herd is considered an economic asset, and individual animal data and developments are disregarded, resulting in a distortion of farm management. Considering individual animal factors is crucial for decision-making.

In contrast to those previous attempts, the prototype developed in this project uses individual animal data recorded using a previously adapted state-of-the-art sensor network [39] for solid-based replacement recommendation. To evaluate the prototype's suitability, it was presented in several discussion rounds and assessed in an initial field test. The overall feedback was positive, identifying further adjustments needed for practical implementation, which will be included in the continuing project.

3.1. Evaluation of the Core Areas

As previously described, four core areas are essential to evaluate the individual development of an animal. These were individually examined and evaluated for functionality. The assessment of milk intake during the calf-rearing period can be positively evaluated, especially the seamless integration of cloud data through coupling via an API connection with the existing technology, the CalfCloud [42], which is suitable for accurate animal evaluation. Here, the factors of milk retrieval quantity, feeding without interruptions, visits without feeding interruptions, and suction speed represent the core evaluation. The milk intake quantity is oriented towards the drinking plan's defined drinking quantity, as shown in Figure 3. Feeding interruption is counted whenever the retrieved milk quantity falls below a defined threshold compared to the previous day. A feeding interruption is counted when the provided milk quantity according to the drinking plan is not sufficiently retrieved, with an exception for ad libitum feeding, which can be separately set. Suction speed describes a change in the speed at which the milk is retrieved in the individual animal's average compared to previous days. A factor is then created from the individual factors through an actual-target value comparison, indicating the milk index for evaluating milk intake throughout the entire feeding period.

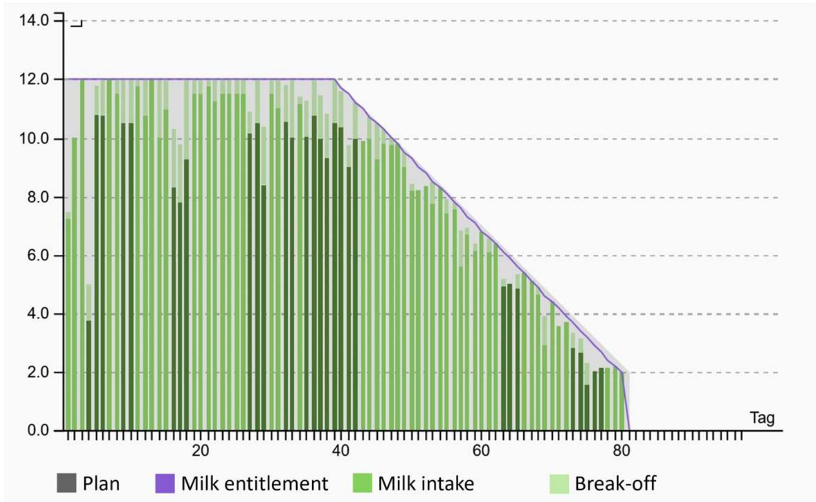


Figure 3. Detected daily milk uptake for a defined calf in relation to the defined feeding plan [42].

Critical, yet unavoidable in many aspects, is the manual input of colostrum and weight data. This can lead to errors and, consequently, inaccurate assessments if the data is not meticulously recorded. Automation in the field of colostrum is challenging to implement overall, as feeding occurs exclusively manually via buckets. It is conceivable to automatically record the milking quantity during the milking of the mother cow, but this does not provide final information about the calf's intake quantity. An automated assessment of colostrum quality, on the other hand, is conceivable and technically feasible immediately after milking by incorporating a refractometer into the milk flow. Therefore, the diligent entry of colostrum data by the user remains essential in the long run. Subsequently, a comparison of actual and target values can be used to assess the calf's colostrum supply based on the entered data. If additional data on a second colostrum intake is available, these can also be used, with a correspondingly defined weighting, to evaluate the overall colostrum intake. Figure 4 shows the overview of the colostrum intake as it is displayed in the prototype.

Details colostrum

Animal	First colostrum	Hours after birth	% Brix	Second colostrum	Hours after birth
[redacted]75732	4000 ml	11.50 h	27 Brix	400 ml	11.50 h

Figure 4. Display of the colostrum intake for a specific calf [52].

