



## Modeling the economic impacts of mobility scores in dairy cows under Irish spring pasture-based management

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### ABSTRACT

Moderate to severe forms of suboptimal mobility on dairy cows are associated with yield losses, whereas mild forms of suboptimal mobility are associated with elevated somatic cell count and an increased risk to be culled. Although the economic consequences of severe forms of suboptimal mobility (also referred as clinical lameness) have been studied extensively, the mild forms are generally ignored. Therefore, the aim of the current study was to determine the economic consequences associated with varying prevalence and forms of suboptimal mobility within spring calving, pasture-based dairy herds. A new submodel predicting mobility scores was developed and integrated within an existing pastured-based herd dynamic model. Using a daily timestep, this model simulates claw disorders, and the consequent mobility score of individual cows. The impact of a cow having varying forms of suboptimal mobility on production and reproduction was simulated. The economic impact was simulated including treatment costs, as well as the production and reproductive impacts of varying levels of suboptimal mobility. Furthermore, different genetic predispositions for mobility issues and their interaction with herd-level management associated with each level of suboptimal mobility were simulated. Overall, 13 scenarios were simulated, representing a typical spring calving, pasture-based dairy herd with 100 cows. The first scenario represents a perfect herd wherein 100% of the cows had mobility score 0 (optimal mobility) throughout the lactation. The remaining 12 scenarios represent a combination of (1) 3 different herd-management levels, and (2) 4 different levels of a genetic predisposition for suboptimal mobility. The analysis showed that a 17% decrease in farm net profit was achieved in the worst outcome (wherein just 5% of

the herd had optimal mobility) compared with the perfect herd. This was due to reduced milk yield, increased culling, and increased treatment costs for mobility issues compared the ideal scenario.

**Key words:** lameness, dairy cattle, dynamic model, grass-based ruminant systems

### INTRODUCTION

Suboptimal mobility refers to any deviation from normal or “optimal” mobility of a dairy cow. Throughout the literature, lameness is considered one of the most important health challenges of dairy cows (Huxley, 2012), and the use of the term lameness tends to refer to moderate to severe forms of suboptimal mobility. In the current study, we use the term suboptimal mobility, which also includes cows with quite mild deviations from optimal mobility. Using the UK Agriculture and Horticultural Development Board (AHDB) mobility scoring scale, good mobility refers to a cow with a mobility score 0, whereas suboptimal mobility refers to any mobility score >0. Specifically, a mobility score of 1 describes a cow with imperfect mobility, a mobility score of 2 describes a cow with impaired mobility, and mobility score of 3 describes a cow with severely impaired mobility (AHDB, 2022).

Moderate to severe forms of suboptimal mobility can have significant impacts on the welfare of dairy cows, due to the associated pain (Callaghan et al., 2003; Flower and Weary, 2009). Severe forms of suboptimal mobility have been shown to be associated with significant production losses in both nongrazing (Green et al., 2002; Bicalho et al., 2008) and pasture-based systems (O'Connor et al., 2020a). Also, in pasture-based systems, suboptimal mobility has been shown to be associated with elevated SCC, increased risk for culling, and prolonged calving interval length (O'Connor et al., 2020a). Although lameness is less of a problem within pasture-based herds compared with cows in year-round confinement type systems (Olmos

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et al., 2009), suboptimal mobility (mobility score >0) prevalence of 38% was previously reported in a pasture-based setting (O'Connor et al., 2019). Insights into the avoidable losses resulting from suboptimal mobility are paramount to the success of campaigns to improve the mobility of dairy cows in dairy systems.

A few previous studies have reported on the economic consequences related to lameness or specific claw disorders causing lameness (Bruijnis et al., 2010; Ettema et al., 2010). Ettema et al. (2010) estimated the economic cost associated with lameness to be up to €192 per cow per year, whereas Bruijnis et al. (2010) estimated the cost of specific claw disorders to be €53 per cow per year. Earlier studies, including that of Enting et al. (1997) and Kossaibati and Esslemont (1997), reported on lameness, perhaps comparable to moderate to severe forms of suboptimal mobility (imperfect gate would not generally have been classified as an animal being lame). Few studies have been published evaluating the economic consequences of mild forms of suboptimal mobility (score 1).

For the majority of the northwest European pasture-based systems, cows are housed during the winter months, but managed at pasture for the remainder of the year. Ireland enjoys a favorable climate for grass production and, therefore, the majority of dairy herds are managed under a spring calving, pasture-based seasonal system. In such a system, over 70% of cows calve between February and March (Irish Cattle Breeding Statistics, 2018). A compact calving season is favored in such a system in an effort to maximize milk produced from grazed grass by managing the interface between peak milk production and peak grass production (Dillon et al., 2005; Shalloo et al., 2014). Dairy cows in typical Irish spring calving, pasture-based systems are exposed to different risk factors compared with cows managed in confinement type systems (O'Connor et al., 2020b), which could potentially mean that the economic consequences of suboptimal mobility may also differ between systems. Therefore, the objective of the current study was to estimate the economic consequences of varying levels of suboptimal mobility (ranging from mild to severe deviations from optimal gait) within spring calving, pasture-based dairy herds.

## MATERIALS AND METHODS

This is a modelling paper; no animal was used or involved in the creation of this paper. To simulate physical and financial performance of typical Irish spring calving, pasture-based, production systems, the following 2 models were combined and used: The Pasture

Based Herd Dynamic Milk model (**PBHDM**; Ruelle et al., 2015) and the Moorepark Dairy Systems Model (**MDSM**; Shalloo et al., 2004). In such a system, cows are turned out to pasture postcalving during the spring as soon as ground conditions allow. More than 70% of the cows calve between January and March (Irish Cattle Breeding Statistics, 2018), and they remain outside grazing for the summer and autumn months, and are partially or fully housed during the winter months (December to January). Holstein, Jersey, and Friesian breeds made up 75, 13, and 9% of the training data, respectively, which is representative of the national dairy population (Ring et al., 2018). A typical diet for a dairy cow in an Irish pasture-based system consists mainly of grazed pasture, predominantly based on perennial rye grass (accounting for 60.2% of the DMI; O'Brien et al., 2018), followed by concentrate feed, accounting for 19% of the diet on a DM basis (Hanrahan et al., 2018). The remainder of the typical diet is made up of grass silage and alternative forages (O'Brien et al., 2018).

To simulate the production impacts of suboptimal mobility on cow performance, a specific mobility sub-model was developed within the PBHDM to simulate claw disorders and the resulting mobility scores for each cow within the herd. The definitions of each mobility score simulated by the submodel are based on the following UK AHDB 4-point scale (AHDB, 2022):

- (1) A score of 0 describes a cow with good mobility that walks with even weight bearing and rhythm on all 4 feet, with a flat back. Long and fluid strides are possible.
- (2) A score 1 describes a cow with imperfect mobility, with uneven steps or shortened strides affecting 1 or more limbs, and it may not be immediately identifiable.
- (3) A score 2 describes a cow with impaired mobility, which is a cow with uneven weight bearing on 1 or more limbs that is immediately identifiable, or has shortened strides, usually associated with an arched back, or the cow has all of these traits.
- (4) A score of 3 describes a cow with severely impaired mobility. A cow with this score is unable to walk as fast as the rest of the "healthy" herd due to more severely impaired mobility compared with score 2.

