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RATIONALE AND LIMITATIONS OF THE DECISION SUPPORT SYSTEMS FOR DAIRY FARMS: A REVIEW

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ABSTRACT

This review aims to summarize the current knowledge about the logical basis of the decision support systems and highlighting future research and development needs for their effective adoptions by dairy farmers. Thus, an emphasis was given on the barriers to their wider uptake in the farming community. The article investigates scientific and professional literature regarding the decision support system framework, according to different factors affecting dairy farm profitability, such as optimal replacement decisions, reproductive performance, economic efficiency, and mortality rates. Accordingly, the description of the various methods being applied was covered. Special attention was drawn on the sustainability agenda, also linking to the idea of benchmarking farm performance and modeling impacts of different management decisions. Benchmarking helps to identify where strengths and weaknesses lie within a farm business. The decision support tools can be used to run various scenarios in the field of structural and technical change on dairy farms. Moreover, they can be tailored for dairy farms that differ in intensity and scale. The multi-actor approach during the development phase of the tools, also enabling dairy farmers to co-design them, may improve the acceptance of co-created solutions at the farm-level. It is also important to drive scientists and extension specialists to provide better understandable outputs by the sets of specific training.

Key words: decision; tool; dairy farm

INTRODUCTION

It has been estimated that the demand for animal-derived protein may double by 2050 (Henchion *et al*., 2017). The importance of animal-source foods in maintaining the health and nutritional status of inhabitants especially in developing countries with limited supply is well described (Neumann *et al*., 2002; Murphy & Lindsay, 2003; Randolph *et al*., 2007; Smith *et al*., 2012). Principal farm-level sustainability concerns in developing regions currently focus on limited food availability due to low agricultural yields, lack of producer education, and inadequacies of transport and sanitary infrastructure (Godfray *et al*., 2010). A common description of sustainability is the ability of a system, a firm or a sector to survive in the long run. The concept of resilience indicates the ability of a system, firm or sector to maintain its structural and functional capacity after a disturbance or shock (Perrings, 1998). Resilience is evidenced by an ability to recover and persist. According to Garmestani *et al*. (2006) the most resilient industries will be those with functions spread across the range of firm size. This will require breeders to maximise their efficiency and mitigate the negative environmental footprint. Farmers are encouraged to redesign and tailor their livestock farming systems to improve their sustainability (Rogers *et al*., 2004, Leeuwis, 2004). Van Calker *et al*. (2005) divided sustainability into four aspects: economic, internal

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social, external, social, and ecological sustainability. They selected profitability as the only attribute for measuring economic sustainability in Dutch dairy farming. More decision support systems (DSS) are now being offered for the farming community to accomplish this task (Andrew *et al*., 2013; Tamayo *et al*., 2010; Zhong-xiao & Yimit, 2008; Melville, 2010; Korte *et al*., 2012; Aubert *et al*., 2012).

Rationale of the DSS

Decision support tools can be designed as standard decision support tools used by advisors to discuss the issue with farmers (Stonehouse *et al*., 2002; Castelan-Ortega *et al*., 2003; Cabrera *et al*., 2005; Veysset *et al*., 2005; Crosson *et al*., 2006; Nelson *et al*., 2002; Fraisse *et al*., 2015). They may also be conceived as tools for a participatory discussion among stakeholders of in different production contexts (Bernet *et al*., 2001), or as prospective tools to support policy-making (Pacini *et al*., 2004, Rennings and Wiggering, 1997). For example, greenhouse gas emissions can be modelled and compared between organic and conventional systems (Kustermann *et al*., 2008). Such models may also be conceived as decision support tools for farmers, especially when the main viewpoint is productive (Diaz-Solis *et al*., 2003; Pla *et al*., 2003) or economic (Schaik *et al*., 2001; Bush *et al*., 2008). Other research models are aimed at a better understanding of farm operations and their consequences (Hervé *et al*., 2002; Cournut and Dedieu, Ingrand *et al*., 2003, 2004; Rotz *et al*., 2005; Andrieu *et al*., 2007).

