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# Multivariate dynamic linear models for estimating the effect of experimental interventions in an evolutionary operations setup in dairy herds

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## ABSTRACT

Evolutionary operations is a method to exploit the association of often small changes in process variables, planned during systematic experimentation and occurring during the normal production flow, to production characteristics to find a way to alter the production process to be more efficient. The objective of this study was to construct a tool to assess the intervention effect on milk production in an evolutionary operations setup. The method used for this purpose was a dynamic linear model (DLM) with Kalman filtering. The DLM consisted of parameters describing milk yield in a herd, individual cows from a herd, and an intervention effect on a given day. The model was constructed to handle any number of cows, experimental interventions, different data sources, or presence of control groups. In this study, data from 2 commercial Danish herds were used. In herd 1, data on 98,046 and 12,133 milkings registered from an automatic milking system (AMS) were used for model building and testing, respectively. In herd 2, data on 3,689 milkings on test days were used for estimating the initial model parameters. For model testing, data from both bulk tank milk yield (85 observations) and test-day milkings (1,471) were used. In herd 1, the manager wanted to explore the possibility of reducing the amount of concentrate provided to the cows in an AMS. In herd 2, the manager wanted to know if the milk yield could be increased by elevating the energy level provided to the cows in a total mixed ration. The experiment conducted in herd 1 was designed with a treatment and a control group, whereas in herd 2 it was a pretest/posttest design. The constructed tool provided estimates (mean and confidence intervals) for each of 3 interventions carried out in both herds. In herd 1, it was concluded that the reduction in concentrate amount provided in the AMS had no negative influence on milk yield. For herd 2, the increased level of energy had a significant positive effect on milk yield but only for the first intervention. In this herd, the effect of intervention was also evaluated for cows in the first lactation and without bulk tank records. The presented model proved to be a flexible and dynamic tool, and it was successfully applied for systematic experimentation in dairy herds. The model can serve as a decision support tool for on-farm process optimization exploiting planned changes in process variables and the response of production characteristics.
**Key words:** dynamic linear model, evolutionary operation, milk yield

## INTRODUCTION

Production conditions on dairy farms are not identical. Therefore, certain solutions regarding, for example, feeding, milking strategy, or management, can bring positive production results for some producers but negative results for others.

The dairy industry is not the only one that has to overcome this problem. Managers employed in the chemical and engineering industry noticed that some production strategies will not work equally well for all factories. A solution for this problem was introduction of evolutionary operations (**EVOP**) methods based on systematic experimentation during the production process (Box, 1957). Evolutionary operation is used for process optimization to find a way to alter production to be more efficient. The major advantages of this method are the application of statistical ideas and the ability to be run during the standard production process in the local environment.

To apply EVOP to a production process, first production characteristics to be improved (for dairy operations, e.g., milk yield, SCC) need to be identified and their current values have to be known. Second, small changes (hereafter called interventions) to the input factors, also called process variables, need to be

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planned and implemented. Alternatively, small changes in the process variables that are invoked during normal production flow on dairy farms can also be monitored and used to gain knowledge. As described by Myers and Montgomery (1995), the changes in the production variables should be relatively small, yet they should be large enough to discover potential improvements in productivity. Third, to properly evaluate the effect of interventions, data on response variables of interest need to be collected and evaluated. Moreover, to properly assess the effect of intervention on the productivity, an estimate of measurement error is required. Finally, based on observed results, the decision on implementing new production conditions (e.g., concerning feeding) should be made.

Evolutionary operation has been widely and successfully applied to the process industries (Box and Draper, 2006); however, applications of the EVOP concept in livestock sciences are rather scarce. To the best of our knowledge, no studies have demonstrated the use of EVOP in the dairy industry. Andersen et al. (2016) demonstrated how the EVOP can guide pig farmers to optimize their production. Using an EVOP framework they have shown that changes in the diurnal rhythm of water consumption can be used to give a rapid indication of the optimal combination of production factors within the herd.

This lack of application of the EVOP approach in dairy production could be due to 2 challenges. The first challenge, valid mostly in the past, was the absence of sufficient data collected during the production process. Nowadays, this is hardly an obstacle due to increasing amount of farmers investing in automatic milking systems (**AMS**), automatic estrus detections systems, and other technologies with automatic data recording. The second, so far unsolved challenge, is the lack of a flexible tool to dynamically estimate the effect of the intervention made to a dairy cattle production system.

The decision support tools currently used in dairy operations are based mainly on key figures, and in some cases on time series analyses, multifactorial analyses, and simulations, each with their own strengths. But when it comes to evaluating the effect of a given change in production method (e.g., feed supplement, grouping of cows, mastitis prevention) in a local situation, the existing systems lack the ability to control for potential confounders and may involve selection bias. In that respect, a potential EVOP tool should fill a gap in the existing systems rather than being an alternative to them.

An efficient tool to be used in EVOP experimental interventions should meet also other requirements. Because the EVOP concept is based on systematic experimentation within an ongoing production process, a tool used for estimating the effect of these systematic changes should provide results frequently (e.g., on daily basis), so that any negative changes to production would be noticed almost immediately and the experiment could be discontinued without major financial losses for a farmer. Moreover, to be used as farm decision support, a tool should not only provide estimates of the mean of the intervention effect but also quantify the uncertainty about the true value of the intervention (i.e., provide estimates regarding variance). In addition, a flexible tool should be able to use data collected from different sources (e.g., daily milk production from AMS, bulk tank, or test-day milkings).

A method based on a dynamic linear model (**DLM**) with Kalman filtering fulfills all requirements listed above. DLM have been widely applied in effect evaluation (West and Harrison, 1997). In dairy production, only 3 applications of DLM with Kalman filtering were described until 2009 (De Vries and Reneau, 2010). Dynamic linear model have been used in monitoring bulk tank SCC in milk (Thysen, 1993), in detecting estrus and diseases in dairy cattle (de Mol et al., 1999), and in monitoring daily milk production (Van Bebber et al., 1999). In recent years, DLM have been used to estimate the production potential of cows as a basis for optimal replacement policies (Nielsen et al., 2010), for prediction of dairy cow mastitis (Jensen et al., 2016), as well as to determine whether dairy cows with subclinical mammary infections recover after antibiotic treatment (Jørgensen et al., 2016). The model constructed by Van Bebber et al. (1999) was used to detect significant changes in the milk production of both individual cows and an entire herd, and could be used in exploiting changes occurring during normal (non-EVOP) production flow in the dairy herd. However, to our knowledge, DLM have not been used with the focus on estimating the effect of EVOP interventions in dairy herds.

A large amount of data on milk production is being accumulated in dairy herds. For example, over 1 million test-day records collected across herds were used for prediction of daily milk, fat, and protein production (Mayeres et al., 2004) or to identify sources of variation able to explain differences between herds in milk production (Caccamo et al., 2010). However, when constructing a decision support tool used for on-farm process optimization, farm-specific data should be used. This is particularly important, as pointed out by Toft and Jørgensen (2002), due to the fact that application of parameters that are common to all herds in a decision support system might lead to flawed results.

The objective of this study was to construct a tool able to estimate the effect of an intervention on milk