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SMART MANAGEMENT OF DAIRY FARMS BASED ON SIMULATION

Osvaldo Palma [1,2], Lluis M. Plà-Aragonés [2], Alejandro Mac Cawley[3], and Víctor M. Albornoz[4],

[1] Dept. of Economics and Administration, Universidad Nacional Andrés Bello, CHILE.
[2] Dept. of Mathematics, Universidad de Lleida, ESPAÑA.
[3] Dept. of Industrial Eng., Pontificia Universidad Católica de Chile, CHILE.
[4] Dept. of Industrial Eng., Universidad Técnica Federico Santa María, CHILE.

ABSTRACT

Milk and beef production is crucial to ensure a cost-effective and sustainable food supply. As the demand for agricultural products increases, making informed decisions are critical. Discrete event simulation, a suitable tool for modeling many complex systems with random variability, offers substantial advantages compared with traditional analytical models. We developed a discrete event simulation model for a dairy herd. The model is shown useful for studying various culling strategies based on disease or reproductive performance. We perform a preliminary validation of the model by comparing steady state behavior to analytical results from a Markov chain model and literature. Our findings demonstrate that twin calving does not significantly affect herd performance. We advocate the use of discrete event simulation integrated in smart management tools, emphasizing its usefulness in decision-making on dairy farms. In future research, we are exploring additional factors such as abortion, mortality, and time variable periods for state variables.

1 INTRODUCTION

Dairy and beef production is essential to ensure a profitable and sustainable food supply. Ruminants, such as cows, account for around 58% of total emissions from crop and livestock production, highlighting their impact on climate change. In addition, the growing demand for agricultural products requires informed decision-making. Despite efforts in agricultural modelling, the adoption of decision support systems by farmers remains limited. A better understanding of farmers' decision-making is essential to addressing environmental challenges and achieving sustainable production. The predicted increase in demand for agricultural food over the next decade further accentuates the need to optimize livestock production and find solutions that balance efficiency with sustainability (Bang et al. 2023).

To effectively address these challenges and optimize milk and beef production, it is necessary to employ advanced scientific and technological approaches. In this context, stochastic simulation emerges as a tool of great relevance. Stochastic simulation stands out as a crucial research method that allows modeling complex systems characterized by random variability (Law 2015), its applicability spans a wide range of disciplines, ranging from economics to biology, as well as logistics and engineering (Rubinstein and Kroese 2016).

There are managerial aspects no clear where simulation may shed light like the economic impact of twin births in dairy cattle. Some authors claim for a cause of economic losses (Cabrera and Fricke 2021) due to the higher incidence of health problems such as dystocia, metabolic diseases, fertility problems, occurrence of mastitis and increased probability of slaughter reducing overall milk production. These negative effects has counterbalanced in part with benefits associated to twin births, such as an increased milk production and the emergence of additional calves. The consequences of twinning are serious for both cows giving birth to twins and twins calves born. It is reported that the average probability of twin births is

4.2% and the average net losses for each of these events ranges between $59 and $161 (Cabrera and Fricke 2021).

Discrete event simulation (DES) offers a unique opportunity for the study of dairy herd management, allowing the variability inherent in this process to be realistically modelled and analyzed. Given the influence of multiple uncertain factors on dairy production, such as climatic conditions, animal health, variations in feed prices among others, DES becomes an important tool for understanding and improving dairy production performance. In addition, DES has substantial advantages compared to traditional analytical models, such as those based on Markov chains and dynamic programming (Law 2015). Analytical models often require simplifications and assumptions incurring in a loss of accuracy that may not reflect the complexity of the actual dairy production. In contrast, simulation makes possible to model realistic interaction among multiple variables, which facilitates the evaluation of management strategies and the assessment of risks, critical elements for bettering informed decision-making in the dairy sector.

The objective of this study is to propose a DES model that reproduces herd dynamics of dairy cows considering the culling for disease or reproductive performance reasons. The model will be verified and validated before showing simple examples of use to demonstrate the role DES can play in the smart management of dairy farms.

2 MATERIALS AND METHODS

A DES model based on the same methodology presented by Plà-Aragonès et al. (2008) and Plà-Aragonés (2005) for the pig industry is adapted and developed for a dairy farm. The model represents herd dynamics and determine herd structure at equilibrium. Cows are culled due to different reasons such as disease or reproductive performance problems. Simulated cows represent they start as heifers at an age of 2 years at first calving. The growth of animals is represented yearly corresponding with a regular parity. Abortions are not yet considered. At each stage, there is a culling probability and when a cow is culled it is replaced at the moment without delay assuming no constraints on availability of heifers. According to the replacement policy adopted by the farmers, the maximum age for culling can be fixed and therefore cows reaching this age are replaced by 2-year-old heifers. The schematic representation of the model is shown in Figure 1.