The benefits of using a decision support tool are that it can improve individual productivity, improve decision quality and problem solving, as well as facilitate interpersonal communication. It can also improve decision-making skills and increase organizational control, present the likelihood of various outcomes resulting from different options (e.g. Power, 2002; Turban *et al*., 2007, Rossi *et al*., 2014, Dicks *et al*., 2014; Parker, 2004, Alenljung, 2008), with the support of appropriate information technology (Lindblom *et al*., 2014).

Limitation of the uptake

Despite the obvious advantages the uptake has been limited (Alvarez and Nuthall, 2006; Gent *et al*., 2013; Parker *et al*., 1997). Moreover, the levels of acceptance are low, because scientists fail to capture the actual needs of the farming sector (e.g. McCown, 2002; 2005; Parker & Sinclair, 2001; Öhlmér, 2001: Öhlmér *et al*., Melville, 2010) and many of the decisions are made with inadequate or incomplete datasets (Elhag and Walker, 2011).

Another challenge is to build models that will easily be appropriable by farmers and that will allow them to consider in-depth changes. Building them in a participatory way with farmers could be one way of making them more appropriable (Woodward *et al*., 2008; Cerf *et al*., 2008). Many studies marked user-friendliness or user involvement and effective communication during the development as a critical factor (Harris & Weistroffer 2009, Stewart, *et al*., 2013; Valls-Donderis *et al*., 2013; Volk *et al*., 2010; Jakku and Thorburn 2010; Meensel *et al*., 2012; Hall *et al*., 2010; Whittaker *et al*., 2013; McIntosh *et al*., 2011; McIntosh *et al*., 2008; Nguyen *et al*., 2006; Robinson, 2004; Freebairn, 2002; Hartwick & Barki, 2001; Newman *et al*., 2000). Furthermore, the usability for different users in varying situations and contexts is important (Rogers *et al*., 2011).

Benchmarking farm performance

National level competitiveness refers to the ability of a country to produce goods and services that meet the test of foreign or world market competition, while simultaneously maintain and expand domestic real income (Kaspersson *et al*., 2002). A key indicator in measuring the economic sustainability of an activity is profitability. If profits are negative, the revenues cannot cover the costs, which after some time will lead to bankruptcy of the firm and its closure. Positive profits as such reflect that an economic activity adds value, that what is produced is valued more highly by society than the inputs used for its production (de Jong, 2013). Furthermore, the return on investment can be measured by the improvement in environmental quality or the improvement in productivity of the agri-sector (Shepherd and Wheeler, 2010). The sustainability agenda indeed supports idea of benchmarking farm performance. Benchmarking itself is according to Franks (2003) not particularly radical for a farm manager to improve farm performance. The exact definition may vary but we can conclude that it involves borrowing good ideas from others about how to improve (Brown, 1995). This method requires specific measures of selected key performance indicators (KPIs) which describe the competitive performance level. More recently, sustainability KPIs are gaining interests too (Iribarren, 2011), while innovations in information and communication technology have opened a window of opportunities for on-line benchmarking via computer or via smartphone (Kaloxylos *et al*., 2014). Moreover, software and reports can be developed with which the indicators are reported back to farmers and added to their "dashboard" for monitoring their farm compared to others (Poppe, 2013). Many authors have already discussed key-issues regarding the design and use of sustainability assessment (e.g. Binder *et al*., 2010; Gasparatos & Scolobig, 2012; Gibson, 2006; Ness *et al*., 2007; Pope *et al*., 2004; Weaver & Rotmans, 2006). A first key-issue is the contested meaning of sustainability and sustainable development (Bond *et al*., 2013; Hopwood *et al*., 2005; Pope *et al*., 2004; Waas *et al*., 2011). As a result, for benchmarking sustainability and farm productivity, there is a need for a well-defined normative dimension of sustainability assessments, including the concept of sustainability (Binder *et al*. 2010). As many authors, Bond and Morrison-Saunders (2013) state the meaning of sustainability should be formulated for every assessment, taking into account the context in which it occurs. Literature reviews also shows that different purposes and levels also suggest different end-users (Van Passel & Meul, 2010).