The automation of weight detection, on the other hand, is more straightforward. For instance, during the feeding period, a front hoof scale integrated into the feeding station can determine the weight for each milk retrieval, establishing a daily average value with a high standard of accuracy [45]. This ensures a highly accurate detection of weight development, allowing for reliable inference of disturbances or changes in animal development. The post-weaning period poses a greater challenge since regular visits to a feeding station no longer occur. One possibility is to integrate a front hoof scale into a concentrate feeding station during this time. This creates a comparable data chain to the feeding phase, allowing a reliable inference of the animal's further weight development. In the absence of these technologies on a farm, manual entry of weight development into the linked database is the only option. To simplify this process, an integrated input page can be used, minimizing additional effort for the end-user. Manual weight recording includes, most importantly, the birth weight, which serves as the baseline for weight development and is a crucial evaluation factor. Additionally, weights such as weaning weight and first insemination weight should be recorded. Further intermediate weighing, such as those for transitioning from individual to group housing, at 100, 200, and 300 days of life, provide a more accurate representation and evaluation of weight development. This ensures that the user can get a detailed display of the weight development of every single animal, as Figure 5 shows. Long-term efforts should focus on finding a practical and reliable method for easily detecting developmental weight.

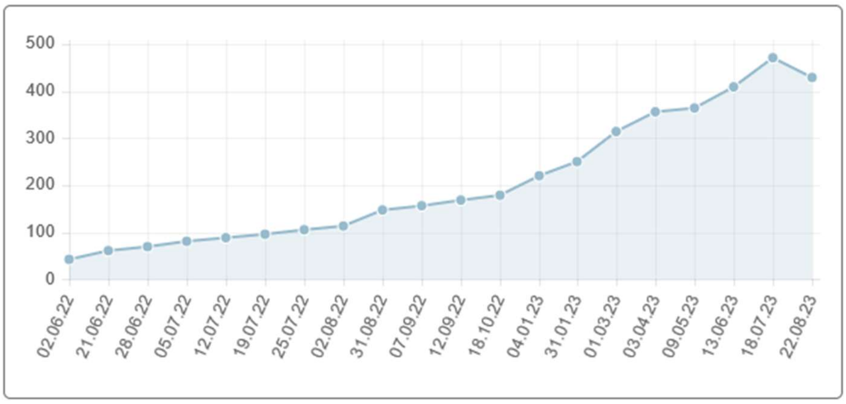


Figure 5. Output overview of the weight development (in kg) of a specific animal for several weighing intervals [52].

Based on regular weighing, the average daily weight gain of the animals can be calculated and presented graphically to the user (compare Figure 6), creating comparability among the animals. In the long term, this allows for the depiction of a farm-specific average development of the animals, serving as a benchmark for the daily weight gain of the animals.

The partially numerical evaluation of an animal's disease history is a good approach to indicate this complex field through an index. The existing assessment scheme according to the four-stage scale comparable to the Wisconsin calf scoring system [23] via the CalfApp-VITAL (visualized in Figure 7) can be utilized to create a numerical assessment of nostrils, eyes, ear position, feces consistency, and breathing. This assessment is further employed using the established point system for additional analysis. Additionally, the movement activity recorded via the collar sensor in the form of hourly acceleration values is a well-quantifiable measure. A comparison with previous days allows inference about changes in animal activity. For both measures, a re-evaluation through an updated comparison of actual and target values can generate a disease index. However, the integration of veterinary findings, inherently non-numerically quantifiable, poses a significant challenge in the ongoing project. A potential solution may involve linking to existing farm management information programs to retrieve treatment information and initially assess it categorically as 'treatment'. Establishing a classification of various diseases is also conceivable in the long term, allowing for some differentiation and preventing a blanket 'poor' rating for an animal treated in a less severe case. In this core area, further development is still needed. There are certain sensor technologies that might add additional use to the already existing system, improving its standardization and evaluation of an animal. However, the area of disease detection in dairy cattle gives numerous opportunities for additional technologies that could be adjusted to the needs of calves and heifers [10]. An additional factor that can be considered for the assessment of animal health is the integration of the barn climate and other quantifiable external influences [53], which should be considered in the long run for the project. In Germany, especially during the summer, heat stress plays a significant role in animal well-being and development [54], while cold stress is not a necessary factor. The additional documentation of temperature changes in the barn can serve as an additional assessment factor, providing insights into whether early measures need to be taken for the well-being of the entire offspring. Data can be related to the entire herd, allowing the detection of overall operational changes that can be comprehensively included in the evaluation.

