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A comparison of 4 predictive models of calving assistance and difficulty in dairy heifers and cows

Caroline Fenlon,*[1] Luke O'Grady,† John F. Mee,‡ Stephen T. Butler,‡ Michael L. Doherty,† and John Dunnion*
*School of Computer Science, and
†School of Veterinary Medicine, University College Dublin, Belfield, D04 W6F6, Dublin 4, Ireland
‡Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, P61 P302, County Cork, Ireland

ABSTRACT

The aim of this study was to build and compare predictive models of calving difficulty in dairy heifers and cows for the purpose of decision support and simulation modeling. Models to predict 3 levels of calving difficulty (unassisted, slight assistance, and considerable or veterinary assistance) were created using 4 machine learning techniques: multinomial regression, decision trees, random forests, and neural networks. The data used were sourced from 2,076 calving records in 10 Irish dairy herds. In total, 19.9 and 5.9% of calving events required slight assistance and considerable or veterinary assistance, respectively. Variables related to parity, genetics, BCS, breed, previous calving, and reproductive events and the calf were included in the analysis. Based on a stepwise regression modeling process, the variables included in the models were the dam's direct and maternal calving difficulty predicted transmitting abilities (PTA), BCS at calving, parity; calving assistance or difficulty at the previous calving; proportion of Holstein breed; sire breed; sire direct calving difficulty PTA; twinning; and 2-way interactions between calving BCS and previous calving difficulty and the direct calving difficulty PTA of dam and sire. The models were built using bootstrapping procedures on 70% of the data set. The held-back 30% of the data was used to evaluate the predictive performance of the models in terms of discrimination and calibration. The decision tree and random forest models omitted the effect of twinning and included only subsets of sire breeds. Only multinomial regression and neural networks explicitly included the modeled interactions. Calving BCS, calving difficulty PTA, and previous calving assistance ranked as highly important variables for all 4 models. The area under the receiver operating characteristic curve (ranging from 0.64 to 0.79) indicates that all of the models had good overall discriminatory power. The neural network and multinomial regression models performed best, correctly classifying 75% of calving cases and showing superior calibration, with an average error in predicted probability of 3.7 and 4.5%, respectively. The neural network and multinomial regression models developed are both suitable for use in decision-support and simulation modeling.

Key words: dystocia, calving assistance, machine learning, external evaluation

INTRODUCTION

Difficult parturition (dystocia) has severe consequences for the welfare of both the dam and calf, including pain, increased risk of surgery, morbidity linked to other diseases, mortality, and culling (Huxley and Whay, 2006; Mee, 2008a). Dystocia also has significant direct and indirect economic consequences (Dematawewa and Berger, 1997). Direct costs include veterinary assistance/treatment at the point of calving and increased risk of dam and calf mortality (Ettema and Santos, 2004). Indirect costs include treatment of dystocia-associated transition cow disorders (Erb et al., 1985; LeBlanc, 2012) and sequelae such as losses in genetic gains associated with mortality or culling, increased BCS loss, reduced milk production, and impaired reproductive performance (Fourichon et al., 1999, 2000; Berry et al., 2007; Fenlon et al., 2017).

The classification systems for calving difficulty vary internationally (Mee, 2008b), but generally consist of unassisted calving (**UC**) events (unobserved or observed), unrequired/nonessential assistance, and required/essential interventions. In Ireland, calving difficulty is recorded by famers using an ordinal scale from 1 to 4 (Mee et al., 2011). In dairy cattle, dystocia generally occurs in less than 5% of calving events (Mee, 2008b), though this figure varies by country and greatly between herds. The most recently reported incidence of scores 1 to 4 in Irish Holstein-Friesian cows were 68.9, 24.3, 4.3, and 2.5%, respectively (Mee et al., 2011)

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[1]Corresponding author: caroline.fenlon@ucdconnect.ie

Risk factors for dystocia associated with the dam have been identified: parity, with first parity animals having a higher incidence of calving difficulty (Johanson and Berger, 2003; Mee et al., 2011); nutritional status and its interaction with age at first calving, particularly undercondition or overcondition at calving (Drew, 1986); and previous history of dystocia (Mee et al., 2011). Similarly, risk factors associated with the calf have been identified: higher birth weight and higher weight relative to the dam's BW (Berry et al., 2007; Mee, 2008b), gestation length, plurality (Ettema and Santos, 2004), and sex (Ettema and Santos, 2004). Embryos produced in vitro resulted in calves with longer gestation, greater birth weight, and greater levels of difficulty than calves arising from AI or in vivo embryos (Kruip and Den Daas, 1997).