The numerical integration combining the indicator results to present it as a single index or composite indicator (Gómez-Limón & Riesgo, 2009; Van Passel *et al*., 2007) is also implemented in the EkonMOD milk tool linking to management decisions and strategic choises available for dairy farmer management in Slovak conditions (Zahradnik, 2017; Záhradník and Pokrivčák, 2016a, 2016b; Zahradnik *et al*., 2018). Generally, each of the application under the umbrella of the EkonMOD milk platform is used to evaluate the economic consequences of different on-farm strategies. The interactive dairy farm model approach was developed at farm level and based on a static approach. This modeling framework was built to serve the purposes of a wider research strategy. The main objective of this activities concerns an analysis of possible effects of changing conditions on different Slovak dairy cow operations. The model developed can be used to run various scenarios in the field of structural and technical change on dairy farms. Moreover, it can be tailored for dairy farms that differ in intensity and scale. The associated assessments should apply sound statistical methods connecting also to the added value coming from the academia and research result available. Furthermore, input procedure to the model (application, software) has to be simplified and user friendly. The main argument for increased end-user acceptance will be the farm specific adjustments corresponding with user-selected strategic processes on the dairy operation. The procedural instrument to guide the use of sustainability assessment tools within strategic decision making was developed by Coteur *et al*. (2016) with framework allowing a farm-specific and flexible approach leading to harmonised actions towards sustainable farming. The time dimension in this study were defined by five phases based on the framework of De Ridder *et al*. (2007). They propose an integrated assessment, followed by problem analysis and finding the options, analysis and finally, the follow-up. The purpose of 5 step approach tailored by Coteur *et al*. (2016) is gaining insights on the sustainability of multiple farm aspects and stressing the importance of the distinction between assessing the farm and interpreting the results is essential in this framework as the interpretation of results occurs preferably in different ways and depends on the tool choice. The improvement strategies will be implemented in a fourth step and correspond to the third analysis phase of de Ridder *et al*. (2007) followed by the benchmarking and follow-ups (Coteur *et al*., 2016). According to the outcomes of EIP-AGRI focus group benchmarking of farm productivity and sustainability performance outcomes final report, the macro level benchmarking analysis involves a more generic framework where specific farm conditions related productivity and sustainability are shaped by policy, law and regulation, and trade. In addition, macro conditions are influenced by economic and social developments and demographics, technical advances and environmental conditions. Following the report the use of benchmarking data in the aggregate form may benefit the agricultural industry, and indirectly or directly the farmer, in achieving greater productivity and sustainability. In addition, benchmarking may inform policy development, guide industry regulators and trade organisations, inform industry research, development and innovation, and provide a wealth of information for advisors and educational institutions. The report also suggests that in general, an ideal macro benchmarking system would give clear indicators on where the greatest impact of policies for encouraging competitiveness, productivity and sustainability could be found (EIP-AGRI, 2016).

Implications for dairy farming

In general, dairy farms are deficient in the use of advanced projection frameworks such as simulations (Bewley *et al*., 2010). Nevertheless, an efficient DSS framework is critical for dairy farming management and decision-making through e.g. optimisation of synthetic systems (Cabrera *et al*., 2006, Booty *et al*., 2009). Herd management practices are essential for the productivity of dairy farms (El-osta and Morehart 2000). Growing the herd brings additional difficulties for the farm management (Gargiulo *et al*. 2018). Moreover, inappropriate farm management can negatively impact health and welfare standards of the productive livestock and lower the economic results of the dairy operation (Calsamiglia *et al*., 2018). Keeping the records on an individual cow level is crucial for optimal management decision if necessary (Barragan *et al*. 2016). However, switching from herd level to a cow level in based on a real-time data acquisition (Debauche *et al*., 2018).

Culling decisions

Optimal replacement decisions are cited as one of the most important factors affecting dairy farm profitability (van Arendonk, 1984), and these decisions are directly affected by fluctuations in milk price, salvage values, and replacement costs. Culling decisions are based primarily on milk production and partially on health status. Despite their economic importance, culling decisions are often made in a nonprogrammed fashion and based partly on the intuition of the decision maker (Lehenbauer and Oltjen, 1998). Little or no effort is made to support replacement decisions using economic or financial methods. Traditionally, culling of dairy cows has been viewed from a historical viewpoint. Many dairy farmers and their consultants calculate their annual culling rate and focus on the percentage of cows culled for a variety of reasons (Eicker and Fetrow, 2003). To improve culling decisions, a more prospective approach is preferable and could result in different culling decisions by producers. High yields of dairy cows frequently contribute to the increased health issues. The consequent costs and labour required decrease the overall farm productivity. Lifelong milk productivity of dairy cows can be referred as crucial indicator for management representatives. Moreover, the m dairy cow's milk yield and the stage of lactation have a significant impact on culling (Rajala-Schultz, 1999). Dairy cows culling and heifer selection in rearing period therefore represent important tasks for every dairy operation. To support management decision, several support models were developed. The problem can be formulated as a multi-hierarchical Markov decision process or optimization dynamic programming model. The ability of farmers to make right decisions at the right times significantly determines the success of any enterprise. This success can be stated as maximizing profit. It has been shown that total profit is highly affected by reproductive performance (Britt, 1985).

