Functional description and terms of use

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Table of contents

1 INTRODUCTION 12

2 FUNCTIONAL ANALYSIS 13

2.1 General 13
2.1.1 Management options of the simulator 14
2.1.1.1 Dynamic simulation with time-related engine 14
2.1.1.2 Mechanistic simulation with discrete event modeling 14
2.1.1.3 Stochastic simulation 14
2.1.1.4 Finite horizon simulation 14
2.1.2 General constants for simulation 14
2.1.3 Initial herd constitution principle 14
2.1.4 Produced data principle 15

2.2 Modules 15
2.2.1 Reproduction 17
2.2.1.1 Constant biological and technical values 17
2.2.1.1.1 Ovulation occurrence 17
2.2.1.1.1.1 Age at puberty 17
2.2.1.1.1.2 Estrus duration 17
2.2.1.1.1.3 Intervals between ovulations (cyclicity) 17
2.2.1.1.2 Estrus detection sensitivity 18
2.2.1.1.2.1 Estrus detection sensitivity for first insemination 18
2.2.1.1.2.2 Estrus detection sensitivity for following inseminations 18
2.2.1.1.2.3 Additional criteria affecting estrus detection sensitivity 19
2.2.1.1.2.3.1 Slippery floors 19
2.2.1.1.2.3.2 Simultaneous estrus 19
2.2.1.1.2.3.3 Dairy production 19
2.2.1.1.2.3.4 Effect of lameness on estrus detection sensitivity 19
2.2.1.1.3 Estrus detection specificity 19
2.2.1.1.3.1 Lack of specificity after calving (or after reproduction for heifers) and before first artificial insemination 19
2.2.1.1.3.2 Lack of specificity for returns after AI 20
2.2.1.1.4 Insemination and fertility 20
2.2.1.1.4.1 Insemination choice 20
2.2.1.1.4.2 Fertility – basic values 20
2.2.1.1.4.3 Grouped calvings 21
2.2.1.1.4.4 Fertility modulation 21
2.2.1.1.4.4.1 Milk production 21
2.2.1.1.4.4.2 Individual potential 21
2.2.1.1.4.4.3 Ketosis effect on fertility 21
2.2.1.1.4.4.4 Lameness effect on fertility 22
2.2.1.1.4.4.5 Veterinary surveillance for fertility problems 22
2.2.1.1.5 Veterinary surveillance 22
2.2.1.1.6 Pregnancy 22
2.2.1.1.6.1 Late embryonic mortality and abortion 22
2.2.1.1.6.2 Pregnancy duration 23
2.2.1.1.6.2.1 Breed and parity 23
2.2.1.1.6.2.2 Sex of the unborn calf 24
2.2.1.1.6.2.3 Twin pregnancy 24
2.2.1.1.7 Cyclicity resumption after pregnancy loss and calving 24
2.2.1.1.7.1 Pregnancy loss case 24

2.2.1.1.7.2 Calving case 25
2.2.1.1.7.3 Treatment in case of cyclicality recovery problems 25
2.2.1.2 Parameters for reproductive management 25
2.2.1.2.1 Breeding age 25
2.2.1.2.2 Estrus detection modes 25
2.2.1.2.3 Slippery floor 26
2.2.1.2.4 Mating plans 26
2.2.1.2.5 Grouped calvings 26
2.2.1.2.6 Herd-specific fertility factor 26
2.2.1.2.7 Minimum post-partum delay before breeding (waiting period) 26
2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility 27
2.2.1.2.9 Breeding contract 27
2.2.1.3 Data produced 27
2.2.1.3.1 Calving-based reproductive performance 27
2.2.1.3.1.1 Primiparous 28
2.2.1.3.1.2 Multiparous 28
2.2.1.3.2 Insemination-based reproductive performance 29
2.2.1.3.2.1 Nulliparous 29
2.2.1.3.2.2 Primiparous and multiparous 30
2.2.1.3.3 Technical reproduction data 30
2.2.2 Lactation 31
2.2.2.1 Constant biological and technical values 31
2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination 31
2.2.2.1.1.1 Breed impact on cumulated milk production 31
2.2.2.1.1.2 Daily production by lactation stage 31
2.2.2.1.1.3 Milk somatic cell count in absence of infection 32
2.2.2.1.1.4 Basic lactation duration – drying-off programming 33
2.2.2.1.1.5 Milk destination 33
2.2.2.1.2 Milk production modulation 34
2.2.2.1.2.1 Parity 34
2.2.2.1.2.2 Drying-off 34
2.2.2.1.2.3 Pregnancy 35
2.2.2.1.2.4 Individual potential 35
2.2.2.1.2.5 Estrus 35
2.2.2.1.2.6 Photoperiod 36
2.2.2.1.2.7 Milking frequency 36
2.2.2.1.2.8 Somatic cell count 36
2.2.2.1.2.9 Mastitis effect on dairy production 37
2.2.2.1.2.10 Ketosis effect on dairy production 37
2.2.2.1.2.11 Lameness effect on dairy production 37
2.2.2.1.2.12 Quarter loss 37
2.2.2.1.2.13 Feeding 37
2.2.2.1.2.14 Daily hazard 37
2.2.2.2 Parameters for lactating farmer management 37
2.2.2.2.1 Drying-off 38
2.2.2.2.2 Milking frequency 38
2.2.2.2.3 Minimum lactation stage for delivered milk 38
2.2.2.2.4 Herd production level 38
2.2.2.3 Data produced 38
2.2.2.3.1 Milk delivery to a dairy 38
2.2.2.3.2 Spread and discarded milk 39
2.2.2.3.3 Performance estimation by monthly test-day 39
2.2.2.3.4 Technical production data 40
2.2.3 Health 42
2.2.3.1 Intramammary infection (IMI) 42
2.2.3.1.1 Constant biological and technical values for IMI 42
2.2.3.1.1.1 IMI description 42
2.2.3.1.1.1.1 IMI types 42