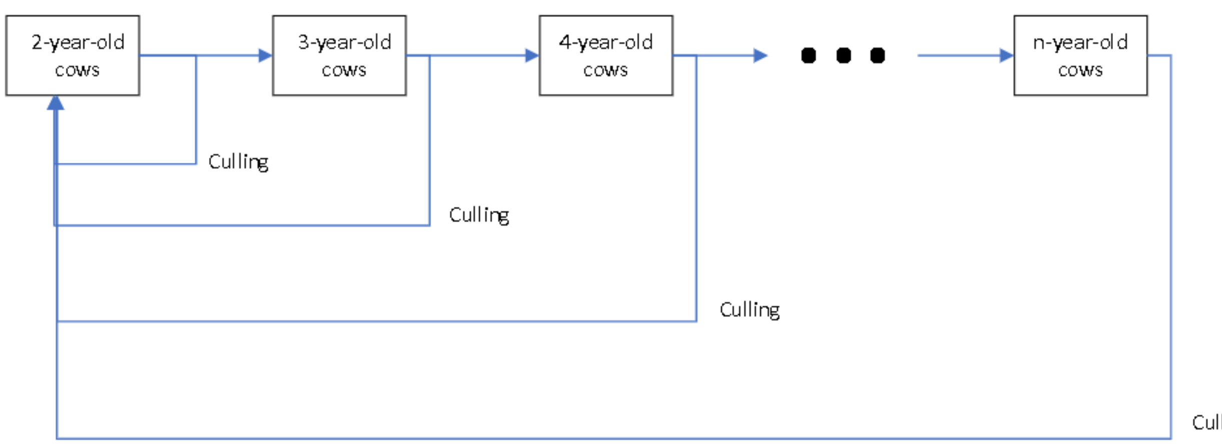


Figure 1: Main states of the simulation model of a herd of cows. Arrows show allowed transitions from one state to another.

The probabilities of culling for specific ages (Table 1) are borrowed from Greer et al. (1980) who obtained these records from 4.660 Hereford cows. The considered culling criteria were for disease or performance issues or because cows reached the maximum age allowed of 10 years.

Table 1: Probability of culling cows belonging to the herd for a maximun age of 10 years (Greer et al. 1980).

Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Culling Probability	0.193	0.153	0.160	0.174	0.161	0.176	0.199	0.279	1

Based on culling probabilities, it is then possible to explore different culling policies with the aim of identifying the advisable maximum lifespan of cows and so, making the model useful for improving the economic value of the herd. For instance, if the maximum age for cows is fixed to eight years, the culling probability of a cow of eight years all would be one (100 % of cows culled) and no older cows in the herd would be possible.

One of the outputs of the model is the economic assessment of the herd at the steady-state either calculated over the total time horizon or yearly. The net economic value of the herd is calculated by the difference between total income minus total cost per cow as shown:

$$Economic\ value\ of\ herd = \sum_{i=1}^{n} Economic\ value\ cow_i = \sum_{i=1}^{n} (Income_i - Cost_i)$$

and the annual net economic value can be easily derived by dividing the Economic value of herd by the total number of years simulated. Depending on the state in which cows are, revenues and costs are calculated per cows until the slaughtering of the animal. Revenues and costs considered are as follows:

$$Economic\ value\ cow_i = (IOFC_i\ +\ INB_i + VD_i) - (VRi \mp\ CIC_i \mp\ Al_i \mp VCi \mp PGi)$$

where *IOFCi* is milk income over the feed cost, *INBi* the input of newborn calf (calf value), *VDi* is the salvage value of a replaced cow (carcass value), *VRi* the replacement cost (Replacement heifer cost), *AIi* the cost of artificial insemination, *VCi* is the veterinary cost and PGi is the loss by twin farrowing. The *IOFC* value will be calculated as:

$$IOFC_i = Mp_i * MP_i - DMI_i * FC$$

where Mp_i is the milk production of month *i*, MP_i is the price per liter of milk of month *i*, DMI_i.is the dry matter intake of month *i* and FC is the feed cost per kg of dry matter (Giordano et al. 2012), values available in Table 2.

Table 2: Economic parameters of the simulation model obtained from Giordano et al. (2012).

Price	**Value**
Milk ($/kg)	0.36
Calf value ($/calf)	100
Carcass value ($/kg)	1.16
Replacement heifer cost ($)	1.3
Veterinary cost ($)	50
Feed cost in lactation ($/kg)	0.17
Feed cost in dry period($/kg)	0.13

In addition to that, DMI is of 25 kg/day (von Keyserlingk and Weary 2010) for each cow and the monthly milk production level for each cow according to its parity is obtained from the data provided by Angel Vásquez et al. (2021) and represented in Table 3.

Table 3: Monthly milk production (kg/month).

Month	2 parities	>=3 parities
1	1252	1025
2	1228	1333
3	1187	1332
4	1129	1264
5	1103	1181
6	935	1025
7	969	1076
8	868	920
9	827	858
10	703	719

Whereas culling probabilities are modified for cows that have experienced twin calvings, is that we proposed a small modification to the original model where cows can be pregnant and have only one calf or be pregnant with twins, the probability of a cow having twin births is 4.2% (Cabrera and Fricke 2021). Figure 2 shows this modification, when a cow is pregnant with twins, they will follow the path below in the figure with no option to continue up the path of cows that have not been pregnant with twins at any time, i.e. their culling probabilities have been modified and remain unchanged until the cow is eliminated from the herd. The model assumes that a cow can have at most only one twin birth during her lifetime.