### Description of the Models

The PBHDM model was developed and described in detail by Ruelle et al. (2015, 2016). The PBHDM is a dynamic, stochastic model developed in C++. The

PBHDM simulates the performance of individual dairy animals from birth to death, with a daily time step. For the lactating cows, the PBHDM simulates the production of milk, fat, and protein yield, whereby the simulation of milk production per day is calculated based on the interaction between the energy and protein intake of the cow, BCS change, and the milk yield of each individual animal. The grass growth in the model is predicted using the Moorepark St. Gilles Grass Growth model (Ruelle et al., 2018). Main outputs of the models include cow intake (both at grazing and indoors), milk production (yield, fat and protein), BCS, cow fertility, and grass growth on daily basis, which can be averaged by month and by year.

### **Genetic Inputs and the Economic Breeding Index**

The Economic Breeding Index (**EBI**) was launched in Ireland in 2001 to identify genetically superior animals to increase profitability within Irish dairy herds (Veerkamp et al., 2002). The EBI and its sub-indices are described in detail by Berry et al. (2007). The EBI is expressed as the expected profit (€) per lactation of the progeny of the specific animal, and the genetic merit values of the component traits are expressed as PTA. In 2020, there were 7 sub-indices within the EBI, which are as follows: milk production (relative emphasis 33%; PTA of milk yield, protein yield, and fat yield), fertility [relative emphasis 33%; PTA of calving interval (in days), PTA of survival], calving (relative emphasis 10%), beef (relative emphasis of 8%), maintenance (relative emphasis 8%), management (relative emphasis 4%), and health (relative emphasis 4%; PTA of lameness, mastitis, and SCC). The PBHDM model has been linked directly with the milk and fertility sub-indices (Ruelle et al., 2018) through the relevant PTA.

The MDSM (Shalloo et al., 2004) is a stochastic budgetary simulation model and has been fully integrated into the PBHDM since 2019. The objective of the MDSM is to simulate pasture-based milk production systems across a range of economic indicators, including profit, when changes are made to the farm being simulated, for instance, to study the effect of mastitis on the profitability of Irish dairy farms (Geary et al., 2012). The model integrates animal inventory and valuation, milk supply, feed requirements, and land and labor utilization with economic analysis (Shalloo et al., 2004). Variable costs accounted for in the MDSM include fertilizer, contractor charges, veterinarian and health costs, artificial insemination, silage and reseed-ing. Fixed costs are also included, such as machinery

maintenance and running costs, farm maintenance, car, telephone, electricity, labor, and insurance.

### **Mobility Submodel**

The newly created submodel for mobility (developed within the PBHDM) and its impact on performance consists of 4 steps, which are outlined briefly in the flow diagram (Figure 1) and described in more detail below.

**Step 1: Claw Disorders.** Five specific claw disorders and their severities were simulated (Table 1). The probabilities were determined from a logistic regression model (Table 2) based on a study involving approximately 7,000 cows, as described in detail by O'Connor et al. (2019). Holstein, Jersey, and Friesian breeds made up 75, 13, and 9% of the data, respectively, which is representative of the national dairy population (Ring et al., 2018). The actual prevalence of the presence and severity of claw disorders for those 7,000 cows has also been reported on by O'Connor et al. (2019). The probability of developing a claw disorder is dependent on BCS, cow parity, as well as the genetic PTA for lameness, and the PTA for milk yield.

In the model, the probability of developing specific claw disorders is calculated on a daily basis and for each claw disorder separately (Table 2), with an interaction with the stage of lactation. The probability of developing a claw disorder has been limited to a period of time during the lactation depending on the claw disorder. For white line disease, the probability of developing the disorder was assumed to be from calving up to 120 DIM, and for sole ulcer, the possibility was assumed to be from calving up to 150 DIM (based on the findings of Amory et al., 2008). The possibility of contracting overgrown claws or sole hemorrhages was assumed to be from calving up to 45 DIM. In the case of an overgrown claw, this was due to the fact that the animals were housed before calving, leading to development of overgrown claw (Atkinson, 2013), which would only be visible once the lactation starts. In the case of sole hemorrhage, this assumption was based on the work of Räber et al. (2006), Bicalho et al. (2009), and Charfeddine and Pérez-Cabal (2017), related to the thickness of the fat pad in the digital cushion during this period. Finally, the possibility of contracting digital dermatitis was assumed to be from calving up to 60 DIM, based on the adaptation by Mostert et al. (2018) of the study by Amory et al. (2008). During the specific periods as described above, the probability for a cow to develop a claw disorder on a given day originates from the regression models presented in Table 2. What this means is that the annual probability of developing a

**Table 1.** Descriptions of claw disorders and their severities simulated within scenarios

Claw disorder <sup>1</sup>	Severity score <sup>2</sup>		
Overgrown claw	1	2	3
White line disease	1	2	3
Sole hemorrhage	1	2	3
Sole ulcer	Present	—	—
Digital dermatitis	Present	—	—

<sup>1</sup>Sole ulcer and digital dermatitis were recorded as binary variables either present or not present in the hind hooves.

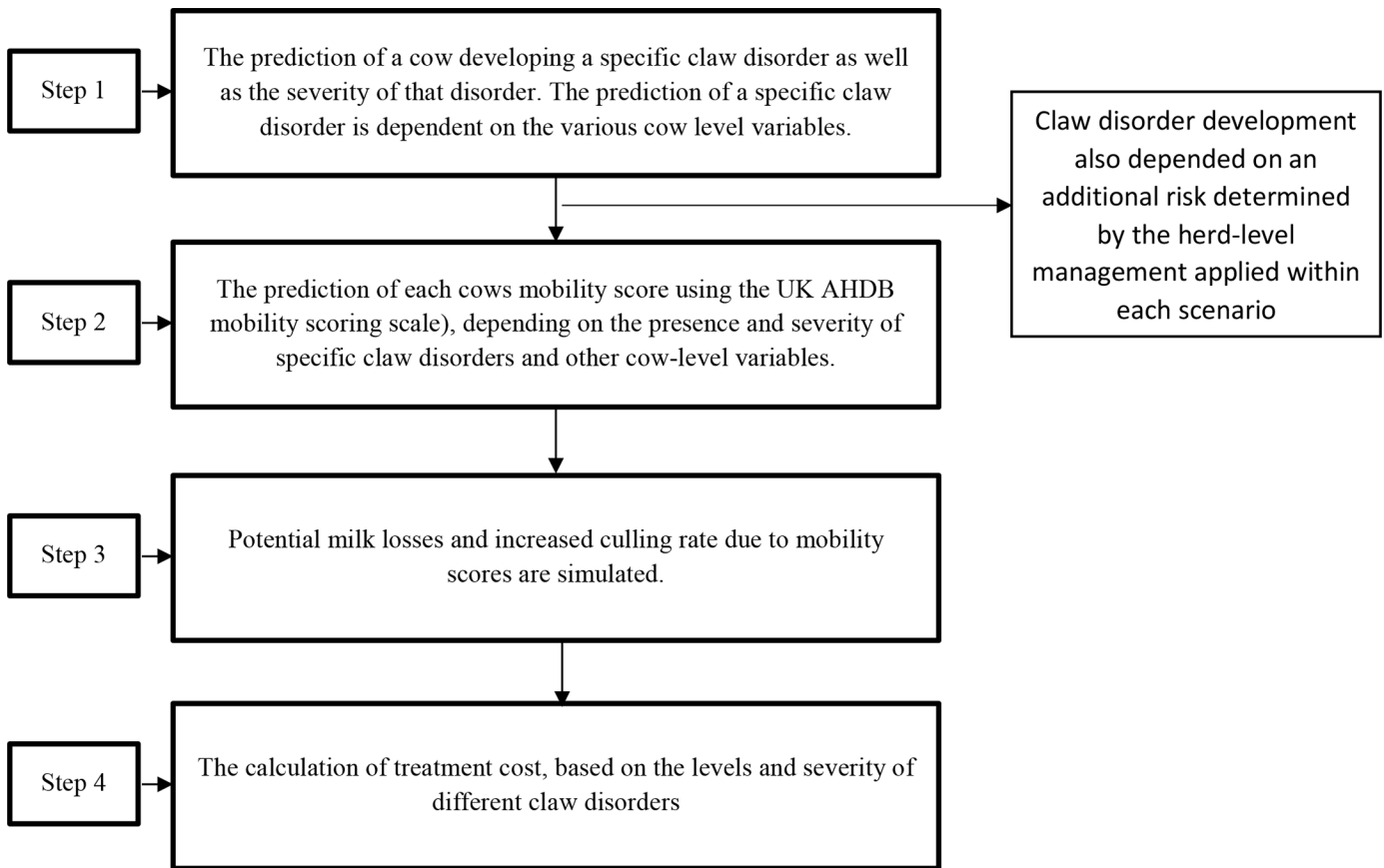
<sup>2</sup>1 = mild; 2 = moderate; 3 = severe.