2.2.3.1.1.1.2 IMI severity levels 42
2.2.3.1.1.1.2.1 Definition of IMI severity levels 42
2.2.3.1.1.1.2.2 Severity levels by IMI type and by lactation stage/cow pregnancy stage at infection time 42
2.2.3.1.1.1.3 IMI consequences 43
2.2.3.1.1.1.3.1 Increase in somatic cell count 43
2.2.3.1.1.1.3.2 Important decrease in milk production 44
2.2.3.1.1.1.3.3 Impact on feeding 44
2.2.3.1.1.1.3.4 Impact of mastitis on susceptibility to other diseases 44
2.2.3.1.1.1.3.5 Mortality and culling risk related to G3 severity 45
2.2.3.1.1.2 IMI incidence 45
2.2.3.1.1.2.1 Periods at risk 46
2.2.3.1.1.2.2 Incidence risk modulation 47
2.2.3.1.1.2.2.1 Individual modulation of incidence risk 47
2.2.3.1.1.2.2.2 Modulation of the incidence risk related to herd management 49
2.2.3.1.1.3 IMI detection 50
2.2.3.1.1.4 Evolution and cure 50
2.2.3.1.1.4.1 Spontaneous healing 50
2.2.3.1.1.4.1.1 Basic spontaneous healing 50
2.2.3.1.1.4.1.2 Cure induced by the cure of a new infection in the quarter 51
2.2.3.1.1.4.2 Mastitis worsening 51
2.2.3.1.1.4.2.1 Clinical recurrence of persistent subclinical infection 51
2.2.3.1.1.4.2.2 Worsening of undetected clinical mastitis 51
2.2.3.1.1.4.3 Healing following treatments 51
2.2.3.1.1.4.4 Relapses 52
2.2.3.1.2 Parameters for IMI management 52
2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis 52
2.2.3.1.2.2 Seasonal impact on IMI incidence 52
2.2.3.1.2.3 Share of bacterial type in incidence 53
2.2.3.1.2.4 Treatment plans 53
2.2.3.1.2.5 Prevention factor for mastitis at the individual level 53
2.2.3.1.2.6 Prevention factor for mastitis at herd level 54
2.2.3.1.2.7 Veterinary care contract option 54
2.2.3.1.3 Specific IMI produced data 54
2.2.3.2 Ketosis (or acetonaemia) 56
2.2.3.2.1 Biological and technical constant values for ketosis 56
2.2.3.2.1.1 Description of ketosis 56
2.2.3.2.1.1.1 Ketosis severity levels 56
2.2.3.2.1.1.2 Zootechnical consequences of ketosis 56
2.2.3.2.1.1.2.1 Effect of ketosis on reproductive performance 56
2.2.3.2.1.1.2.2 Impact of ketosis on milk production performance 57
2.2.3.2.1.1.2.3 Feeding impact 58
2.2.3.2.1.1.2.4 Effect of ketosis on susceptibility to other diseases 58
2.2.3.2.1.1.2.5 Ketosis culling and mortality 58
2.2.3.2.1.2 Incidence 58
2.2.3.2.1.2.1 Basic incidence 58
2.2.3.2.1.2.2 Incidence risk modulation 59
2.2.3.2.1.2.2.1 Modulation of the ketosis incidence depending on genetics 59
2.2.3.2.1.2.2.2 Modulation of the ketosis incidence depending on lactation rank 60
2.2.3.2.1.2.2.3 Modulation of the ketosis incidence depending on production level 60
2.2.3.2.1.2.2.4 Modulation of the ketosis incidence depending on season 60
2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes 60
2.2.3.2.1.2.2.6 Modulation of the incidence of ketosis, in multiparous women, linked to the duration of the previous lactation 60
2.2.3.2.1.2.2.7 Modulation of the incidence of ketosis, in primiparous females, related to age at first calving 61

2.2.3.2.1.2.2.8 Modulation of the incidence of ketosis by the use of intra-ruminally administered monensin boluses (Kexxtone®) 61
2.2.3.2.1.3 Ketosis detection 61
2.2.3.2.1.3.1 Subclinical ketosis 61
2.2.3.2.1.3.1.1 Cetodetect ® 61
2.2.3.2.1.3.1.2 Herd Navigator ® 61
2.2.3.2.1.3.1.3 Blood test 62
2.2.3.2.1.3.2 Clinical ketosis (detected) 62
2.2.3.2.1.4 Evolution and healing of ketosis 62
2.2.3.2.1.4.1 Duration of ketosis 62
2.2.3.2.1.4.2 Aggravation of an episode of subclinical ketosis 63
2.2.3.2.1.4.3 Detection of a case of clinical ketosis, treatment 63
2.2.3.2.1.4.4 Recurrence of ketosis 63
2.2.3.2.2 Ketosis-related husbandry parameters 63
2.2.3.2.2.1 Prevention factors 63
2.2.3.2.2.1.1 Global prevention factor 63
2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®) 64
2.2.3.2.2.2 Detection options 64
2.2.3.2.2.2.1 Cetodetect ® option during milk control 64
2.2.3.2.2.2.2 Herd Navigator ® option of the milking robot 64
2.2.3.2.2.3 Treatment plan 64
2.2.3.2.3 Specific produced ketosis data 65
2.2.3.3 Lameness 66
2.2.3.3.1 Biological and technical constant values for lameness 66
2.2.3.3.1.1 Description of lameness 66
2.2.3.3.1.1.1 Lameness types 66
2.2.3.3.1.1.2 Lameness severity levels 66
2.2.3.3.1.1.3 Zootechnical consequences of lameness 67
2.2.3.3.1.1.3.1 Effect of lameness on reproductive performance 67
2.2.3.3.1.1.3.2 Impact of lameness on milk production performance 67
2.2.3.3.1.1.3.3 Feeding impact 68
2.2.3.3.1.1.3.4 Effect of ketosis on susceptibility to other diseases 68
2.2.3.3.1.1.3.5 Lameness-related culling and mortality 68
2.2.3.3.1.2 Incidence 68
2.2.3.3.1.2.1 Basic incidence 69
2.2.3.3.1.2.2 Incidence risk modulation 69
2.2.3.3.1.2.2.1 Individual modulation of impact risk 69
2.2.3.3.1.2.2.2 Modulation of the risk of incidence linked to herd management 70
2.2.3.3.1.3 Lameness detection 73
2.2.3.3.1.4 Evolution and healing of lameness 73
2.2.3.3.1.4.1 Duration of lameness 74
2.2.3.3.1.4.2 Aggravation of a lameness episode 74
2.2.3.3.1.4.3 Recurrence of lameness 74
2.2.3.3.2 Lameness-related husbandry parameters 74
2.2.3.3.2.1 Prevention factors 74
2.2.3.3.2.1.1 Global prevention factors 74
2.2.3.3.2.1.2 Option to prevent infectious lameness by using a foot bath 75
2.2.3.3.2.1.3 Foot bath frequency option 75
2.2.3.3.2.1.4 Option to prevent infectious and non-infectious lameness through trimming 75
2.2.3.3.2.2 Detection options 75
2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment 75
2.2.3.3.2.4 Treatment plan 76
2.2.3.3.3 Specific data produced on lameness 76
2.2.3.4 Neonatal infectious gastroenteritis (GENNI) 77
2.2.3.4.1 Biological and technical constant values for GENNI 77
2.2.3.4.1.1 GENNI description 77
2.2.3.4.1.1.1 GENNI types 77
2.2.3.4.1.1.2 GENNI severity levels 77