Heifer replacement

Reproductive performance received special attention in the literature (Olynk and Wolf, 2009; Cabrera and Giordano, 2010; Giordano *et al*., 2011; Giordano *et al*., 2012, Ettema 2011) as a result of its prominent economic impact on the profitability of dairy operations. Numerous studies have analyzed the optimum replacement interval in dairy herds and factors that affect these decisions (van Arendonk, 1985; Kristensen, 1988; De Vries, 2004, Demeter *et al*., 2011; Cabrera, 2012). Simultaneous accounting of several biological and economic parameters is necessary to determine the optimum time of replacing a cow. Milk production level, pregnancy, stage of lactation, parity and transition probabilities such as involuntary culling, pregnancy, and abortion are considered the most important factors affecting replacement decisions (Kalantari *et al*., 2010). Alternative approaches have been proposed to handle these factors and find the optimum replacement strategy including marginal net revenue (MNR) (van Arendonk, 1984), dynamic programming (DP) (Smith, 1973; van Arendonk, 1985; De Vries, 2004), and stochastic simulation models (Kristensen and Thysen, 1991). The first two methods are based on the production function approach in which the cow's revenue and costs are modelled during cow's lifetime (Groenendaal *et al*., 2004). The limitation of MNR is its inability to include the variation in expected milk production of the present cow and subsequent replacement heifers, and the genetic gain of replacement heifers (Groenendaal *et al*., 2004). The DP technique overcomes two limitations. However, due to its complexity, the usage of DP models has been restricted to research analysis and not for building decision support systems for practical decision-making and on-farm management. The Monte Carlo stochastic simulation approach has been used to calculate the total expected net returns during next year and that value was used for ranking animals. Kristensen and Thysen (1991) compared the decisions being made by DP and stochastic simulation and reported insignificant difference between the two models. Recently, Cabrera (2012) used a Markov chain simulation model to find a suboptimal replacement strategy. In brief, this method calculates the net present value for a cow and its potential replacement, which could be used to decide whether to keep or replace a dairy cow. This method does not have the complexity of DP models and overcomes the limitation of MNR method because it can include expected variations in the cow and replacement performances. Cabrera (2012) reported that trend and replacement strategies found with the newly Markov chain model would be similar to those found with DP models. However, such study did not include a formal comparison with a DP model. Kalantari *et al*. (2014) has found a strong correlation (95 %) in replacement decisions resulting from using two completely different modeling approaches: The classical and state-of the- art dynamic programming framework and a newly developed technique using simple simulation of Markov chains. Post optimality analyses demonstrated that overall long-term herd structure and herd net returns resulting from models' replacement policies were very similar. These results strongly support that the newly developed Markov chain is a good alternative for practical dairy decision-making and for the development of decision support systems.