claw disorder for the cow is divided by the number of days the cow can develop the claw disorder, and not divided by 365 d (as this would be an underestimation of the probability). The model simulated specific claw disorders and their severity on a per cow basis rather than on a per leg/claw basis. Three different herd-management levels were defined as follows: (1) good management—referring to a herd with no added increase in the risk of developing claw disorders, (2) average management—referring to a herd with an additional

10% risk of developing claw disorders, and (3) poor management—referring to a herd with an additional 20% risk of developing claw disorders. The changed probability of developing claw disorders due to herd-level management issues were based on the outputs of O'Connor et al. (2020b), wherein certain herd-level factors were associated with an increased prevalence of suboptimal mobility within a herd. Each day, a cow has a certain probability of developing a specific severity of each claw disorder ( $P_{\text{claw disorder}}$ ), which was calculated as follows:

$$P_{\text{claw disorder}} = \frac{\frac{R}{1 + R} + \text{Mgt}}{\text{ndays}},$$

where R is the exponential of the result of the regression for the corresponding claw disorder, as outlined in Table 2. Mgt is the value used to define the level of management at the herd level, where good, average, or poor Mgt refers to a 0%, 10%, or 20% increase in the risk of developing a claw disorder, respectively. The



**Figure 1.** Flow diagram of the mobility submodel developed in the current study. AHDB = Agriculture and Horticultural Development Board.



**Table 2.** Coefficients for simulating the development of claw disorders in the hind hooves based on the findings of O'Connor et al. (2019)

Item	Overgrown claw	Sole hemorrhage	White line disease	Sole ulcer	Digital dermatitis
Intercept	-0.62	-0.30202	-0.63470	-4.97139	-3.79056
BCS <3.00			Reference value		
BCS = 3.00	0.09545	0.20548	0.10147	-0.01085	0.06488
BCS <3.00	0.31353	0.42385	0.14837	-0.03764	-0.16393
Parity 1			Reference value		
Parity 2	0.73188	0.07835	0.36712	-0.72219	-0.04653
Parity 3+	0.82915	0.19271	0.96390	1.09005	0.42324
PTA lame <sup>1</sup>	3.26271	5.11261	7.79122	16.99691	3.12356
PTA milk <sup>2</sup>	0.00038	0.00230	0.00105	-0.00015	0.00057

<sup>1</sup>Predicted transmitting ability for lameness.

<sup>2</sup>Predicted transmitting ability for milk production.

variable ndays represents the number of days a cow can develop that claw disorder, as described above.

When a cow is simulated to develop a specific claw disorder, the model randomly simulates the severity based on the study of O'Connor et al. (2019; Table 3), and the length of time the cow will have the developed claw disorder was simulated based on the reports of Bruijnjs et al. (2010), and is outlined in Table 4. After this length of time, that specific claw disorder will be cured; however, that cow may have another claw disorder, which will determine her mobility score.

**Step 2: Mobility Scoring Prediction.** The mobility score of each cow is simulated daily depending on the specific claw disorder and severity that the cow has on that day (as simulated during the previous step). The prediction of the mobility scores is based on the study of O'Connor et al. (2019) using the UK AHDB 4-point mobility scoring scale as described above (AHDB, 2022). In the previous study by O'Connor et al. (2019), the association between mobility scores and claw disorders was reported on, and based on this association, the newly developed submodel predicts a cow

mobility score, depending on the type and severity of the claw disorder(s) she already has.

The coefficients of the regression used to simulate mobility scores in the study of O'Connor et al. (2019) were used in the model presented in the current paper to predict the mobility score of each cow on a daily basis (Table 5). The probability for a cow to be in a specific mobility score category is dependent on claw disorder type and severity, BCS, cow parity, as well as the genetic PTA for lameness, and the PTA for milk yield. The calculation of the probability of having a certain mobility score ( $P_{MS}$ ) is as follows, and is recalculated daily, whereby the mobility score with the highest probability is the one assigned to that cow for that day:

$$P_{MS0} = \frac{1}{1 + R_1 + R_2 + R_3} \times 100,$$

$$P_{MS1} = \frac{R_1}{1 + R_1 + R_2 + R_3} \times 100,$$

**Table 3.** Percentage chance for cows having a specific severity of each claw disorder with scenarios based on the findings of O'Connor et al. (2019)

Claw disorder <sup>1</sup>	Severity <sup>2</sup>	% of cows <sup>3</sup>
Overgrown claw	1	68
	2	26
	3	6
Sole hemorrhage	1	62
	2	25
	3	12
White line disease	1	65
	2	19
	3	15

<sup>1</sup>Sole ulcer and digital dermatitis not included as these disorders were scored as present or not present and not scored for severity.

<sup>2</sup>1 = mild; 2 = moderate; 3 = severe.

<sup>3</sup>n = 6,927.

**Table 4.** Length of time (d) a cow has a claw disorder before treatment within scenarios adapted from Bruijnjs et al. (2010)

Claw disorder	Day <sup>1,2</sup> (n)
Overgrown claw 3 <sup>2,3</sup>	89
Sole hemorrhage 3 <sup>4</sup>	103
White line 3 <sup>5</sup>	89
Sole ulcer <sup>6</sup>	77
Digital dermatitis <sup>6</sup>	108

<sup>1</sup>All claw disorders with a severity score 1 and 2 (mild and moderate claw disorders) are treated at the end of the lactation by a professional hoof trimmer.

<sup>2</sup>Number of days present before treated by a veterinarian.