2.2.3.4.1.1.2.1 GENNI severity levels definition 77
2.2.3.4.1.1.2.2 Distribution of severity levels according to GENNI type 77
2.2.3.4.1.1.3 GENNI consequences 77
2.2.3.4.1.1.3.1 Delay in the sale of the calf 78
2.2.3.4.1.1.3.2 Decrease in average growth 78
2.2.3.4.1.1.3.3 Decrease in milk production during first lactation 78
2.2.3.4.1.1.3.4 Mortality 78
2.2.3.4.1.2 GENNI incidence 79
2.2.3.4.1.2.1 GENNI incidence 79
2.2.3.4.1.2.2 Incidence modulation 79
2.2.3.4.1.2.2.1 Incidence modulation 79
2.2.3.4.1.2.2.2 Herd modulation 79
2.2.3.4.1.3 GENNI detection 81
2.2.3.4.1.4 GENNI progression and recovery 81
2.2.3.4.1.4.1 Spontaneous healing 81
2.2.3.4.1.4.2 GENNI duration 81
2.2.3.4.1.4.3 GENNI flare up 81
2.2.3.4.1.4.4 Treatments 81
2.2.3.4.2 GENNI-related husbandry parameters 81
2.2.3.4.2.1 Sensitivity of detection of minor GENNI 81
2.2.3.4.2.2 Proportion of each type of pathogen in the incidence 81
2.2.3.4.2.3 Quality control of colostrum and colostrum bank management 82
2.2.3.4.2.4 Time spent for colostrum and quantity received 82
2.2.3.4.2.5 Proportion of calves receiving colostrum 82
2.2.3.4.2.6 Vaccination of pregnant cows 82
2.2.3.4.2.7 Position of the calf pen 82
2.2.3.4.2.8 Hygiene score 82
2.2.3.4.2.9 Treatment plan 82
2.2.3.4.2.10 Overall GENNI prevention factor 82
2.2.3.4.3 Specific data produced relating to GENNI 82
2.2.3.5 Paratuberculosis 84
2.2.3.5.1 Biological and technical constant values for paratuberculosis 84
2.2.3.5.1.1 Paratuberculosis description 84
2.2.3.5.1.1.1 Stages of infection 84
2.2.3.5.1.1.1.1 Sensitive (S) 84
2.2.3.5.1.1.1.2 Refractory (R) 84
2.2.3.5.1.1.1.3 Transiently infected (IT) 84
2.2.3.5.1.1.1.4 Latent infection (IL) 84
2.2.3.5.1.1.1.5 Subclinical infection (IM) 85
2.2.3.5.1.1.1.6 Clinically infected (IC) 85
2.2.3.5.1.1.2 Consequences of paratuberculosis 85
2.2.3.5.1.1.2.1 Culling increase 85
2.2.3.5.1.1.2.2 Further decline in milk production 85
2.2.3.5.1.1.2.3 Impact on slaughter value 85
2.2.3.5.1.1.2.4 Impact on susceptibility to other diseases 85
2.2.3.5.1.1.2.5 Mortality and culling risk 85
2.2.3.5.1.2 MAP quantity 86
2.2.3.5.1.2.1 Individual contribution (excretion) 86
2.2.3.5.1.2.2 Spontaneous decomposition (μ) 87
2.2.3.5.1.3 Incidence of paratuberculosis 87
2.2.3.5.1.3.1 Routes of contamination and periods of risk 87
2.2.3.5.1.3.1.1 Orofecal route 87
2.2.3.5.1.3.1.2 In utero route 88
2.2.3.5.1.3.1.3 Route via milk and colostrum 88
2.2.3.5.1.3.1.4 Direct transmission from calf to calf 89
2.2.3.5.1.3.2 Modulation of the risk of incidence 89
2.2.3.5.1.3.2.1 Genetic modulation 89
2.2.3.5.1.3.2.2 Modulation linked to farm management 89