Accurate prediction of the risk of dystocia at an individual cow level could inform preventative actions and farm management decisions. A limited number of studies have attempted to predict the probability of dystocia. Binary models comparing assisted calving and UC events in various breeds of dairy and beef cows have been created using logistic regression (Johanson and Berger, 2003; Bureš et al., 2008; Mee et al., 2011). A study of Canadian Holstein calving events performed least squares analysis to model 4 levels of calving difficulty (Klassen et al., 1990). However, few studies have evaluated the predictive ability of calving difficulty models. A series of studies used classification trees, support vector machines, neural networks (**NN**), and generalized linear models to distinguish between UC and difficult calving (**DC**) events for Polish Holstein-Friesians managed in indoor production systems (Zaborski and Grzesiak, 2011; Zaborski et al., 2014a,b). The models were evaluated using root mean square error and prediction sensitivity, specificity, and accuracy. Another study of Polish Holstein-Friesian cows modeled 4 levels of calving ease using classification trees and again evaluated the results using classification error measures (Piwczyński et al., 2013).These discrimination tests measure a model's ability to correctly classify cases, (i.e., the separation between the possible outcomes). Another type of evaluation is available for probabilistic models (Tedeschi, 2006). Methods of calibration allow the identification of any areas of poor fit or bias in the predictions, by comparing predicted probabilities to true proportions of events in groups of similar records.

The aim of the present study was to create and evaluate predictive models of calving assistance and dystocia for use in decision-support tools and simulation modeling. Our objective was to employ a range of machine learning techniques to create a model using data commonly recorded by dairy farmers.

MATERIALS AND METHODS

Data

A total of 1,686 records of calving events from the years 2000 to 2010 were sourced from the Ballydague and Curtins research herds at Teagasc's Animal and Grassland Research and Innovation Centre, Moorepark, County Cork, Ireland. These herds were representative of recommended Irish grass-based farming systems with a diverse range of cow genetics (Horan et al., 2005). An additional 390 calving events from 2015 were available from 8 herds of Holstein-Friesian cows. These herds were involved in a herd health and fertility consultancy program operated by the School of Veterinary Medicine, University College Dublin (Somers et al., 2015). All of the herds operated seasonal breeding, with the recorded calving events happening between January and April.

Along with the dam tag number and calving date, records available from each herd's herd management software included calving difficulty score and BCS. Calf-level information included birth weight, sex, sire, and binary indicators of stillbirth (dead calf born at term) and twinning. Details of AI service dates, pregnancy diagnosis, and BCS from the preceding lactation were also available. Additionally, breed, genetic economic breeding values and PTA for traits of economic importance were available from the Irish Cattle Breeders Federation (**ICBF**) national database. In total, approximately 120 variables were available for consideration in the modeling process.

The date of each service event that resulted in conception was confirmed by ultrasound scan between 30 and 60 d postservice or by subsequent calving 282 ± 15 d postservice. The gestation length was calculated from this service event.

Calving Assistance

Calving assistance was measured on an ordinal scale: 1 = UC; 2 = slight assistance (**SA**; assistance by 1 person with no use of mechanical calving aids); 3 = considerable difficulty (**CD**; with intervention by 2 people or the use of mechanical calving aids); 4 = veterinary assistance (**VA**; with or without the need for surgical intervention).

As model outcomes, SA was retained as level 2, and a DC was defined as levels 3 and 4 combined as a single group. Where twinning occurred and different calving difficulty scores were recorded for each calf, the higher value was used as the overall score for the calving. Three additional binary variables were created indicating pre-