Heifers rearing period

The replacement heifer program is particularly important, and its primary goal is to breed these animals at an early age with optimal body weight to achieve easy calving with minimum investments (Fricke, 2004). Dairy farmers face a complex dilemma in minimizing costs associated with rearing heifers while ensuring or enhancing lifetime economic productivity. Decisions about heifer management interact with underlying biological aspects of growth, thereby influencing future profitability of the herd (Mourits *et al*., 1999). A basic approach to reduce costs is to shorten the non-productive period of dairy heifers, which can be accomplished by breeding heifers earlier to reduce the age at first calving (AFC); Abeni *et al*., 2000; Daniels, 2010). Dairy heifers are normally inseminated for the first time at about 15 months of age to calve at approximately 2-years of age. At the age of 15 months, they reach only about 60 % of mature body weight (Coffey *et al*., 2006). The management decision on when to start breeding is a management one, but it is generally influenced by nutrition and growth rate during the rearing period (Carson *et al*., 2002; Serjsen, 2005). Many studies suggest that the optimal AFC is ≤ 24 months (Mourits *et al*., 1999; Gabler and Heinrichs, 2003; Shamay *et al*., 2005). Pirlo *et al*., (2000) also confirmed that AFC can have a significant effect on both milk production capacity and longevity. The relation of lifetime milk performance to calves rearing period and fertility issues in the typical UK dairy farms was also evaluated by Wathes *et al*. (2008). However, most of those researchers based their conclusions on milk production rather than whole economic measurements. Ettema and Santos (2004) found that only 2.7 % of US Holstein dairy farms achieved the recommended targets of AFC ≤ 24 with live-weights ≥ 560 kg. The tendency for additional returns from higher number of new-born calves was also confirmed in sheep by Bonev and Kostadinova (2011). Fricke (2003, 2004) proved that the delay in age at first calving in heifers generated additional costs from higher culling rate, dystocia, and metabolic disturbances. According to the author, the optimum age at first calving of heifers was 24 months. Calving heifers at an older age has many disadvantages other than increasing their non-productive life and delaying potential milk income. When heifers calve at ages greater than 24 to 25 months, larger inventories or numbers of heifers must be maintained in the heifer herd. Increasing the age at calving also increases the generation interval, delaying the introduction of genetically superior replacements in the herd (Bailey *et al*., 2009).

Performance of Slovak Holstein dairy herds

According to the Result of dairy herd milk recording in Slovak republic, which are annually conducted by the Breeding services of Slovak republic, the optimal AFC for national conditions supports the previous foreign studies and research papers conclusions. Based on these outcomes it can be stated, that reducing AFC in Slovak Holstein herd had improved the length of productive life, number of lactations, lifetime yield as well as lifetime yield per day of Holstein dairy cows (BS SR, 2017). Based on the milk recording in control year 2014/2015 performed by the BS SR, it can be concluded that the lifetime milk yield of Holstein heifers first calving in 24 months amounted 21279 kg. The two additional months in AFC transformed in 104 € loss per cow. Adding another two months over the 26 months AFC will almost double the negative economic impact (-210 €). Holstein heifers first calving in 30 months have generated a -442.68 € loss a per cow basis. Negative impact on the lifetime yield was also well documented even for AFC below the optimal 24 months. Heifers with 21 months of AFC produced 1342 kg less amount of milk generating a -375.76 € loss in control year 2014/2015. Furthermore, the recent study by Huba *et al*. (2017) supports this results for Slovak Holstein dairy herds in 2016. The Holstein first calving heifers at 23 months confirmed to have the highest milk yield per lactation as well as lifetime milk yield per day. However, the highest value of lifetime milk yield was reached by Holstein heifers first calving in 24 months.