2.2.3.5.1.3.2.3 Seasonal impact on incidence ... 89
2.2.3.5.1.3.2.4 Veterinary care contract ... 89
2.2.3.5.1.3.3 Calibration ... 89
2.2.3.5.1.4 Detection of cases of paratuberculosis ... 90
2.2.3.5.1.4.1 Description of the tests used ... 90
2.2.3.5.1.4.1.1 Serum ELISA test ... 90
2.2.3.5.1.4.1.2 Faecal PCR test ... 90
2.2.3.5.1.4.2 Practical use of tests ... 90
2.2.3.5.1.4.2.1 Testing strategy for clinically affected cows ... 90
2.2.3.5.1.4.2.2 Regular screening strategy ... 90
2.2.3.5.1.4.2.3 Strategy for regular and infrequent screening ... 91
2.2.3.5.1.5 Progression and recovery from paratuberculosis ... 91
2.2.3.5.1.5.1 Spontaneous healing ... 91
2.2.3.5.1.5.2 Flareup ... 91
2.2.3.5.1.5.3 Recovery following treatment ... 92
2.2.3.5.2 Herd management practices relating to paratuberculosis ... 92
2.2.3.5.2.1 Occurrence of cases of paratuberculosis ... 92
2.2.3.5.2.2 Hygiene ... 92
2.2.3.5.2.3 Genotyping ... 92
2.2.3.5.2.4 Test strategy ... 92
2.2.3.5.3 Data generated relating to paratuberculosis ... 92
2.2.3.6 General health produced data ... 93
2.2.4 Genetics ... 96
2.2.4.1 Biological and technical constants related to genetics ... 96
2.2.4.1.1 Genetic values associated with phenotypic traits ... 96
2.2.4.1.1.1 Common criteria of genetic values associated with phenotypic traits ... 96
2.2.4.1.1.2 Criteria of genetic values associated with breed-dependent phenotypic traits ... 97
2.2.4.1.2 Individual genetic value ... 97
2.2.4.1.2.1 True genetic value ... 97
2.2.4.1.2.2 Individual potential in adult stage ... 97
2.2.4.1.3 Genetic value of bulls for insemination (including natural) ... 99
2.2.4.1.3.1 Catalogue of "bulls" genetic values ... 99
2.2.4.1.3.2 Annual genetic progress ... 99
2.2.4.1.4 Genetic value of calves born from identified parents ... 99
2.2.4.1.4.1 Heredity ... 100
2.2.4.1.4.2 Meiosis hazard ... 100
2.2.4.1.4.3 Heterosis ... 100
2.2.4.2 Parameters for genetic management ... 100
2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue 100
2.2.4.2.2 Genetic strategy ... 101
2.2.4.3 Data produced ... 101
2.2.5 Population and batch management ... 102
2.2.5.1 Constant biological and technical values ... 102
2.2.5.1.1 Herd population ... 102
2.2.5.1.1.1 Gradual herd increase ... 102
2.2.5.1.1.2 Herd population management ... 102
2.2.5.1.1.2.1 Sale of female calves ... 102
2.2.5.1.1.2.2 Heifer sales and adult cow culling ... 102
2.2.5.1.1.2.2.1 Decision to no longer inseminate ... 102
2.2.5.1.1.2.2.2 Culling for population regulation ... 103
2.2.5.1.1.2.2.3 Pregnant heifer sale ... 103
2.2.5.1.1.2.3 Purchase of heifers ... 103
2.2.5.1.1.3 Mortality ... 103
2.2.5.1.2 Batch management ... 104
2.2.5.1.2.1 Assignment ... 104
2.2.5.1.2.2 Indoor/outdoor housing ... 105
2.2.5.2 Parameters for population and batch management ... 106
2.2.5.2.1 Population ... 106

2.2.5.2.1.1 Initial cow breed ... 106
2.2.5.2.1.2 Average number of adult cows ... 106
2.2.5.2.1.3 Annual herd renewal rate ... 106
2.2.5.2.1.4 Female calves management strategy ... 106
2.2.5.2.1.5 Maximum lactation number ... 106
2.2.5.2.1.6 Production performance of the cow regarding the one of the herd ... 107
2.2.5.2.1.7 SCC level ... 107
2.2.5.2.1.8 Break-even point for milk production ... 107
2.2.5.2.2 Batch management ... 107
2.2.5.2.2.1 Stabling and grazing ... 107
2.2.5.2.2.2 Straw bed ... 107
2.2.5.3 Data produced relating to population management ... 108
2.2.6 Feeding ... 109
2.2.6.1 Constant biological and technical values ... 109
2.2.6.1.1 Rations ... 109
2.2.6.1.2 Faeces produced ... 109
2.2.6.2 Parameters for feeding management ... 109
2.2.6.2.1 Balanced diet ... 109
2.2.6.2.1.1 Unweaned calf feeding ... 110
2.2.6.2.1.2 Weaned calf feeding ... 110
2.2.6.2.1.3 Heifer feeding ... 110
2.2.6.2.1.4 Lactating cow feeding ... 110
2.2.6.2.1.5 Dry cow feeding ... 111
2.2.6.2.2 Production concentrate diets ... 111
2.2.6.3 Data produced ... 111
2.2.6.3.1 Milk, concentrate and minerals and vitamins consumed by calves ... 111
2.2.6.3.2 Forage, concentrate and minerals and vitamins consumed by heifers ... 112
2.2.6.3.3 Forage, concentrate and minerals and vitamins consumed by cows ... 112
2.2.7 Accounting ... 114
2.2.7.1 Accounting parameters ... 114
2.2.7.1.1 Reproduction ... 114
2.2.7.1.2 Production ... 114
2.2.7.1.3 Health ... 115
2.2.7.1.4 Genetics ... 117
2.2.7.1.5 Population ... 117
2.2.7.1.6 Feeding ... 117
2.2.7.1.7 Other accounting items ... 118
2.2.7.2 Data produced ... 118

3 TECHNICAL MODALITIES TO USE THE SIMULATOR ... 120

3.1 General principle governing the operation of the simulator ... 120
3.1.1 Farm creating ... 120
3.1.2 Accounting model creating ... 120
3.1.3 Protocol creating ... 120
3.1.3.1 Simple protocols ... 121
3.1.3.2 Crossed protocols ... 121
3.1.4 Running the simulation and obtaining the results ... 121