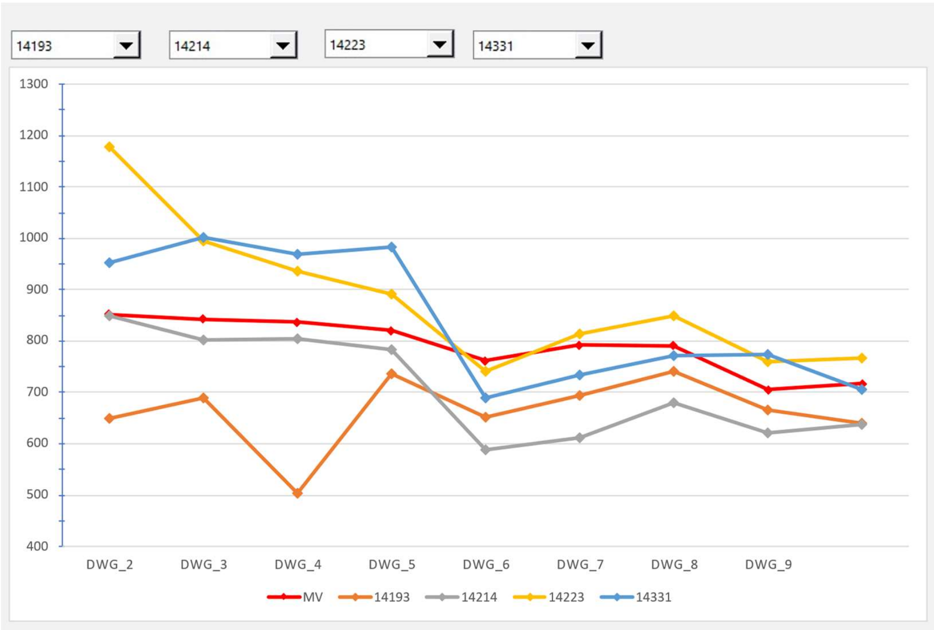


Figure 6. Output of the daily weight gain (DWG) in grams per day of four selected calves during the rearing period from birth until approximately 650 days of age with ten weighing intervals. The red line shows the mean value (MV) over all examined animals from one of the experimental farms (n = 240) [own diagram].

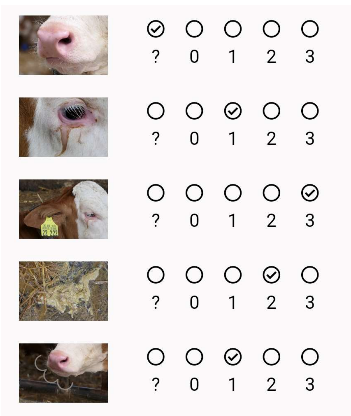


Figure 7. Evaluation scheme for (abnormal) changes in the nostrils, eyes, ear position, feces consistency, and breathing to detect health issues with an additional numeric output [46].

3.2. Established Standardized Evaluation Scheme

As initially described, a standardized evaluation scheme for replacement decisions is needed for board application on dairy farms. In this project, the evaluation of animals in the four aforementioned core areas is based on a numerical actual versus target value comparison. This assessment can take place directly on the used low-code platform, allowing real-time evaluation of each animal at any stage of its life. A robust benchmark was defined by comparing the stored target values in a database, aligning with current research, scientific knowledge, and experiences from collaborating experimental farms. Continuous adjustment of this benchmark occurs through comparisons with additional literature and ongoing research in relevant areas, ensuring the long-term relevance of the system. The individually recorded actual values for each animal can be accessed at any time for comparison. While the colostrum index is defined no later than after the second colostrum intake and remains unchanged, the milk index continuously changes throughout the entire nursing period and can be updated and accessed daily based on daily milk intake. After weaning, similar to the colostrum index, the milk index becomes fixed and unalterable. In contrast, the weight index remains adjustable throughout the entire animal development. It can be updated after each re-weighing of the animal, allowing for a new assessment of weight development depending on the animal's age. Initial target values for the birth, weaning, and first insemination of the corresponding dairy breed were predefined, framing the growth comparison. Birth weight, a significant part of weight evaluation, is aligned with these factors for an actual versus target value comparison, resulting in the weight index. The disease index can also be determined through an actual versus target value comparison with defined parameters. Unlike other indices, the assessment scheme is partially reversed here, interpreting a missing evaluation through CalfApp-VITAL as the absence of a need for assessment due to the lack of a diagnosis. Lastly, the change in the animal's activity can be assessed using the default, comparing changes to individual behavior in the preceding days without a fixed target value. This allows for the individual assessment of each animal.