<sup>3</sup>Overgrown claw 3 refers to a severe form of an overgrown claw.

<sup>4</sup>Sole hemorrhage 3 refers to a severe form of a sole hemorrhage.

<sup>5</sup>White line 3 refers to a severe form of a white line.

<sup>6</sup>Sole ulcer and digital dermatitis were recorded as binary variables as either present or not present in the hind hooves and are treated the same way as severity score 3 of other types of claw disorders.

**Table 5.** Coefficients for predicting mobility scores within scenarios, based on the findings of O'Connor et al. (2019)

Item	Category	Mobility score 1	Mobility score 2	Mobility score 3
Intercept		-1.32	-3.70	-5.56
Overgrown claw	1	0.22	-0.18	-0.33
	2	0.40	0.77	0.37
	3	1.13	2.46	3.16
Sole hemorrhage	1	0.19	-0.16	-0.20
	2	0.27	0.19	0.24
	3	0.37	0.73	0.06
White line disease	1	0.11	0.33	-0.53
	2	0.22	0.62	-0.04
	3	0.33	1.48	1.34
Sole ulcer	Present	0.57	1.96	2.65
Digital dermatitis	Present	0.65	1.90	3.31
BCS	<3.00		Reference	
	=3.00	-0.33	-0.70	-1.17
	>3.00	-0.50	-1.13	-2.38
Parity	=1		Reference	
	=2	0.36	0.64	0.72
	≥3	0.92	1.63	1.80
PTA lame <sup>1</sup>		6.03	12.20	18.91
PTA milk <sup>2</sup>		0.00	0.00	0.00

<sup>1</sup>Predicted transmitting ability for lameness.

<sup>2</sup>Predicted transmitting ability for milk production.

$$P_{MS2} = \frac{R_2}{1 + R_1 + R_2 + R_3} \times 100,$$

$$P_{MS3} = \frac{R_3}{1 + R_1 + R_2 + R_3} \times 100,$$

where  $R$  is the exponential of the regression for the mobility score 0, 1, 2, or 3, as outlined in Table 5.

**Step 3 Milk Losses and Culling.** In the present study, milk yield loss due to suboptimal mobility was estimated based on the results reported by O'Connor et al. (2020a). Milk yield losses were assumed to happen for an average length of 3 mo after the development of a specific claw disorder, which was based on the length of time a cow is likely to have a claw disorder (Bruijnjs et al., 2010). Therefore, cows with a mobility score 1 had no impact on milk yield, whereas a daily milk yield loss of 6% for each day appeared for a cow with mobility score 2, and 16% for each day at mobility score 3. Daily milk yield losses were based on an annual milk yield loss of 1.6% for mobility score 2 and 6% for mobility score 3, compared with the average yield corrected for a 305-d lactation O'Connor et al. (2020a), based on the score at the 2 scoring periods.

For cows simulated to have suboptimal mobility (mobility score >0) at any time throughout the lactation, there is an increased risk to be culled. The increased risk was calculated by multiplying the models base culling risk (circa 9% as the input for the base probability

to be culled for any reason other than reproduction) by the odds ratios reported by O'Connor et al. (2020a). Therefore, a cow with a mobility score 0 had no additional risk to be culled for mobility reasons, a cow with a mobility score 1 had an additional 2% chance to be culled, a cow with a mobility score 2 had an additional 4% chance to be culled, and a cow with a mobility score 3 had an additional 28% chance to be culled. This was assumed to be based on the highest mobility score a cow had during the lactation. Because we had only 2 mobility score measurements, it is possible that the cow's mobility score was different during the other periods. It is not expected that this would have a material impact on the conclusions of this study.

**Step 4: Treatment.** In the model presented in the current study, it was assumed that veterinary treatment was applied for all claw disorders with a severity score of 3 (severe disorder), and for cows simulated to have sole ulcers and digital dermatitis. A herd health approach was applied wherein veterinary assistance was applied once per month or where required on farm (i.e., at the end of each month the veterinarian was called to treat the animals simulated to have a claw disorder of severity level 3). If none were present in the herd, no veterinarian was called. In the current study, it was assumed that all treatment for mobility issues was carried out by a veterinarian (and not by the farmer themselves). The average veterinary call-out charge and the cost per cow to treat claw disorders is outlined in Table 6 (IFA, 2020). It was assumed that

veterinary assistance would only be acquired during day time hours as it is highly unlikely that a farmer would call a veterinarian for lameness issues outside of normal working hours. Similar to the study of Bruijn et al. (2010), it was also assumed that treatment occurred once per claw disorder. The only exception to this assumption was for all cases of sole ulcers and digital dermatitis, which required 2 visits (described in Table 6). Finally, on a date around the time of the end of the lactation and when cows were being housed for the winter, a professional hoof trimmer visit was applied to the farm. During this visit, all cows with a suboptimal mobility were treated (i.e., only cows with a mobility score >0 were treated), as recommended by the mobility scoring scale used in this study (AHDB, 2022). Therefore, if all cows on the farm had a mobility score of 0, the professional hoof trimmer was not needed. The average call-out charge for a professional hoof trimmer is €60.00, which is the current industry standard in Ireland. The cost per cow after the call charge is €9.00 per cow.

**Sensitivity Analysis and Model Evaluation**

A sensitivity analysis was conducted concerning milk price by testing both a lower base milk price (26 cents per liter) and higher base milk price (32 cents per liter), relative to the base milk price implemented for the 4 scenarios (29 cents per liter). Model evaluation was completed by comparing the outputs of the model to the actual data. The outcomes of both the sensitivity analysis and the evaluation are described in the results section below.

**Scenario Analysis**

Thirteen scenarios were simulated and are listed below. Each scenario was simulated 500 times over a 10-yr period. Scenarios were simulated for a 100-cow dairy herd under typical Irish spring calving, pasture-based management.

The first scenario represents a perfect herd, wherein all the cows had mobility score 0 (optimal mobility) and no claw disorders throughout the lactation. This scenario resembles the best-case scenario. The remaining 12 scenarios represent a combination of (1) 3 different herd-management levels, including good, average, or poor,

$$Mgt_{Lame}^{Good} \left( \begin{matrix} Mgt = 0\% \text{ additional risk to develop claw} \\ disorders based on herd level management \end{matrix} \right),$$

**Table 6.** Calculation of cost of veterinary treatment for claw disorders

Claw disorder <sup>1</sup>	Category	Cost <sup>2</sup> (€)
Overgrown claw	1	0
	2	0
	32	26.08 <sup>3</sup>
Sole hemorrhage	1	0
	2	0
	32	26.08 <sup>3</sup>
White line disease	1	0
	2	0
	32	26.08 <sup>3</sup>
Sole ulcer <sup>4</sup>	Present	60.15
Digital dermatitis <sup>4</sup>	Present	55.15

<sup>1</sup>Only claw disorders simulated to be severity level 3, and all cases of sole ulcer and digital dermatitis required veterinary treatment.

<sup>2</sup>Call-out charge for a veterinarian estimated to be €52.50 divided by total number of cows requiring treatment (average cost in Ireland; IFA, 2020).

<sup>3</sup>Veterinary cost of €104.30/h and 15 min required to treat a claw disorder was assumed.