Economic impacts

Mortality rates and culling of dairy animals are the critical indicators for dairy operation productivity. As reported by Fetrow *et al*. (2006) culling or exiting is the departure of cows from the herd because of sale, slaughter, salvage, or death. In most cases the cow that exits is replaced. The term "cull" than refers to all the cows that leave the dairy operation regardless of their destination or condition at departure. The report also implies that some may object to including cows that are sold for dairy purposes as part of a general cull category, as the word "cull" generally means to separate off for undesirable reasons. However, quantifying the amount of culling on dairies is highly beneficial in the comparison of herds (Fetrow *et al*., 2006). The literature review outlined a several approaches to describe the culling process on dairy farms including Terms like "yearly turnover" and "cows leave, %" (AgSource Cooperative Service, 2005), "culling rate" by Hoekema, 1999 a,b and also by Brett, 2003), "proportion removed from herd" (Smith *et al*., 2000), "percent left herd" (Gangwer *et al*., 1993), and "replacement rate" (Allaire, 1981). Dohoo and Dijkhuizen, 1993; Radke, 2000) even argued to distinguish the cause of culling as either "biological" (also known as "forced") or "economic". For any case mentioned, a more precise approach is to average the cow inventory at monthly intervals over the year (DRMS, 1997). Furthermore, Fertow *et al*. (2006) evaluated different herd turnover calculation methods. The calculation of herd turnover rate by two approaches for 4 combinations of herds, representing stable or expanding herds with moderate or intense culling. The alternative calculation (adding the number culled into the denominator) substantially underestimated the risk of culling in herds. The preferred calculation accurately estimates the risk of culling, even in rapidly expanding herds, as long as the mean cow inventory (denominator) was calculated on at least a monthly basis (Fertow *et al*., 2006). The pasture-based herd management system are to be reviewed with respect to the different routines and subsequent issues related to local conditions and husbandry systems used. This remark also supports the benchmarking with relevant peer operations and creation of individual farm information system. According to Compton *et al*. (2017) dairy industries and farmers need benchmarks for culling and mortality against which they can compare themselves, as well as improved understanding of the extent of any change and of any associated factors. Moreover, these events are inevitable and common, understanding their extent and causes at the herd or industry level is challenging because culling and mortality are influenced by economic, social, management, and animal disease factors. In turn, culling and mortality have important economic and animal welfare consequences (Compton *et al*, 2017). The study of de Vries *et al*. (2011) also indicated that high culling rates, including mortality, refers to the poor animal welfare status. Moreover, calf mortality has been identified as one of the most important indicators of dairy farm health status (Ortiz-Pelaez *et al*., 2008) and also represents economic losses to the dairy industry due to delayed genetic progress, fewer replacements available for voluntary culling of the lactating herd, and increased cost of replacement (Raboisson *et al*, 2013). The annual economic damage resulting from stillborn and loss of calves is reported to be about $125 million (Meyer *et al*., 2001). It can be concluded that the total costs of calf and heifer mortality are probably underestimated (Ortiz-Pelaez *et al*., 2008). According to the work of Meyer *et al*. (2001), Berglund *et al*. (2003) and e.g. Steinbock *et al*. (2003), the continuous increase in calf-heifer mortality reported in many countries during the last decade suggests that the economic and welfare stakes related to the mortality of young cattle are also increasing. Furthermore, farmers also have been shown to alter their own culling criteria and decision making based on sociological issues (demographic characteristics, attitudes, education, degree of involvement in dairy groups) in addition to economic or biological ones (Beaudeau *et al*., 1996).

CONCLUSION

The management of dairy operations can be complex and daunting, while confronting many factors that are changing over time. Many farmers already discuss milk yields and other parameters among them, but sophisticated DSSs can provide more complex and independent analysis of dairy operation performance. The main goal of this approach is to improve individual profitability and better understanding of dairy business through evidence-based decisions.

There are a selection of tools available to perform on-farm analyses and assist in effective decision making process; but a key requirement is the system thinking element as a part of day-to-day farm routines rather than an ex-post evaluations. This remark also supports the benchmarking with relevant peer dairy farms and development of individual farm expert systems. Benchmarking tools typically help to identify where strengths and weaknesses lie within a farm business. By comparing with similar enterprises, benchmarking enables farmers to improve individual business performance and tackle the market volatility. This will ensure that the farm business is on the best possible roadmap for the future sustainable development.

Limitations of the uptake and lack of effective communication can be addressed by developing adapted DSS, using the multi-actor approach principles throughout the whole development process. By enabling dairy farmers to design and co-create potential solutions we may improve the implementation and speed up innovation on the ground through the interactive innovation model. It is important to incentivise scientists for their impact on agricultural practice by easy understandable outputs for end-users. The system of specific training courses will be needed to accomplish this task. Moreover, the availability of extension specialists or innovation transfer brokers for growing farming community would be limited in the future. Information and communication technologies have huge potential to partially tackle this issue with the switch from 'intuitive' to 'smart' decision making models. Effective adoption of specifically tailored DSS has already demonstrated the potential to bring economic, social and environmental benefits at local, national and global levels.

This study attempts to summarize the current knowledge about the logical basis of the decision support systems. The information provided here, however, may not be considered as complete. For instance, recent research aimed at national agricultural and innovation system structure and performance was not included in the present study. Further research is needed to better understand the links between the actors involved (e.g. farmers, advisors and scientists). The greater consideration of farm-level and end-user inputs and greater efficiency in respond to practice needs are critical.

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