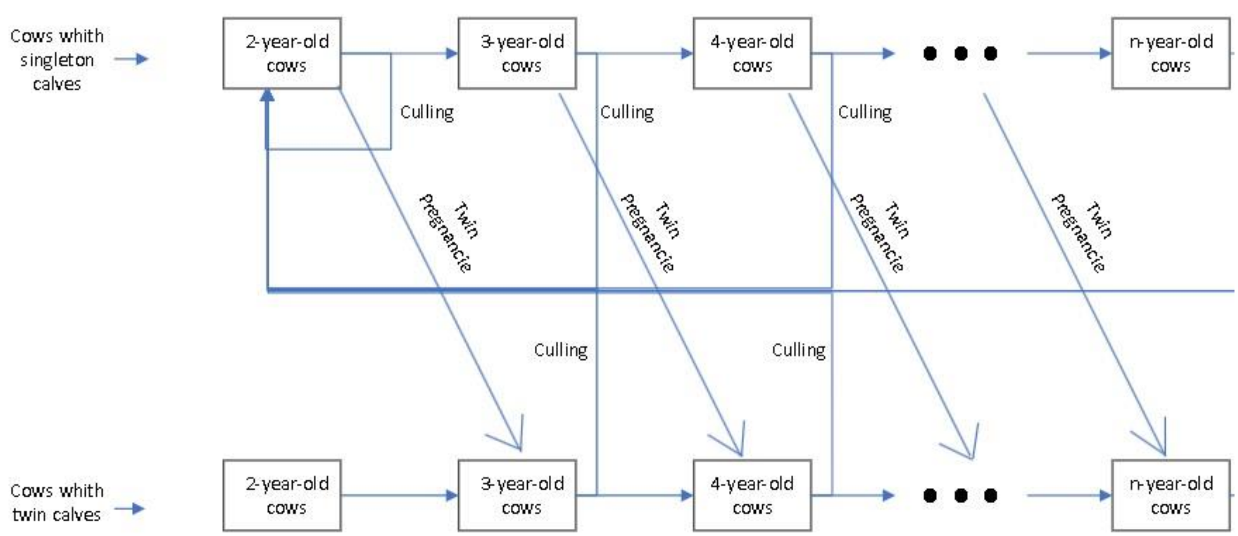
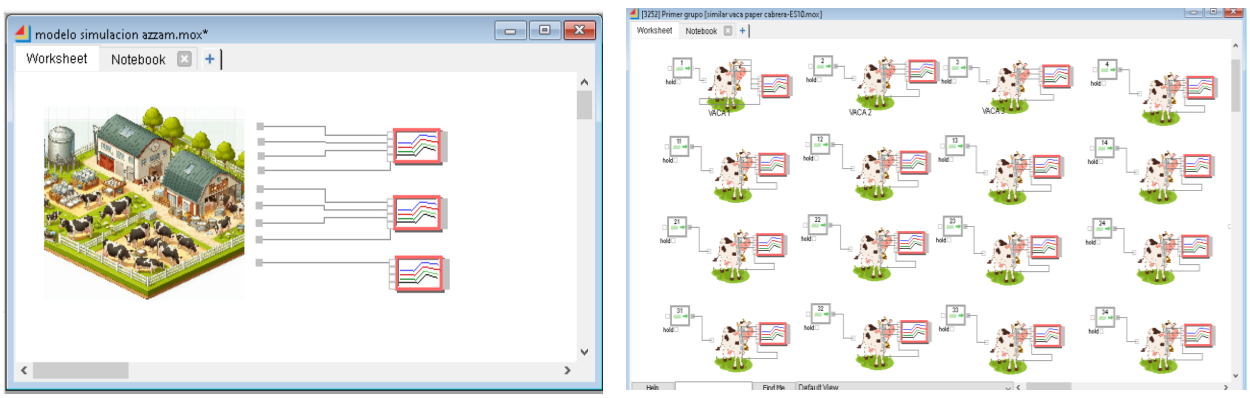


Figure 2: Modification of the original model to study the problem of twin calvings.