3.2 Variants of the simulator ... 121
3.2.1 Application Programming Interface (API) ... 121
3.2.1.1 Command relating to farms ... 122
3.2.1.1.1 Farm creation ... 122
3.2.1.1.2 Farm rename ... 122
3.2.1.1.3 Obtaining the list of farms ... 122
3.2.1.1.4 Obtaining farm parameters ... 123
3.2.1.1.5 Modifying the parameters of a farm ... 123

3.2.1.1.6 Farm duplication 124
3.2.1.1.7 Farm deleting 124
3.2.1.2 Commands related to simulation protocols 124
3.2.1.2.1 Creation of a protocol 124
3.2.1.2.2 Renaming a protocol 125
3.2.1.2.3 Obtaining protocol list 125
3.2.1.2.4 Obtaining protocol parameters 125
3.2.1.2.5 Modifying protocol settings 126
3.2.1.2.6 Protocol deleting 126
3.2.1.2.7 Management of cross-protocol parameters 126
3.2.1.2.7.1 Adding a list of breeding parameter values to be crossed 126
3.2.1.2.7.2 Delete a list of breeding parameter values having been crossed 127
3.2.1.2.7.3 Changing the header name of the discriminants 127
3.2.1.2.7.4 Obtaining the header discriminant names of a protocol 127
3.2.1.3 Reference values 127
3.2.1.4 Restoring previous values 128
3.2.1.5 Simulation launch command 128
3.2.1.6 Command to obtain the latest summarised simulation results 129
3.2.1.7 Command to retrieve the latest gross simulation results 129
3.2.1.8 Message codes 130
3.2.2 Web application 130
3.2.2.1 Creating and configuring a farm 131
3.2.2.2 Creating and configuring a simulation protocol 132
3.2.2.3 Running the simulation 133
3.2.2.4 User management 134
3.2.3 Standalone application 135
3.2.4 R package 135
3.2.4.1 Installing the R package 135
3.2.4.2 Using R package 135
3.2.4.2.1 Creating farms using the R package 135
3.2.4.2.2 Creating accounting models using the R package 136
3.2.4.2.3 Creating protocols using the R package 136
3.2.4.2.4 Running the simulation using the R package 137
3.2.4.2.5 Retrieving results using the R package 137

3.3 Result structure 138

3.4 Sensitivity analysis 139

3.5 Technical data 139

4 ACKNOWLEDGEMENTS 140

5 DOCUMENTARY SOURCES 141

6 TABLES 149

7 FIGURES 154

APPENDIX I: LIST OF THE KEYS AND FORMATS OF THE HUSBANDRY PARAMETERS 156

APPENDIX II: LIST OF ACCOUNTING MODEL PARAMETER KEYS 162

APPENDIX III: R PACKAGE USE EXAMPLE 165

1 Introduction

As part of its own research work or in partnership with ONIRIS-INRAE, UMR BIOEPAR used the first-generation "ECOMAST" simulator. This simulator was developed internally and was launched during the thesis on "Ex-ante evaluation of the economic efficiency of programs to control intra-mammary infections in dairy cattle farming" (Hortet, 2000). This simulator, dedicated to dairy herd management and to the technical and economic impacts of mastitis, was designed as a database associated with a simulation engine designed to implement treatments.

Its renewal was decided in 2015 with an immediate focus on a flexible multi-agent system (Gontier, Bareille et Picault, 2022) based on the functional analysis of the previous version , updated, a generic and open conceptual model designed according to an agile methodology inspired from "XP", and the full exploitation of the performance of the latest programming languages and tools.

This simulator was designed to compare management strategies in health disorders and reproduction in a dairy cattle herd, in terms of disease frequency, food consumption, animal performance and dairy cattle technical and economic results.

This document, divided into two main chapters, aims to present the functional analysis intended to describe the technical and biological constraints of livestock management taken into account in the simulations, and the technical procedures for using the simulator.

2 Functional analysis

This document part describes the data and processes related to the functional simulation's requirements. It matches the user or researcher's needs with the simulation's solution set up to respond to it.

Based on recent publications and taking into account expert advice, the simulator aims to take into account all areas of interest involved in the life of the herd and its management. These domains, structured as modules, are each the subject of a chapter.

The "General" section defines the transversal and common aspects of each of these modules. Finally, the last part of this chapter describes the means available to the user to set up its scenarios.

2.1 General

The Dairy Health Manager simulator (DHM) was designed to simulate a dairy cattle herd in a particular farming context. Only dairy production is considered in the simulator with the assumption that the farmer defines the size of his livestock according to its production's objectives and his premises. Developed on a self-centered model basis, it introduces the interest of finely representing the herd by allowing the integration of individuals' diversity and their biological responses' variability.

In this context, the simulator makes it possible to take into account the differences and the genetic variability within and between breeds due to crossing. Furthermore, it enables to consider the interactions between the different decisions based on individual character, such as insemination type choice and culling criteria. The modeling aims to represent the biological processes and the more technical ones related to the farmer's decision-making.