Overall, the assessment scheme using an actual versus target value comparison is very well-suited for the intended purpose. The system's actuality is fully ensured through partial individual changes and adjustable or self-changing target values.

3.3. Rearing Recommendation for the User

The output of the selection recommendation for the animal owner is subsequently provided through a simple traffic light system. The four previously defined individual indices are combined to form an overall index that assesses the growth of an animal (compare the decision tree in Figure 8). The severity of the assessment ultimately determines the allocation of red, yellow, or green light, directly informing the animal owner about the suitability of the individual animal based on its specific growth (compare Figure 9a). Regarding the traffic light system, an animal evaluated with a red light is not recommended for further breeding; an animal evaluated with a yellow light might be chosen for further breeding but is not ideal, while an animal evaluated with a green light meets the set requirement and should be considered for further breeding. The four individual indices are equally valued to calculate the overall index. The standardized animal assessment created in this way also enables comparability between individual animals, even if they are in different stages of development. If necessary or desired, the animal owner has the option to examine the individual aspects of growth in detail, allowing for a clear understanding of the selection recommendation (compare Figure 9b). Regarding the individual traffic lights for the four indices, an animal evaluated with a red light does not meet the requirements, and an animal evaluated with a yellow light is close to the requirements, an animal evaluated with a green light meets the requirements or lies above them. Here, for the overall indices, the optimum to reach for a breeding recommendation would be 100%. An animal with a tolerance of 5% is still evaluated as suitable for further breeding, while an animal with a reduction of 15% or more is evaluated as not suitable for further breeding.

Additionally, there is a long-term goal to enable animal owner to individually adjust the target values to the operational standard, allowing the evaluation scheme to provide an intelligent assessment of the animal. The individually calculated scores for each animal can be compared separately, ensuring comparability among the animals (compare Figure 10). This allows the livestock owner to make informed decisions regarding the further use of the animal and, if necessary, to access additional details about the animal's development.