The simulation model was developed in ExtendSim (Krahl and Nastasi 2014) to take advantage of this tools to implement discrete event simulation models either in continuous time or discrete time. ExtendSim has standard libraries with blocks performing different functions such as the generation of random numbers from different statistics distributions, reading and writing data in Excel files, writing data to store the results of the models and useful functions to graph the results. ExtendSim allows also the encapsulation of blocks into hierarchical blocks and one of them is built to represent the entire herd. Coding of blocks is performed with the own programming language, MODL, very similar to C. Figure 3 (a) shows the hierarchical block representing the herd model developed in Extendsim. The figure for the icon is customizable and for this model it is chosen a stable, which integrates a herd of 1000 cows (Figure 3(b)). In this way, it is possible to represent different herd sizes since the number of cows in the barn can be changed easily. In addition, we also built a version of the simulation model in which the block that represents the herd corresponds to a sole block of Extendsim where all functionality of the model is coded. This version produces the same result but with less computational time. The first version was used to prototyping while the second one for solving the more complex instances. The simulation time in all the cases was considered 1000 steps (years). After a transient period at the beginning of the simulation (i.e. the so-called warming period), the herd reached a steady state used in the calculation of the key performance indexes. The first 12 months were not used for calculation.



(a) **(b)**

Figure 3: Representation of the model developed in Extendsim (3a) consisting of 10 hierarchical blocks, each hierarchical block containing 64 blocks that each represent an animal (3b).

3 RESULTS AND DISCUSSION

3.1 Verification and Validation

For the verification and validation of our model and its results we compared the analytical model of Markov Chains (Kleijnen 1995). Markov chains are a special type of stochastic processes that are characterized by the Markov property: given the current state of the process, its future behavior does not depend on the past. In other words, "given the present, the future is independent of the past". This method is used to model situations where future events only depend on the current state and not on previous history. Their application spans areas such as finance, logistics, epidemiology, and more, and they are critical for predicting probabilities and making informed decisions. In addition, by solving the problem, it is possible to obtain the equilibrium state of the system, which represents a stable distribution of probabilities in which the process remains long-term (Hillier 2010). For this purpose, a spreadsheet was used to introduce the transition probabilities matrix corresponding to the Markov chain and calculating dairy herd dynamics year by year iterating the product of the matrix from the initial population until the steady state was reached. The analytical model accounts for states and transitions, where nodes and links between nodes represented in Figure 1 corresponds to the states of the model and the possible transitions between states respectively. The outcome observed was the same to the average herd distribution by ages with the simulation model presented in Table 4.

In the literature, an early study of Azzam et al. (1990), they solved the problem of the age equilibrium distribution of dairy cows using a similar approach based on Markov Chains. They considered the culling probabilities of cows presented in Table 1 experimenting with different probabilities, as well as exploring different slaughter policies. The analytical solution of Azzam et al. (1990) is presented in Table 4 for case where cows can reach a maximum age in the herd of 10 years, the average age of the herd is 4.78 years. These results show almost zero difference between the DES models and the analytical Markov chain model. Simulation models provide the possibility of solving more complex problems than those solved with analytical models because of its ability to adapt to different situations (Law 2015) and they are a good alternative to analytical models like Markov chains avoiding the need of developing more complex tools such as the elaboration of software capable to manage large matrices. The proposed DES is considered a valuable tool since the representation of dairy herd dynamics allow researchers to know the herd distribution of cows in the herd and evaluate herd performance under different herd management policies, for example, policies leading to obtain the optimal economic replacement of cows, taking into account in a more specific way different health problems affecting mortality or milk performance such as lameness or mastitis, besides the prediction of meat production in the case of beef producing cows. In addition, simulation models can be very useful when combined with machine learning methods (von Rueden et al. 2020). In this way, it is possible to generate dairy herd data for the training of predictive or prescriptive models through previously validated simulation models, considering the perspective that machine learning models benefits of discovering and learning knowledge unveiled by simulation (Cockburn 2020) with potential advances generation in the field of dairy-cattle production. However, the proposed simulation model has several limitations such as that it does not incorporate the economic analysis of the herd. In this first instance it only incorporates the possibility of culling for health or reproductive issues but does not include other characteristics and the time step of the simulation is one year. The flexible use of shorter time intervals for state variables can make the model more suitable to explore different management situations.

Table 4: Dairy herd distribution at equilibrium, maximum age of 10 years.

Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Simulated	0.212	0.171	0.145	0.122	0.101	0.084	0.069	0.056	0.04
Azzam et al. (1990)	0.212	0.171	0.145	0.122	0.101	0.084	0.07	0.056	0.04

The average age of the cows belonging to the herd is calculated easily considering the vectors of herd structure V = [0.212; 0.171; 0.145; 0.122; 0.101; 0.084; 0.069; 0.056; 0.040] combined with corresponding ages E = [2; 3; 4; 5; 6; 7; 8; 9; 10] and performing $E*V^T$, resulting in an average age of the herd of 4.77 years. Figure 4 and Figure 5 show the number of animals aged 2 and 3 years respectively as the simulation time elapses, both figures show that in a few years after the start of the simulation, the number of animals in each state tends to oscillate around the equilibrium level mentioned in Table 1 (b). In the case of cows that are 2 years old, it is possible to determine that the confidence interval with a significance level of 5% is reduced and its minimum and maximum limits are 210.13 and 217.73 respectively for the last 30 years simulated (once reached the steady-state), so the values oscillate very close to the mean (mean 212.66, standard deviation of 5.51, t-value of 2.045, running the simulation five times and following Whelch's method (Osais 2017), the same is true for the number of cows that are at other parity levels, i.e. age of cow.