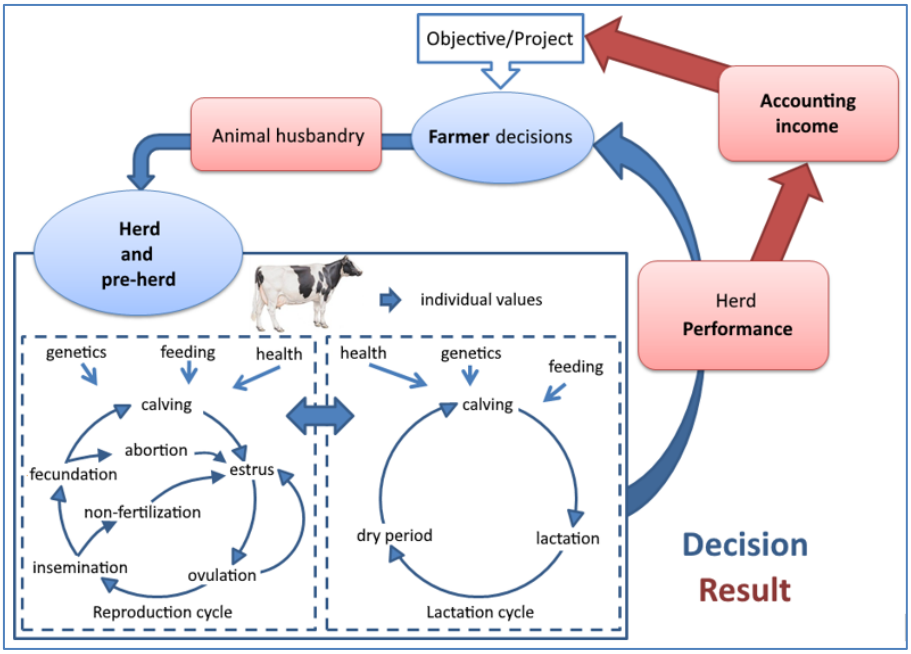


Figure 1 : Biological processes and farmer decisions used in the simulator

Before explaining the data and processes related to the different modules, it is necessary to define their common aspects, which are the simulator's management options and constant data. It is necessary to define their types as well as when they are specific, how to add individuals in the dairy herd and the method to produce data results.

2.1.1 Management options of the simulator

The DHM simulator implements the management options of the time-dependent dynamic simulation, as well as the mechanistic simulation with discrete event modeling and stochastic simulation (Hortet, 2000). It acts on finite horizon.

2.1.1.1 Dynamic simulation with time-related engine

The dynamic simulation is based on modeling the timing of the events that generate change in the attributes' value. In our case, it makes it possible to make actions at a time step defined as 1 day.

2.1.1.2 Mechanistic simulation with discrete event modeling

The elementary simulation unit is an animal at its different stages of life (from birth to sale/death). It is represented by a set of attributes.

The simulation result is constructed by reproducing the stages of the mechanisms involved in individuals' life cycle and, in particular, during discrete event occurrence (for instance, reproduction and health events, or the herd's daily milk production). Thus the evolution of the attributes values depends on the occurrence of the simulated events (for instance, pregnancy onset or the occurrence of an intra-mammary infection) or corresponds to an incrementation (for instance, lactation, pregnancy and drying-off stages).

2.1.1.3 Stochastic simulation

Renewed with the same input parameters, the simulation does not necessarily produce the same results. Indeed, the simulator, based on the probability and variability rules described in the following chapters, will not deliver the same results through several simulations launched successively.

2.1.1.4 Finite horizon simulation

The simulator's point is to compare, both technically and in matters of account the transition phase between the initial and final situations and to not simply compare two static states. This is why the simulation period is defined over a finite space of time.

2.1.2 General constants for simulation

The general constant values include the simulator common data, apart from specialized modules for particular domains (described in paragraph *2.2 Modules on page 15*). By definition, these values can't be modified. Their questioning would require an evolution of the simulator.

Three dairy and three beef breeds are used in the simulator:

Dairy breeds	Montbeliarde
	Normande
	Holstein
Beef breeds	Blanc bleue belge
	Charolaise
	Limousine

Table 1: Breeds involved

Reproduction breeds are only used in the simulator for inseminations, and their products are sold soon after birth.

A cow udder is composed of 4 quarters managed individually.

2.1.3 Initial herd constitution principle

When the simulation starts, a pre-simulation is carried out starting from a situation where the herd does not yet have any cows. They are purchased progressively, at a rate that will then allow a population regulation depending on the renewal setting defined by the user.

This management is described in the population and batch management module (paragraph *2.2.5*)

2.1.4 Produced data principle

Whatever the module concerned, the data is produced regularly (daily, weekly, monthly and annual for the campaign or punctual (recording of actions / events when they occur). They are provided at the simulation's end in the form of "tables" results, available from "csv" files for the standalone version, with ";" as field separator and "," as decimal separator, they are located in the folder designated as the one for the results described in paragraph *3.3 Result structure*. For the R package, results are available in a dataframe.

Thus, from this raw data, all the necessary analyses will be possible natively with software like "R" for example.

In addition to the standard data formats used (integer, float, bool, ...), typed formats are used in the parameter files and the results produced, they are determined as follows:

Format's name	Value definitions
Campaign	Expressed in the format <YYYY starting year>-<year end year in "YYYY" format>, based on the start date of the simulation. If the exercise is to start in January, the campaign is expressed as <exercise year in YYYY format>
Date	Expressed in the format <YYYY-MM-DD>
Breed	Possible values: - 0: Montbeliarde, - 1: Normande, - 2: Holstein, - 3: Blanc bleue belge, - 4: Charolaise, - 5: Limousine.
Insemination type	Possible values: - 0: Natural insemination, - 1: Conventional artificial insemination, - 2: Male sexed artificial insemination, - 3: Female sexed artificial insemination.
Infection status	Possible values: - G0: Healthy, - G1S: Subclinical G1 infection, - G1C: Clinical G1 infection, - G2: G2 infection.

Table 2: Type data formats

2.2 Modules

The biological and technical / decisional functions are differentiated in the simulator. They are described and programmed in the form of 7 interrelated modules.

These modules are:

- Reproduction,
- Lactation,
- Health,
- Genetics,
- Population and batch management,
- Feeding,
- Accounting.