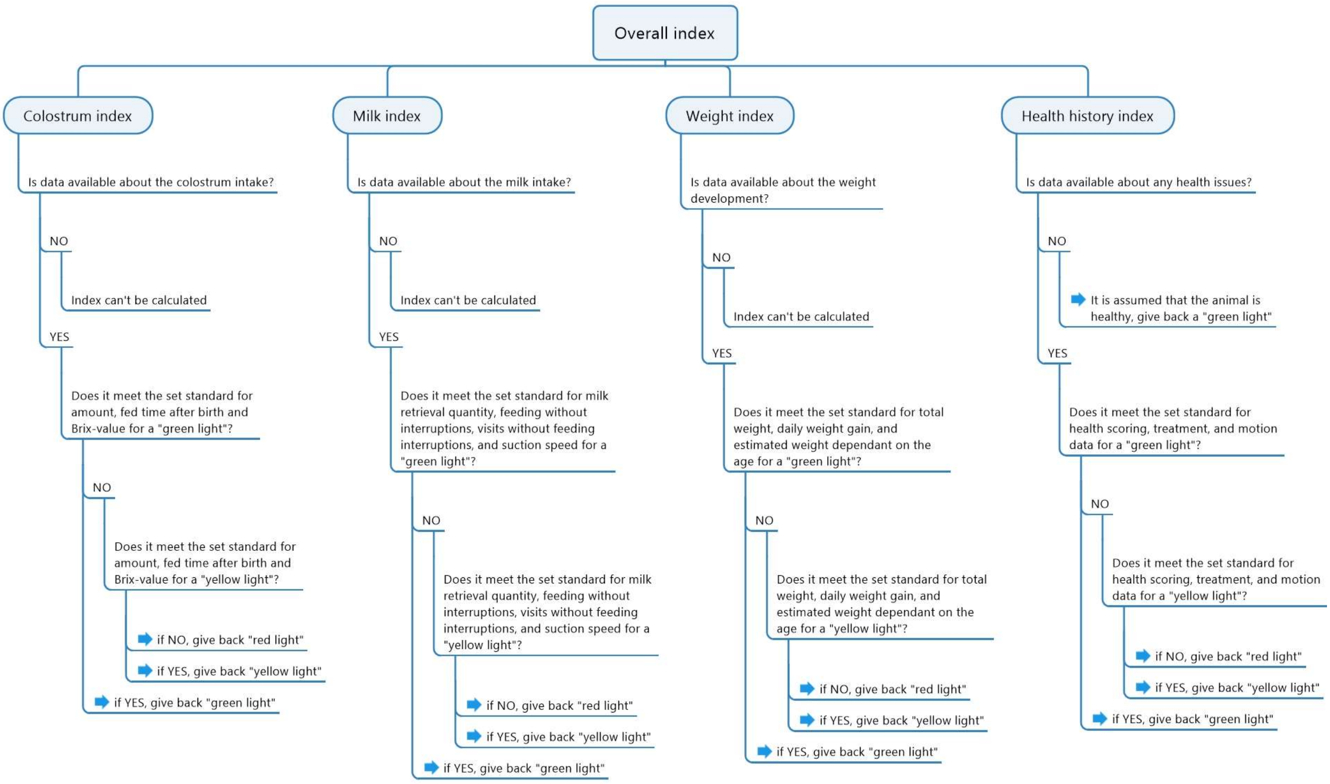
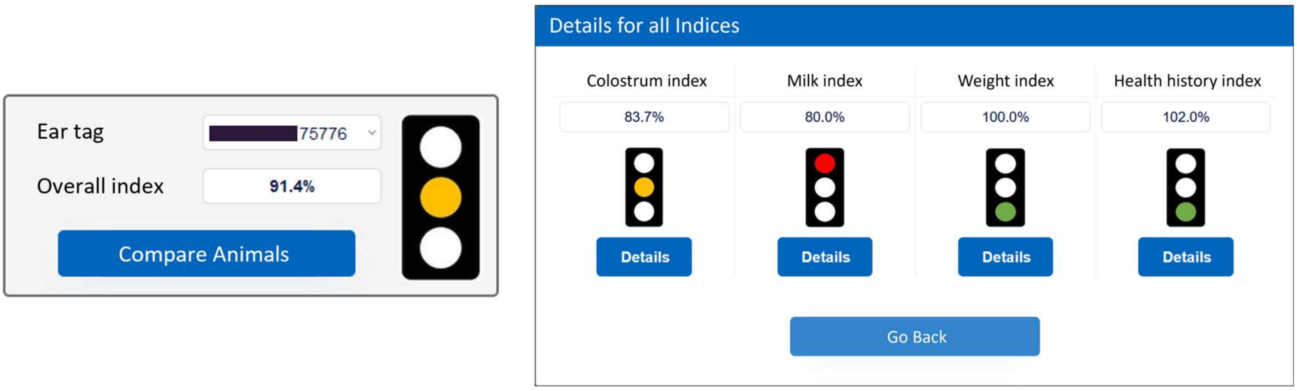
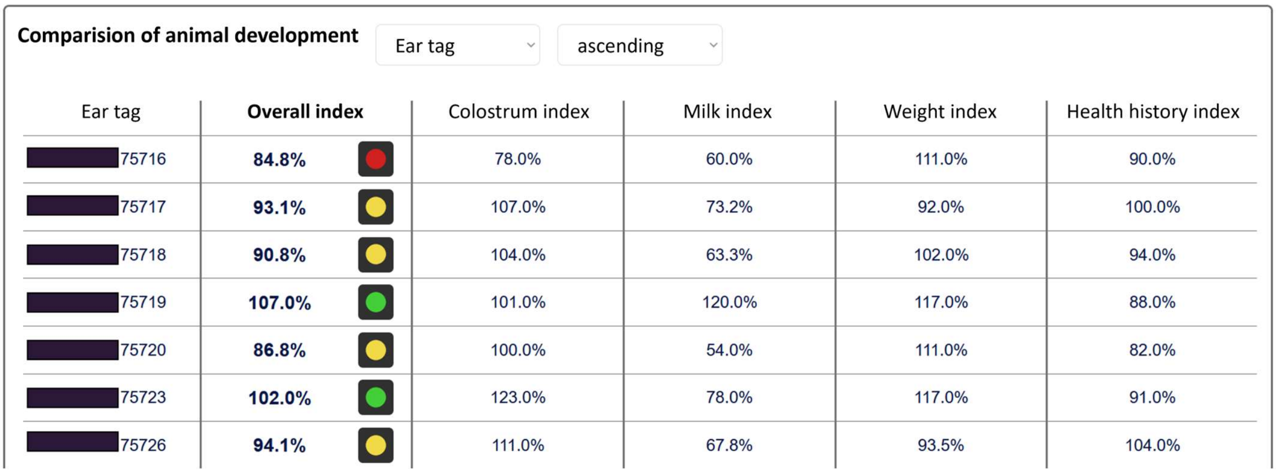