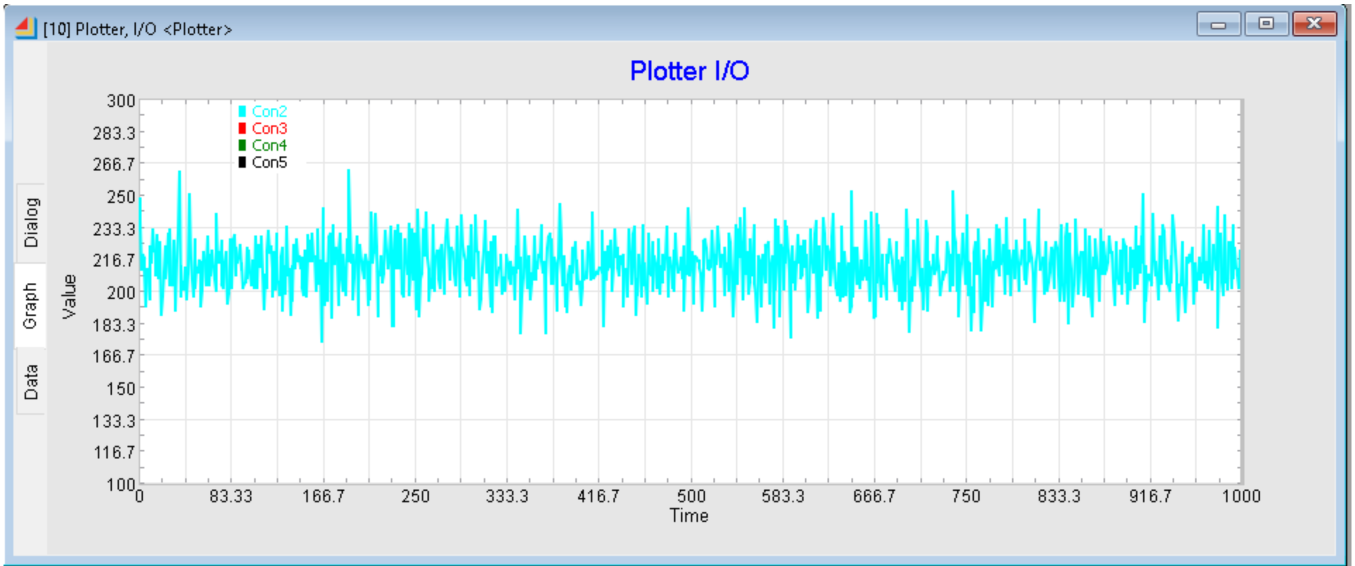


Figure 4: Evolution of the number of two-year-old animals as the simulation time elapses.

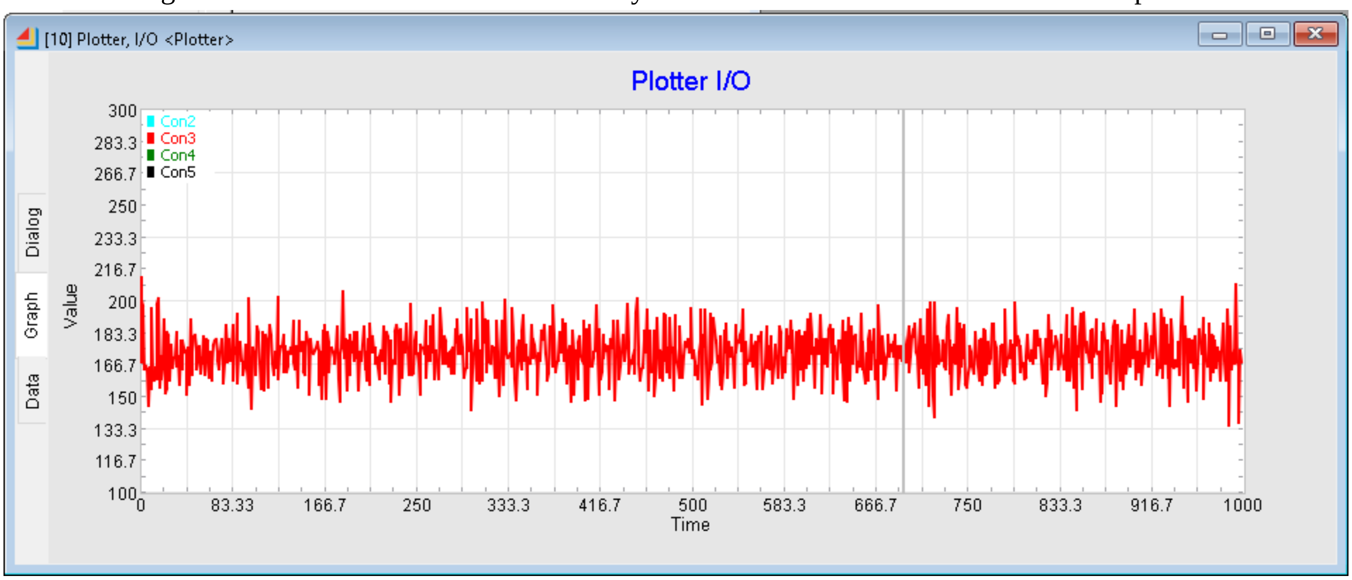


Figure 5: Evolution of the number of three-year-old animals over the simulation period.