They interact in the following way:

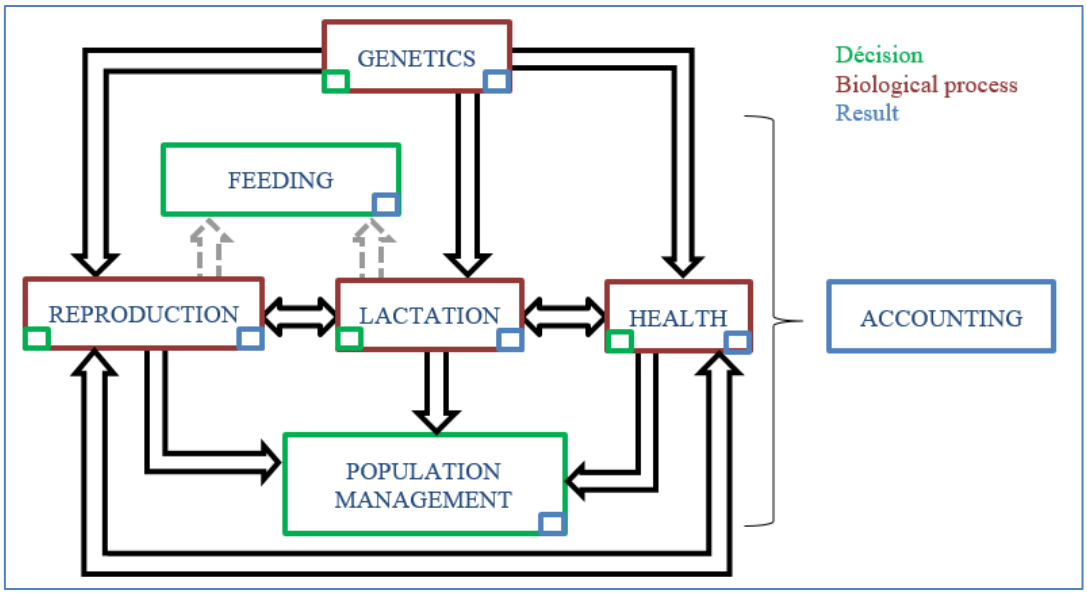


Figure 2: Diagram of the organization in modules and interaction representation

The biological effects of reproduction and lactation on feeding are not simulated in the current state of the software, only the knowledge of the rations to be distributed makes it possible to define the parameters of the cows' diet in relation to the expected production objective. The "Accounting" module provides a summary of all the accounting acts performed during the simulation.

The following chapters describe, for each module, the biological and technical constant values implemented for the domain concerned, the animal's attribute values that can evolve as the simulation proceeds, the management parameters, which can thus make up the desired scenarios, and finally the specific data that will be produced at the end of the simulation.

While most of the data described in the following lines is taken from referenced publications, those with no reference is estimates based on expert opinion, on values already included in the "ECOMAST" simulator (Billon, 2015), and trial and error for the calibration of unobservable phenomena.

These data are in general bases. They are established by the herd effect (phenomena not represented in the simulator) that applies to all cows uniformly, and are weighted by individual events (identified and described) occurring throughout the simulation.

2.2.1 Reproduction

This module integrates all aspects implemented to simulate the animals' ability to reproduce. While these phenomena may depend heavily on biological rules, they are however led by the farmer's decisions.

2.2.1.1 Constant biological and technical values

The constant values that are applied in the simulations' contexts and which affect reproduction deal with ovulation, its detection, insemination, pregnancy and resumption of post-partum ovarian cyclicity.

The simulator differentiates cow reproduction stages in the following way:

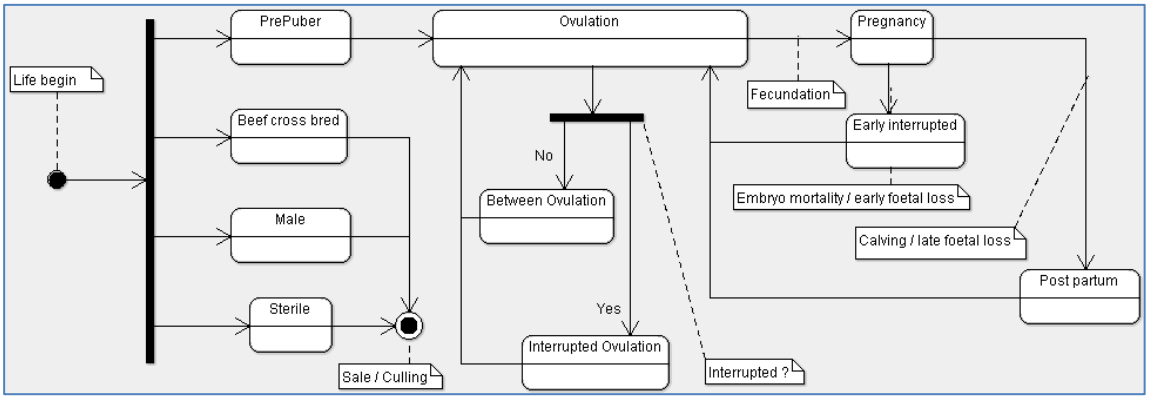


Figure 3: Reproduction stages

Calves crossed with a beef breed, male calves and sterile female calves are not kept in the herd (see paragraph *2.2.5.1.2.1 Assignment*).

2.2.1.1.1 Ovulation occurrence

Ovulation occurs at the age defined as that of puberty. They appear during cycles that can be irregular and result in estrus.

2.2.1.1.1.1 Age at puberty

The age at puberty of dairy females is between 6 and 15 months (i.e., 300 days on average), regardless of their breed (Bareille *et al.*, 2016). The fixed value used is therefore 300 days.

2.2.1.1.1.2 Estrus duration

Since dairy cow estrus lasts between 8 and 23 hours (Kerbrat et Disenhaus, 2004), the value used for the simulation was set at 1 day.

2.2.1.1.1.3 Intervals between ovulations (cyclicity)

This criterion is not breed-related (Bareille *et al.*, 2016). The values used are as follows (Hagen et Gayrard, 2005):

	Average number of days
Heifers	20 days
Cows	21 days

Table 3: Days between ovulations

The standard deviation used is one day.

These values are a base. Various events as described below may change the duration.

2.2.1.1.2 Estrus detection sensitivity

Sensitivity is the ability to detect cows that are currently in estrus (Chanvallon *et al.*, 2011).

The percentage of detection probability used includes the character that can be related to the cow's expressivity and the detection sensitivity by the farmer (Disenhaus *et al.*, 2010). It varies according to:

- the breed,
- the detection mode
- parity
- the ovulation rank
- the insemination rank (integrating lack of specificity after calving and during insemination return),

The sensitivity of estrus detection can also be influenced by lameness.