Figure 8. Decision tree for the evaluation of the growth of an animal.



(**a**) (**b**)

Figure 9. Representation of the selection recommendation as a traffic light system: (**a**) overall assessment; (**b**) assessment of individual core areas [52].



Comparision of animal development | Ear tag | ascending

Ear tag	Overall index	Colostrum index	Milk index	Weight index	Health history index
[redacted]75716	**84.8%**	78.0%	60.0%	111.0%	90.0%
[redacted]75717	**93.1%**	107.0%	73.2%	92.0%	100.0%
[redacted]75718	**90.8%**	104.0%	63.3%	102.0%	94.0%
[redacted]75719	**107.0%**	101.0%	120.0%	117.0%	88.0%
[redacted]75720	**86.8%**	100.0%	54.0%	111.0%	82.0%
[redacted]75723	**102.0%**	123.0%	78.0%	117.0%	91.0%
[redacted]75726	**94.1%**	111.0%	67.8%	93.5%	104.0%

Figure 10. Comparison of the development scores for several animals on a specific farm [52].

Among the previously mentioned challenges, in addition to the farm-specific adaptability, are individual software issues and the continuous comparison of target values with literature to ensure ongoing updates. After troubleshooting, an initial functionality test is planned. This practical test will allow testing the system's performance under real conditions, identifying further weaknesses, and improving the prototype. The integration of several additional information sources is possible in the long run. This includes the evaluation of breeding data from the mother and father animals and further sensor technologies available on the market.

3.4. Further Scientific Research

From a scientific perspective, the extensive collection of animal data provides an interesting foundation for further analysis. If the system can be established on a wide range of agricultural farms, and farmers permit the continued use of the data, it could, for example, reveal correlations between diseases in various life stages of an animal and its later milk performance. This could lead to a more precise decision recommendation, as additional factors can be considered in the final evaluation based on the insights gained. For further refinement of the animal evaluation, the integration of additional data is conceivable. For example, the use of rumen boluses may be suitable for detailed assessment of rumination activity, as well as for determining water intake. These two factors are particularly interesting during the heifer rearing period, as otherwise, the data availability is relatively sparse. In addition, the integration of climate data from the barn can provide further insight into the welfare of the herd and be included in the evaluation. Considering days with heat stress during the rearing time could form an additional factor. Initial research in this field has already shown that respiratory diseases in the first eight weeks of life have a measurable impact on the later milk performance of dairy cows, with a larger sample recommended for a conclusive statement [55]. Such and similar studies would be conceivable and feasible through widespread adoption and data collection in the long term.

4. Conclusions

The integration of digital sensor technologies and state-of-the-art sensors into agriculture holds great potential for more precise and sustainable practices. This applies equally to dairy cattle farming and the rearing of young animals. When considering data collection during the calf and heifer period, a significant data gap, especially during the heifer period, can be identified and addressed using the presented sensor network. The further processing of data in the form of a data-driven decision support system for animal owners on whether to retain or cull an animal is novel and not currently available in a comparable manner in the market. The current status of the prototype represents an innovation for young animal rearing in dairy cattle farming, with the target value comparison providing a simple and understandable scheme to make data-driven and transparent recommendations. There is long-term potential for further improvement to optimally support the animal owner in their work, provide standardized recommendations, and make optimal decisions from a business perspective. The successful development of the prototype in *Calf and Heifer Net* represents a significant step toward data-driven decision-making in calf and heifer rearing.

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