3.2 Calculations for the Base Case

Once validated the model several examples of practical use were developed for illustrative purpose. The different outputs calculated were all based on the steady-state distribution, like the economic performance. For the base case, the net value was of $2020 per cow per year (i.e. $168 per cow per month). The different concepts used to calculate the net revenue are detailed in Table 5. Giordano et al. (2012) proposed a dairy herd model as a Markov Decision Process considering daily transition probabilities for events of aging, replacement, mortality, pregnancy and calving, obtaining a net value per cow of $3179 for the case of the artificial insemination program that generates pregnancy rates for the first service of 42% and 30% for subsequent services. The difference to our proposal is mainly due to the fact that they represent several details not included in our proposal, as well as the simulation time step. Two years before, Cabrera (2010) calculated the structure and economic value of a dairy herd also employing a Markov Decision Processes model by using monthly transition probabilities between different states, and different types of diet for feeding the caws. Associated costs of diet for nitrogen excretion was considered and included in the net value calculated per cow and per month ranging from $10.98 to $132.16, having in this case lower values than those obtained by our simulation model. This difference with respect to our proposal is mainly due to the time step used in the simulation related with the strategic or tactical use of the model, apart the consideration of different types of diet, mortality, abortions, pregnancies with different probabilities values and environmental cost associated with nitrogen excretion.

Table 5: Economic evaluation of the simulation base case for a maximum age of 10 years.

Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Milk Revenue ($/year)	776361	660133	559796	470046	388831	325195	268414	215188	155740
Food Cost	315084	254633	215930	181311	149984	125438	103536	83005	60074
Twin birth loss	1154	990	847	676	573	473	377	270	272
Calf Value	17061	14471	12170	10048	8443	6935	5564	4015	-
Cost IA	15729	12711	10779	9051	7487	6262	5168	4144	2999
Veterinary Cost	10570	8542	7244	6083	5032	4208	3473	2785	2015
Replacement heifer cost	53042	33981	30135	27518	21062	19256	17971	20200	52399
Waste value	3183	2039	1808	1651	1264	1155	1078	1212	3144
Herd Net Value	401026	365785	308839	257108	214400	177648	144531	110014	41125
Net Value Per Cow	2020								

3.3 Application of the Model for Exploring Different Culling Policies

In the case of adopting the policy of culling animals with a maximum age of ten, nine or eight years, then there is a culling probability of one for all animals at the end of the ten, nine or eight years respectively when running the simulation for each instance. This way it is possible to compare the outcome and see what the best option is. The results of the distribution of average ages and economic valuation when the maximum age is eight years is presented in Table 6, the average age is 4.29 years and the net value per cow is $2012 per cow per year, which implies a net value lower than the case of maximum culling age of 10 years previously presented.

Table 6: Herd structure at equilibrium compared with the results of Azzam et al. (1990) for a maximum age of 8 years.

Age	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Probability of finding an age-specific animal maximum age of 8 years of our simulation result	0.234	0.190	0.160	0.135	0.111	0.093	0.077
Probability of finding an age-specific animal (Azzam et al. (1990)) maximum age of 8 years	0.235	0.189	0.160	0.135	0.111	0.093	0.077
Economic valuation of our simulation result for a maximum age of 8 years.							
Milk Revenue ($/year)	859332	734137	618221	521624	428891	359341	297519
Food Cost	348758	283179	238467	201206	165436	138609	114762
Twin birth loss	1277	1088	909	754	630	518	0
Calf Value	23400	19000	16000	13500	11100	9300	7700
Cost IA	17410	14136	11904	10044	8258	6919	5729
Veterinary Cost	11700	9500	8000	6750	5550	4650	3850
Replacement heifer cost	58711	37791	33280	30537	23232	21278	100100
Waste value	3523	2267	1997	1832	1394	1277	6006
Herd Net Value	448400	409710	343658	287665	238278	197943	86784
Net Value Per Cow	2012						