<sup>4</sup>Sole ulcer and digital dermatitis required 2 visits by a veterinarian; visit 1 wherein a shoe at an additional cost of €8 was applied to a case of sole ulcer, or a bandage at an additional cost of €3 was applied to a case of digital dermatitis, and visit 2 wherein shoe or bandage was removed.

$$\text{or } Mgt_{Lame}^{Average} (Mgt = +10\% \text{ additional risk}),$$

$$\text{or } Mgt_{Lame}^{Poor} (Mgt = +20\% \text{ additional risk});$$

and (2) 4 different levels of a genetic predisposition for suboptimal mobility: very poor, good, average, or poor

$$PTA_{Lame}^{Good} (PTA \text{ for lameness} = -0.5),$$

$$\text{or } PTA_{Lame}^{Average} (PTA = 0.00),$$

$$\text{or } PTA_{Lame}^{Poor} (PTA = +0.05),$$

$$\text{or } PTA_{Lame}^{Very\ poor} (PTA = +0.2).$$

The genetic levels (good, average, and poor) are comparative to real life scenarios, whereas the genetic level of “very poor” describes a hypothetical worst-case scenario.

The scenarios run are as follows:

- 1) Perfect herd, which refers to an entire herd of cows with good mobility (mobility score 0).
- 2)  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$
- 3)  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Good}$
- 4)  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$

**Table 7.** Average prevalence of claw disorders and their severity within each simulation

Simulation		Disorder <sup>3</sup>										
Management level <sup>1</sup>	Genetics level <sup>2</sup>	OG 1	OG 2	OG 3	SH 1	SH 2	SH 3	WL 1	WL 2	WL 3	SU 1	DD 1
Optimal	Optimal	0	0	0	0	0	0	0	0	0	0	0
Good $Mgt_{Lame}^{Good}$	Good $PTA_{Lame}^{Good}$	25	10	3	21	5	8	21	6	6	0	2
	Average $PTA_{Lame}^{Average}$	26	10	3	23	5	9	25	7	7	1	3
	Poor $PTA_{Lame}^{Poor}$	28	11	3	26	6	11	28	8	7	3	3
Average $Mgt_{Lame}^{Good}$	Very poor $PTA_{Lame}^{Very Poor}$	32	12	3	31	7	13	35	11	9	22	5
	Good $PTA_{Lame}^{Good}$	29	11	3	25	6	10	25	8	7	10	12
	Average $PTA_{Lame}^{Average}$	30	12	3	27	6	11	29	8	8	11	12
	Poor $PTA_{Lame}^{Poor}$	32	12	3	29	7	12	32	9	8	12	12
Poor $Mgt_{Lame}^{Good}$	Very poor $PTA_{Lame}^{Very Poor}$	35	14	4	34	8	14	38	11	10	29	14
	Good $PTA_{Lame}^{Good}$	32	13	3	28	6	12	29	9	8	18	20
	Average $PTA_{Lame}^{Average}$	34	13	3	30	7	12	32	9	8	19	20
	Poor $PTA_{Lame}^{Poor}$	35	13	4	32	7	13	35	10	9	20	20
	Very poor $PTA_{Lame}^{Very Poor}$	38	15	4	36	8	15	40	12	11	36	22

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management ( $Mgt$ ) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

<sup>3</sup>OG = overgrown claw; SH = sole hemorrhage; WL = white line disease; SU = sole ulcer; DD = digital dermatitis; OG/SH/WL 1 = mild, 2 = moderate, and 3 = severe; SU/DD 1 = present.

- 5)  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Average}$
- 6)  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Average}$
- 7)  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Average}$
- 8)  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Poor}$
- 9)  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Poor}$
- 10)  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Poor}$
- 11)  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Very Poor}$
- 12)  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Very Poor}$
- 13)  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Very Poor}$

For example, scenario 2 above ( $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$ ) refers to a herd wherein all cows had no added risk of developing claw disorders based on the quality of the management at herd-level ( $Mgt_{Level} = 0$ ) and had the lowest likelihood genetic predisposition for suboptimal mobility ( $PTA_{Lame}^{Good} = -0.05$ ). The  $Mgt_{Level}$  used in this scenario is based on the results of O'Connor et al. (2020b). The  $PTA_{Lame}$  used as an input in this scenario corresponds to the best  $PTA_{Lame}$  value present in the actual data set.

## RESULTS AND DISCUSSION

In the current study, one of the aims was to simulate mobility scores (specifically the AHDB mobility scores) as this allows effects, actions, and treatments to be simulated for each mobility score for farmers. As outlined in Table 7 and 8 (and as described in the model validation section above), the submodel developed in the current study successfully simulated mobility scores for a typical spring calving, pasture-based dairy herd with reasonable agreement with actual data. Previously, Bruijnjs et al. (2010) developed a model to predict specific claw disorders (as either subclinical or clinical) with a monthly time step within typical Dutch dairy systems. The model developed by Bruijnjs et al. (2010) successfully predicted a prevalence of disorders corresponding to such systems. However, the model developed by Bruijnjs et al. (2010) did not in turn predict mobility scores, which was the desired outcome of the present study, whereby predictions for cows to have specific severities of claw disorders (regardless of being clinical or not) were used to predict mobility scores. Similar to Bruijnjs et al. (2010), Mostert et al. (2018) also developed a model to predict specific claw disorders. The main difference between the model developed by Mostert et al. (2018) and the model developed in the current study is that claw disorders in the current study can



**Table 8.** Prevalence of mobility score within each simulation

Simulation		Mobility score 0		Mobility score 1		Mobility score 2		Mobility score 3	
Management level <sup>1</sup>	Genetics level <sup>2</sup>	Average	SD	Average	SD	Average	SD	Average	SD
Optimal Good $Mgt_{Lame}^{Good}$	Optimal								
	Good $PTA_{Lame}^{Good}$	97	1.93	3	1.70	0	0.45	0	0.09
	Average $PTA_{Lame}^{Average}$	90	5.16	8	4.93	1	0.74	0	0.16
	Poor $PTA_{Lame}^{Poor}$	72	10.24	25	9.58	2	1.46	0	0.37
Average $Mgt_{Lame}^{Good}$	Very Poor $PTA_{Lame}^{Very Poor}$	9	4.13	61	5.26	22	4.44	8	4.11
	Good $PTA_{Lame}^{Good}$	92	3.46	6	2.95	1	1.14	0	0.33
	Average $PTA_{Lame}^{Average}$	81	6.19	15	5.57	3	1.64	0	0.60
	Poor $PTA_{Lame}^{Poor}$	62	9.30	31	8.05	5	2.50	1	1.06
Poor $Mgt_{Lame}^{Good}$	Very Poor $PTA_{Lame}^{Very Poor}$	6	3.56	53	5.25	25	4.66	16	5.12
	Good $PTA_{Lame}^{Good}$	86	4.54	10	3.85	3	1.76	0	0.57
	Average $PTA_{Lame}^{Average}$	73	6.66	21	5.74	5	2.31	1	1.00
	Poor $PTA_{Lame}^{Poor}$	53	8.29	35	6.71	8	3.14	3	1.63
	Very Poor $PTA_{Lame}^{Very Poor}$	5	3.12	46	5.08	26	4.86	23	5.64

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management ( $Mgt$ ) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

occur during a defined period of time. However, in the model developed by Mostert et al. (2018), claw disorders could only strictly be developed on just 1 specific day during the lactation.

**Model Validation**

**Claw Disorders.** The simulated prevalence of claw disorders within a herd in each scenario is outlined in Table 7. The good management herd scenarios ( $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$  or  $PTA_{Lame}^{Average}$  or  $PTA_{Lame}^{Poor}$  or  $PTA_{Lame}^{Very Poor}$ ) consistently have a lower proportion of cows with any type claw disorders compared with the average mobility herd scenarios ( $Mgt_{Lame}^{Average} - PTA_{Lame}^{Good}$  or  $PTA_{Lame}^{Average}$  or  $PTA_{Lame}^{Poor}$  or  $PTA_{Lame}^{Very Poor}$ ) and poor ( $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$  or  $PTA_{Lame}^{Average}$  or  $PTA_{Lame}^{Poor}$  or  $PTA_{Lame}^{Very Poor}$ ) mobility herds. This is in agreement with the actual data set; for example, in the simulated  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$ , approximately 32, 13, and 3% of cows had a mild, moderate, or severe type overgrown claw disorders (Table 7), respectively, which is in reasonable agreement with the top 5 farms in the data set (referring to the 5 herds with highest prevalence of mobility score 0 cows), which consisted of 30, 11, and 2% of cows having mild, moderate, or severe type overgrown claw disorders, respectively.

**Mobility Scores.** The simulated scenarios are in reasonable agreement with the actual data set [for both claw disorders (Table 7) and mobility score prevalence

(Table 8)], wherein the top 5, median 5, and bottom 5 farms (referring to herd-level prevalence of mobility score 0 from highest to lowest) in the actual data set are comparable to the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$ ,  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$ , and  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Poor}$  scenarios, respectively (Table 8). For example, in the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$  scenario, on average 86, 10, 3, and 0% of cows have mobility score 0, 1, 2, and 3, respectively, whereas within the top 5 farms in the actual data set, 77, 18, 4, and 0% of cows have mobility score 0, 1, 2, and 3, respectively. For the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Average}$  scenario, 73, 21, 5, and 1% of cows have mobility score 0, 1, 2, and 3, respectively, which corresponds well to the actual data set, wherein the median 5 farms is made of 65, 29, 5, and 1% mobility score 0, 1, 2, and 3 cows. Finally, for the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Poor}$  scenario, it was estimated that 53, 35, 8, and 3% of cows had a mobility score 0, 1, 2, and 3, respectively. Compared with the bottom 5 farms (in the actual data set) wherein 54, 31, 13, and 3% of cows had mobility score 0, 1, 2, and 3, respectively.

**Milk Yield and Culling**

Table 9 presents the impact of management and genetic level on the average culling rate, replacement rate, and milk yield per cow of each scenario. Table 10 presents the simulated average milk yield of cows with mobility score 2 or 3, compared with the potential milk yield (if that cow had optimal mobility, mobility score

**Table 9.** Average ( $\pm$  SD) culling rate, replacement rate, and milk yield per cow within each simulation

Simulation		Culling rate <sup>3</sup>	Replacement rate <sup>4</sup>	Milk <sup>5</sup>
Management level <sup>1</sup>	Genetics level <sup>2</sup>			
Optimal	Optimal	9	25	6,724 ( $\pm$ 118)
Good $Mgt_{Lame}^{Good}$	Good $PTA_{Lame}^{Good}$	9	25	6,721 ( $\pm$ 117)
	Average $PTA_{Lame}^{Average}$	9	25	6,721 ( $\pm$ 119)
	Poor $PTA_{Lame}^{Poor}$	9	25	6,715 ( $\pm$ 118)
	Very poor $PTA_{Lame}^{Very Poor}$	11	27	6,613 ( $\pm$ 129)
	Good $PTA_{Lame}^{Good}$	9	25	6,721 ( $\pm$ 118)
Average $Mgt_{Lame}^{Good}$	Average $PTA_{Lame}^{Average}$	9	25	6,715 ( $\pm$ 119)
	Poor $PTA_{Lame}^{Poor}$	9	25	6,705 ( $\pm$ 119)
	Very poor $PTA_{Lame}^{Very Poor}$	13	28	6,550 ( $\pm$ 133)
	Good $PTA_{Lame}^{Good}$	9	25	6,714 ( $\pm$ 118)
	Average $PTA_{Lame}^{Average}$	9	25	6,708 ( $\pm$ 117)
Poor $Mgt_{Lame}^{Good}$	Poor $PTA_{Lame}^{Poor}$	10	26	6,689 ( $\pm$ 121)
	Very poor $PTA_{Lame}^{Very Poor}$	14	29	6,494 ( $\pm$ 136)

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management (*Mgt*) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

<sup>3</sup>Cows culled for any reason other than reproductive reasons.

<sup>4</sup>Heifers brought into the herd to replace culled cows.

<sup>5</sup>Kilograms of milk per cow.

0, throughout the lactation) within each scenario (cow with mobility score 1 did not have any milk yield loss due to the structure of the model). For example, a cow with mobility score 3 within the  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Poor}$  scenario was estimated to have an actual milk yield of 4% less than her estimated potential milk (Table 10), whereas a cow with mobility score 2 within the same  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Poor}$  scenario was estimated to have actual milk yield of 1.4% less than her estimated potential milk yield.

The yield losses simulated in the current study for cows with suboptimal mobility were modeled based on the study of O'Connor et al. (2020a), and the predicted daily yield losses in the current study agree with the aggregated yield losses reported in O'Connor et al. (2020a). Furthermore, the yield losses simulated in the current study for a cow with mobility score 3 in the  $PTA_{Lame}^{Poor} - Mgt_{Lame}^{Poor}$  scenario are also comparable to the losses reported in the study of Archer et al. (2010). The cows in the study of Archer et al. (2010) were managed under a year-round calving, pasture-based systems, wherein cows with severe mobility issues experienced milk yield losses of up to 4.8% throughout the lactation. In the current study, the estimated prevalence of mobility scores within each scenario, as outlined in Table 7, was based on the worst mobility score of that cow throughout the lactation, and not the average.

Therefore, it is possible that a cow simulated to have a mobility score 3 was likely to have been a mobility score 1 or 2 for a period before progressing to mobility score 3, which results in a varying milk yield loss within each mobility score (Table 10).