3.4 Exploring the Impact of Twin Calvings

Cabrera and Fricke (2021) carry out a review of the problem of twin births and mention that the values of losses due to births of this type between $59 and $161. One of the publications contained in this review is Eddy et al. (1991), who obtain a net loss per cow of $112 as a result of losses of $212 due to i) average delay of 25 days in the pregnancy of cows that have experienced twin births, ii) 0.5 extra artificial insemination services, 14% increase in the rate of post-calving of twins and increased costs of veterinary treatments, losses that are partly offset by additional revenues of $100 from i) increased milk production per 235 liters of milk per cow per year and ii) increase of 0.75 extra calves for cows with twin calvings compared to cows that become pregnant with only one offspring. As the interest is to know the net loss of a cow, and in order to make correct comparisons, we carry out an analysis of marginal costs and benefits for an animal, also considering the economic data provided by Eddy et al. (1991) in order to make correct comparisons, where for example it is considered that on this occasion the cost of a replacement cow is 590 pounds (on this occasion the value of replacement cow previously delivered by Table 2 will not be taken into account) and that each cow that has experienced a twin calving increases its probability of slaughter by 14%, plus the conversion factor between dollars and pounds is 1.33 (Cabrera and Fricke 2021). When considering an incremental cost analysis for a cow, when comparing our simulation results with twin calvings and the empirical results delivered by Eddy et al. (1991). For a cow, the only relevant cost is the additional replacement cost of slaughtered cows. Other costs and benefits such as additional milk production, additional calves, increased veterinary costs, increased open days, and increased number of artificial insemination services will not change for a single animal. In this way, our result of running the simulation with the culling probability data for each year increased by 14% yields an increase in the cost per replacement of slaughtered cows for a value of $53.74, compared to the value of $109.86 (82.60*1.33) reported by Eddy et al. (1991). This difference may be due to the fact that our model has simulation times of 1 year, which can constitute large time intervals, in addition our model considers transition probabilities that have changed over time, such as the change in time of the probability of twin births presented in Cabrera and Fricke (2021). In addition to not considering in detail other details in the model that can impact herd dynamics, such as calving, ketosis, mastitis, and other problems. However, our result is close to the lower limit of twin birth losses of $59.

In order to understand economic impact of different control techniques to avoid twin births, the simulation model was used, but this time decreasing the increases in the probability of slaughtering of cows farrowing twins and considering the values 14%, 12%, 10%, 8%, 6%, 4% and 2%. On Table7 it is shown the results related to the cost of replaced cows due to slaughter and we can conclude that on average the total replacement cost can be reduced on average by $8 for every 2% decrease in the increment of the probability of slaughtering, which in practice could be a relatively small value. This way, it is observed the need of reviewing the different components of cost and the explicit cost for avoiding twins. There is a trade-off between the cost of reducing the probability of twin calving and the replacement cost, this is the clue to advice an active reduction of twin calving or not.

Table 7: Cow replacement costs for additional slaughter of cows that have experienced twin calving compared to cows belonging to a herd that does not have this problem, compared to different values of increased odds of slaughter for cows with twin calving.

Increased chance of culling for cow with twin calving	Total replacement cost for additional culling of cows with twin calvings compared to herd without cows with twin calvings
14%	53.74
12%	45.27
10%	38.14
8%	33.89
6%	23.57
4%	12.29
2%	6.75

4 CONCLUSIONS

Our work aimed to gain insight into smart management capabilities in dairy herds provided by a DES representing the evolution of a herd with a high number of cows over time. The model operation was verified with an analytic model of Markov chains and validated with other models published in the literature successfully. The use of DES provides a good opportunity to explore different management alternatives like culling. We illustrate the use of the model analyzing the maximum lifespan of cows and the impact of twin calvings. In contrast with published literature considering economic losses of twin calves due to the increased probability of slaughter, mastitis, ketosis among other disease problems of cows, particularly when the increase in the probability of slaughter of 14%, we obtain that the average benefit of reducing by 2% the increase in the probability of culling for a cow with twin calving implies a marginal benefit of $8. This observation lead us to claim for the use of tailored parameters representing the economic behavior of individual dairy farms because results could be different. These aspects are important to be taken into account when developing smart management tools. In this sense, we state DES is a good methodology to collaborate with AI-techniques. Our approach is going to be extended in future adding more features, such as considering abortions, mortality reasons, and a variable time step.

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REFERENCES

Vásquez, A., M. García, E. Sessarego, and N. Chagray. 2021. "Modeling the Lactation Curve in Holstein Cows From a Dairy Farm in the Valley of Huaura, Peru | Modelación de la Curva de Lactación en Vacas Holstein de un Establo en el Valle de Huaura, Perú". *Revista de Investigaciones Veterinarias Del Peru 32*(1): e19488.

Azzam, S. M., A. M. Azzam, M. K. Nielsen, and J. E. Kinder. 1990. "Markov-Chains as a Shortcut Method to Estimate Age Distributions in Herds of Beef-Cattle Under Different Culling Strategies". *Journal of Animal Science 68*(1):5–14.

Bang, R. N., M. Guajardo, and B. G. Hansen. 2023. "Recent Advances in Decision Support for Beef and Dairy Farming: Modeling Approaches and Opportunities". *International Transactions in Operational Research 30*(6):2807–2839.

Cabrera, V. E. 2010. "A large Markovian Linear Program to Optimize Replacement Policies and Dairy Herd Net Income for Diets and Nitrogen Excretion". *Journal of Dairy Science 93*(1):394–406.

Cabrera, V. E. and P. M. Fricke. 2021. "Economics of Twin Pregnancies in Dairy Cattle". *Animals 11*(2):1–14.

Cockburn, M. 2020. "Review: Application and Prospective Discussion of Machine Learning for the Management of Dairy Farms". *Animals 10*(9):1–22.

Eddy, R. G., O. Davies, and C. David. 1991. "An Economic Assessment of Twin Births in British Dairy Herds". *The Veterinary Record 129*(24):526–529.

Giordano, J. O., A. S. Kalantari, P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2012. "A Daily Herd Markov-Chain Model to Study the Reproductive and Economic Impact of Reproductive Programs Combining Timed Artificial Insemination and Estrus Detection". *Journal of Dairy Science 95*(9):5442–5460.

Greer, R. C., R. W. Whitman, and R. R. Woodward. 1980. "Estimation of Probability of Beef-Cows Being Culled and Calculation of Expected Herd Life". *Journal of Animal Science 51*(1):10–19.

Hillier, F. S. 2010. *Introduction to Operations Research*. 9.ª edition. México: McGraw-Hill Education.

Kleijnen, J. P. C. 1995. "Verification and Validation of Simulation-Models". *European Journal of Operational Research 82*(1):145–162.

Krahl, D. and A. Nastasi. 2014. "Reliability Modeling with Extendsim". In *2014 Winter Simulation Conference (WSC)*, 4219–4225 https://Informssim.Org/Wsc14papers/Includes/Files/476.Pdf.

Law, A. 2015. *Simulation Modeling and Analysis*. Fifth edition. Tucson, Arizona: McGraw-Hill Education.

Osais, Y. E. 2017. *Computer Simulation: A Foundational Approach Using Python.* 1st Edition. New York: CRC Press.

Plà-Aragonés, L. M. 2005. "A Stochastic Model for Planning Swine Facilities". In *2005 Winter Simulation Conference (WSC)*, 2378–2384 https://doi.org/10.1109/WSC.2005.1574529.

Plà-Aragonès, L. M., V. Flores Marias, and S. V. Rodríguez-Sánchez. 2008. "A Simulation Model for Intensive Piglet Production Systems". In *2008 Winter Simulation Conference (WSC)*, 2871–2875 https://doi.org/10.1109/WSC.2008.4736408.

Rubinstein, R. Y. and D. P. Kroese. 2016. *Simulation and the Monte Carlo Method*. Third Edition. New Jersey: Wiley.

von Keyserlingk, M. A. G. and D. M. Weary. 2010. "Review: Feeding Behaviour of Dairy Cattle: Meaures and Applications | Le Comportement Alimentaire des Bovins Laitiers: Quantification et Applications". *Canadian Journal of Animal Science*, *90*(3):303–309.

von Rueden, L., S. Mayer, R. Sifa, C. Bauckhage, and J. Garcke. 2020. "Combining Machine Learning and Simulation to a Hybrid Modelling Approach: Current and Future Directions". In *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, edited by M. R. Berthold, A. Feelders, and G. Krempl, 548–560. Cham: Springer.

AUTHOR BIOGRAPHIES

OSVALDO PALMA is a PhD student in Engineering and Information Technology at the Universidad de Lleida and instructor professor in the Department of Economics and Administration at the Universidad Nacional Andrés Bello. His research interests is the simulation an artificial intelligence. His email address is osvaldo.palma@unab.cl.

LLUIS M. PLA is an associate professor in the Department of Mathematics at University of Lleida (UdL) and a Senior Researcher in the *Animal Breeding Research group* at the Agrotecnio CERCA Center. His research interests include operational research and artificial intelligence methods applied in agriculture and forest management, with special reference to simulation, dynamic programming, planning, Markov decision processes and production planning. Coordinator of the EURO-Working group: Operational Research in Agriculture and Forest management and responsible of the CYTED network Artificial Intelligence for sustainable Agriculture. He is a member of INFORMS and EURO. His e-mail address is lluismiquel.pla@udl.es.

ALEJANDRO MAC CAWLEY is an Associate Professor in the Industrial and System Engineering Department in the School of Engineering at Pontificia Universidad Católica de Chile. His research applies operation research and logistics techniques in the natural resource and biological systems, specifically in the agricultural, health, and mining sectors. The research has focused on production planning under uncertainty, Lean Healthcare, determining optimal maintenance policies, and using industry 4.0 technologies and big data/sensors in decision-making. He holds a Ph.D. from the School of Industrial and Systems Engineering at the Georgia Institute of Technology, with a field of specialization in Supply Chain Engineering. His email address is amac@uc.cl.

VÍCTOR M. ALBORNOZ received the BSc and MSc in Math from Pontificia Universidad Católica de Chile (PUC) in 1989 and 1993, respectively and holds a Ph.D. in Engineering also from PUC in 1998. Currently, he is an Assistant Professor at the Industrial Engineering Department of Universidad Técnica Federico Santa María (USM) in Santiago de Chile. He is author of more than 25 journal articles and over 60 conference proceeding papers in the field of Operations Research. His email address is victor.albornoz@usm.cl.