In the current study, the model base culling risk (culling for any reason other than reproductive) was predicted to be 9% for all the scenarios except for the  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Very Poor}$ ,  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Very Poor}$ ,  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Poor}$ , and  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Very Poor}$  scenarios, which were estimated to have a 11, 13, 10, and 14%, respectively (Table 9). The higher culling rates estimated for those scenarios is due to an increased prevalence of suboptimal mobility. This higher prevalence of suboptimal mobility within a herd is also a contributing factor for the lower average milk yield on a per cow basis (Table 9) within those scenarios, due to a higher replacement rate and, therefore, a higher proportion of parity 1 cows within the herd. The association between mobility issues and culling has been reported on throughout the literature (Booth et al., 2004; Machado et al., 2010). The current study predicts culling due to mobility issues based on the results of O'Connor et al. (2019), wherein an association between all levels of

**Table 10.** Average compared with the potential milk yield per cow (kg) and milk yield losses within each simulation

Management level <sup>1</sup>	Genetics level <sup>2</sup>	Mobility score 2			Mobility score 3			Entire herd		
		Milk yield <sup>3</sup>	Ptn milk yield <sup>4</sup>	Milk yield loss (%)	Milk yield	Ptn milk yield	Milk yield loss (%)	Milk yield	Ptn milk yield	Milk yield loss (%)
Optimal Good $Mgt_{Lame}^{Good}$	Optimal	6,985	7,082	1.4	6,939	7,168	3.2	667,536	667,536	0.00
	Good $PTA_{Lame}^{Good}$	6,925	7,014	1.3	6,834	7,063	3.2	667,510	667,531	0.02
	Average $PTA_{Lame}^{Average}$	6,893	6,983	1.3	6,770	6,995	3.2	667,226	667,369	0.05
Average $Mgt_{Lame}^{Good}$	Poor $PTA_{Lame}^{Poor}$	6,943	7,040	1.4	6,396	6,602	3.1	666,739	667,082	0.01
	Very poor $PTA_{Lame}^{Very Poor}$	6,889	6,984	1.4	6,286	6,474	2.9	667,146	667,205	0.05
	Good $PTA_{Lame}^{Good}$	6,844	6,938	1.3	6,235	6,416	2.8	666,624	666,935	0.10
Poor $Mgt_{Lame}^{Good}$	Average $PTA_{Lame}^{Average}$	6,967	7,065	1.4	6,543	6,814	4.0	665,865	666,507	0.03
	Poor $PTA_{Lame}^{Poor}$	6,889	6,988	1.4	6,447	6,689	3.6	666,545	666,753	0.11
	Very poor $PTA_{Lame}^{Very Poor}$	6,834	6,933	1.4	6,421	6,657	3.6	665,486	666,252	0.22
Entire herd	Good $PTA_{Lame}^{Good}$	6,762	6,890	1.9	6,254	6,587	5.1	663,877	665,318	0.82
	Average $PTA_{Lame}^{Average}$	6,714	6,843	1.9	6,196	6,548	5.4	656,216	661,661	1.32
	Poor $PTA_{Lame}^{Poor}$	6,677	6,806	1.9	6,170	6,528	5.5	649,669	658,382	1.75
	Very poor $PTA_{Lame}^{Very Poor}$						643,917	655,374		

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management ( $Mgt$ ) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

<sup>3</sup>Kilograms of milk per cow.

<sup>4</sup>Potential (Ptn) milk yield refers to the milk yield that cow would have ideally produced if she did not have suboptimal mobility.

suboptimal mobility and culling was found, using mobility scores of cows at 2 time points throughout that lactation. This could lead to an overestimation of the impact of culling in this study, as some of the cows in O'Connor et al. (2019) scored as a 1 during the 2 locomotion scoring events would have more than likely been scored at 2 (or maybe even 3) at a different time of the lactation, leading to an overestimation of the impact of a score 1 on the culling probability.

Therefore, a limiting factor of the current study is that cows with a mobility score 1 (found to have an increased risk to be culled) were based on a mobility score from a single time point and not sequential data.

### Receipts, Costs, and Profitability

The aspects of farm net profit that change due to milk yield loss, treatment costs and replacement rates are outlined in Tables 11 and 12. The greatest profit (€88,297; SD €9,503) was achieved in the perfect herd scenario, and the second highest profit (1% lower than perfect herd scenario) was achieved by the  $PTA_{Lame}^{Good} - Mgt_{Lame}^{Good}$  scenario (considered to be a good herd with just 3% of the herd having suboptimal mobility), whereas the lowest profit (17% lower than perfect herd scenario) was achieved in the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Very Poor}$  scenario (considered to be a hypothetical worst-case scenario wherein 95% of the herd have suboptimal mobility).

The spread in farm profitability varied dependent on the scenario. For example, the lowest variability was achieved in the perfect herd scenario (11%). Although, in the worst scenario, there was a lower profitability and an associated higher spread in profitability. The combined effect of a lower and more variable profit increases the problems associated with increased lameness and reduced herd mobility.

Treatment costs calculated in the present study refer to the costs associated with a veterinary or professional hoof trimmer's time and equipment. In this study, routine claw trimming treatment costs ranged from approximately €764 (SD €155) for the  $PTA_{Lame}^{Good} - Mgt_{Lame}^{Good}$  scenario (hypothetical best-case scenario), up to €3,803 for the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Very Poor}$  scenario, which is a hypothetical worst-case scenario herd with the highest increased risk of developing claw disorders due to poor herd-level management, and with the highest genetic predisposition for suboptimal mobility (Table 11). As for other studies including the study of Bruijnjs et al. (2010), Charfeddine and Pérez-Cabal (2017) also estimated the economic losses associated with specific claw disorders; however, unlike the current study, both stud-

ies specifically focused on estimating the costs associated with individual claw disorders on a per case basis. Bruijnjs et al. (2010) estimated the treatment costs of both subclinical and clinical claw disorders (in a default herd of 65 cows managed under typical Dutch year-round calving, pasture-based system), and found that clinical cases of claw disorders (including a varying of types of claw disorders) were associated with treatment costs of up to €289 for the herd per year. This estimation accounts for veterinarian treatment, professional hoof trimmer trimming, and additional treatment such as antibiotics. The treatment costs for the good mobility herd scenarios ( $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$ ,  $Mgt_{Lame}^{Average} - PTA_{Lame}^{Good}$ , and  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Good}$ ) in the current study are much greater than those reported by Bruijnjs et al. (2010). This could likely be explained by the fact that routine preventative treatment is accounted for in the present study, resulting in mobility score 1 cows having treatment costs associated with them, whereas fewer treatments are applied in the study by Bruijnjs et al. (2010).

Average total milk receipts for each scenario are outlined in Table 11. The perfect herd scenario had the greatest milk receipts, followed by the good management herd scenarios ( $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$ ,  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Average}$ ,  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Poor}$ , and  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Very Poor}$ ), followed by the average and poor management herd scenarios. In Table 12, the economic losses due to milk yield reductions, increased culling, treatment costs, and overall farm net profit loss for the good, average, and poor management scenarios are compared with the perfect herd scenario. The greatest farm net profit loss (compared with the perfect herd scenario) was evident in the  $Mgt_{Lame}^{Poor} - PTA_{Lame}^{Very Poor}$  scenario with €15,028. Of this, milk yield loss made up 45% (€6,684), increased culling made up 29% (€4,323), and treatment costs made up the remaining 26% (€3,803) of total farm net profit loss. In comparison, Bruijnjs et al. (2010) estimated a total cost of approximately €1,800 (45% of total losses) due to milk yield losses (including discarded milk due to antibiotic treatment for severe mobility issues) associated with subclinical and clinical claw disorders in a typical Dutch dairy production herd, wherein the total costs were estimated to be approximately €4,000.

Sensitivity analysis concerning milk price was completed by testing both a lower base milk price (26 cents per liter) and higher base milk price (32 cents per liter), relative to the base milk price implemented for the 4

**Table 11.** Average ( $\pm$  SD) treatment costs per mobility score, milk receipts, and farm net profit with each simulation

Management level <sup>1</sup>	Simulation				Average treatment cost (€)				Total treatment cost	Milk receipt	Farm net profit
	Genetics level <sup>2</sup>	Mobility score 0	Mobility score 1	Mobility score 2	Mobility score 3	Mobility score 3					
Optimal Good $Mgt_{Lame}^{Good}$	Optimal	612	130	—	—	—	—	—	764 ( $\pm$ 155)	213,192 ( $\pm$ 3,942)	88,297 ( $\pm$ 9,503)
	Good $PTA_{Lame}^{Good}$	544	309	309	20	1	—	—	908 ( $\pm$ 165)	213,194 ( $\pm$ 3,837)	87,529 ( $\pm$ 9,536)
	Average $PTA_{Lame}^{Average}$	352	665	665	138	3	15	—	1,170 ( $\pm$ 172)	213,078 ( $\pm$ 4,047)	87,239 ( $\pm$ 9,477)
	Poor $PTA_{Lame}^{Poor}$	8	872	872	1,314	518	—	—	2,712 ( $\pm$ 216)	212,916 ( $\pm$ 3,990)	86,568 ( $\pm$ 9,594)
Average $Mgt_{Lame}^{Good}$	Very poor $PTA_{Lame}^{Very Poor}$	1,157	315	315	125	10	—	—	1,607 ( $\pm$ 193)	210,019 ( $\pm$ 4,263)	80,018 ( $\pm$ 10,369)
	Good $PTA_{Lame}^{Good}$	837	625	625	234	28	—	—	1,724 ( $\pm$ 199)	213,116 ( $\pm$ 3,991)	86,537 ( $\pm$ 9,581)
	Average $PTA_{Lame}^{Average}$	509	955	955	361	106	—	—	1,931 ( $\pm$ 202)	212,988 ( $\pm$ 4,063)	86,132 ( $\pm$ 9,607)
	Poor $PTA_{Lame}^{Poor}$	6	827	827	1,423	1,024	—	—	3,280 ( $\pm$ 236)	212,620 ( $\pm$ 4,134)	85,331 ( $\pm$ 9,718)
Poor $Mgt_{Lame}^{Good}$	Very poor $PTA_{Lame}^{Very Poor}$	1,447	483	483	279	25	—	—	2,234 ( $\pm$ 220)	208,161 ( $\pm$ 4,483)	76,556 ( $\pm$ 10,716)
	Good $PTA_{Lame}^{Good}$	975	852	852	448	64	—	—	2,339 ( $\pm$ 228)	212,981 ( $\pm$ 39,52)	85,674 ( $\pm$ 9,491)
	Average $PTA_{Lame}^{Average}$	573	1,149	1,149	577	239	—	—	2,538 ( $\pm$ 226)	212,733 ( $\pm$ 4,039)	85,083 ( $\pm$ 9,734)
	Poor $PTA_{Lame}^{Poor}$	5	795	795	1,503	1,501	—	—	3,803 ( $\pm$ 257)	212,175 ( $\pm$ 4,153)	83,755 ( $\pm$ 9,754)
	Very poor $PTA_{Lame}^{Very Poor}$									206,508 ( $\pm$ 4,654)	73,269 ( $\pm$ 10,769)

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management ( $Mgt$ ) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

**Table 12.** Economic costs due to milk yield loss, increased culling, and treatment for the good, average, poor, and very poor management scenarios compared with the perfect herd scenario

Simulation		Milk yield loss	Increased culling <sup>3</sup>	Treatment cost	Total farm net profit loss
Management level <sup>1</sup>	Genetics level <sup>2</sup>				
Optimal	Optimal	0	0	0	0
Good $Mgt_{Lame}^{Good}$	Good $PTA_{Lame}^{Good}$	-2	7	764	768
	Average $PTA_{Lame}^{Average}$	113	37	908	1,058
	Poor $PTA_{Lame}^{Poor}$	275	284	1,170	1,730
	Very poor $PTA_{Lame}^{Very Poor}$	3,173	2,395	2,712	8,280
Average $Mgt_{Lame}^{Good}$	Good $PTA_{Lame}^{Good}$	76	78	1,607	1,760
	Average $PTA_{Lame}^{Average}$	254	187	1,724	2,166
	Poor $PTA_{Lame}^{Poor}$	572	464	1,931	2,967
	Very poor $PTA_{Lame}^{Very Poor}$	5,031	3,431	3,280	11,742
Poor $Mgt_{Lame}^{Good}$	Good $PTA_{Lame}^{Good}$	210	179	2,234	2,623
	Average $PTA_{Lame}^{Average}$	459	417	2,339	3,215
	Poor $PTA_{Lame}^{Poor}$	1,017	987	2,538	4,542
	Very poor $PTA_{Lame}^{Very Poor}$	6,684	4,541	3,803	15,028

<sup>1</sup>Refers to the specific level of increased risk for a cow to develop a claw disorder based on herd-level management (*Mgt*) factors.

<sup>2</sup>Cow-level genetic PTA for lameness.

<sup>3</sup>Culling costs were estimated indirectly as the remaining loss after accounting for milk yield loss costs and treatment costs.

scenarios (29 cents per liter). For the  $Mgt_{Lame}^{Good} - PTA_{Lame}^{Good}$  scenario, the overall farm net profit was €65,554, €87,529, and €109,440 with the 26, 29, and 32 cents per liter base milk price. Across all scenarios when a higher base milk price (32 cent per liter) is implemented, the proportion of economic losses as a result of a lower milk yield is less important relative to the overall farm net profit.

This study uses mainly Irish data, enriched with published studies, to simulate mobility score and its impact on farm profitability. Like all modeling exercises, many assumptions are included in this analysis that create risks for the models to deviate from reality. However, ensuring that these assumptions are based on relevant studies reduces that risk. The new sub-model to predict mobility scores is incorporated into the PBHDM and can be used in its current format by researchers. One of the main limitations of the current model is that it represents a dairy herd managed in a spring calving, pasture-based system, typical of what is most commonly practiced in Ireland; therefore, it may not be fully relevant for other management systems or countries. The analysis was completed for a 100-cow herd, and it would be anticipated that scale would have an effect on the outcomes expected. Mobility issues could be exasperated as herd size and cow

walking distance increases. There is also the effect of economies of scale.

## CONCLUSIONS

We developed a simulation model for predicting claw disorders and mobility scores, which resulted in a realistic output in terms of prevalence of both claw disorders and mobility scores for typical Irish spring calving, pasture-based systems. From this study, we conclude that as the prevalence of cows with sub-optimal mobility scores (even mild suboptimal mobility scores) increases within a herd, the overall farm net profit decreases. This study concludes that overall farm net profit can decrease by up to €15,028 associated with a hypothetical worst-case mobility scenario, which represents a 17% loss compared with the best-case mobility scenario. Of this €15,028 loss, milk yield loss made up 45% and increased culling cost made up 29%, whereas treatment cost associated with claw disorders made up the remaining 26%. For the non-hypothetical worst-case scenario, overall farm net profit was reduced by €4,542, compared with the best-case scenario. Of this €4,542 loss, milk yield loss made up 22%, increased culling cost made up 22%, whereas treatment cost associated with claw disorders made up the remaining 56%. This decrease in overall



farm net profit is due to increased culling, reduced milk yield, and treatment costs for cows within the herd with claw disorders and the resulting suboptimal mobility.

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