There are two categories to differentiate: detection sensitivity for first insemination, and those related to insemination return.

2.2.1.1.2.1 Estrus detection sensitivity for first insemination

The following table makes it possible to estimate estrus detection probability for first insemination.

	Detection mode	Heifers	Primiparous			Multiparous		
		All ovulations	1st ovulation	2nd ovulation	Following ovulations	1st ovulation	2nd ovulation	Following ovulations
Montbeliarde	Embedded sensor	90%	80%	82%	84%	82%	85%	88%
	Farmer	60%	50%	52%	54%	52%	54%	58%
	Robot	80%	70%	72%	74%	72%	75%	78%
	Bull (*)	100%						
Normande	Embedded sensor	90%	80%	82%	84%	82%	85%	88%
	Farmer	60%	50%	52%	54%	52%	54%	58%
	Robot	80%	70%	72%	74%	72%	75%	78%
	Bull (*)	100%						
Holstein	Embedded sensor	85%	75%	77%	79%	77%	79%	81%
	Farmer	55%	45%	47%	49%	47%	49%	51%
	Robot	75%	65%	67%	69%	67%	69%	71%
	Bull (*)	100%						

Table 4: Estrus detecting sensitivity for first insemination

(*) considered to be in the female batch

These values were estimated based on those implemented by the "ECOMAST" simulator.

Note: if the first heat is not observed within 100 days of being (re)bred (reduced delay if absence of a veterinary reproduction contract), treatment for undetected heat is given to the cow (see treatment of case "c" in *Table 17: Veterinary treatment plan under the breeding contract*).

2.2.1.1.2.2 Estrus detection sensitivity for following inseminations

Sensitivity may be different depending on insemination rank. The following table establishes the related probabilities:

	Detection mode	Heifers	Primiparous		Multiparous	
		All returns	1st return	2nd return	1st return	2nd return
Montbeliarde	Embedded sensor	90%	84%	84%	88%	88%
	Farmer	60%	64%	59%	68%	63%
	Robot	80%	74%	74%	78%	78%
	Bull (*)	100%				
Normande	Embedded sensor	90%	84%	84%	88%	88%
	Farmer	60%	64%	59%	68%	63%
	Robot	80%	74%	74%	78%	78%
	Bull (*)	100%				
Holstein	Embeddded sensor	85%	79%	79%	81%	81%
	Breede	55%	59%	54%	61%	56%
	Robot	75%	69%	69%	71%	71%
	Bull (*)	100%				

Table 5: Estrus detection sensitivity for following inseminations

(*) considered to be in the female batch

Beyond the insemination ranks in the table above, the probabilities used are those of ovulations in *Table 4: Estrus detecting sensitivity for first insemination.*

These values were estimated on the basis of those implemented by the "ECOMAST" simulator.

2.2.1.1.2.3 Additional criteria affecting estrus detection sensitivity

Detection sensitivity probabilities can be reduced / increased by coefficients taking into account additional criteria related in particular to management and accommodation conditions.

2.2.1.1.2.3.1 Slippery floors

A factor of 0.5 is applied to the detection once obtained (except for bulls). This is a management option described in paragraph *2.2.1.2.3 Slippery floor*.

2.2.1.1.2.3.2 Simultaneous estrus

Concomitant estrus facilitates their detection. The multiplicative values applied in this case are as follows:

2 estrus	+ than 2 estrus
1.3	1.4

Table 6: Multiplicative value increasing sensitivity in the case of concomitant estrus

2.2.1.1.2.3.3 Dairy production

A 50 kg / day milk production has the effect of reducing by 50% the previously estimated estrus detection probability in all signs (Disenhaus *et al.*, 2010).

The multiplicative value v applied to estrus detection probability is calculated as follows:

$$v = 1 - (\frac{\text{DMP}}{100}))$$

$$v \geq 0$$

(DMP = daily milk production)

2.2.1.1.2.3.4 Effect of lameness on estrus detection sensitivity

The sensitivity of heat detection is impaired when the cow is lamed, as described in paragraph *2.2.3.3.1.1.3.1.1 Effect of lameness on estrus detection sensitivity*.

2.2.1.1.3 Estrus detection specificity

A lack of specificity is when the farmer considers cows in estrus when they are not. This applies only to artificial inseminations (AI). Natural inseminations (mating) are not concerned.

The specificity error rates are of two kinds:

- the specificity after calving, when the last estrus day is known,
- the specificity during returns after IA when the last estrus day is unknown.

The percentages set out below reflect the probability of making this mistake when finding estrus.

2.2.1.1.3.1 Lack of specificity after calving (or after reproduction for heifers) and before first artificial insemination

Probabilities of a lack of specificity are applied for the different representative periods.

- *Heifers*

Regarding heifers, these are animals that have never been inseminated since the decision to start reproduction or since their last unsuccessful pregnancy:

Detection mode	1 to 46 days after starting reproduction	47 days and more after starting reproduction
Embedded sensor	1%	2%
Farmer	4%	5%
Robot	2%	3%

Table 7: Probability of a lack of specificity for heifers

- *Cows*

Regarding cows, it's about the ones that have not yet been inseminated since their last calving:

Detection mode	Primiparous			Multiparous		
	40-69 days after pregnancy	70-100 days after pregnancy	More than 100 days after pregnancy	40-69 days after pregnancy	70-100 days after pregnancy	More than 100 days after pregnancy
Embedded sensor	1%	2%	5%	1%	2%	5%
Farmer	4%	5%	13%	4%	5%	13%
Robot	2%	3%	6%	2%	3%	6%

Table 8: Probability of a lack of specificity for cows after calving

2.2.1.1.3.2 Lack of specificity for returns after AI

When an artificial insemination has been performed following an actual ovulation detection, and that it has been successful, a 7% probability of a lack of specifity is simulated, after IA, by a normal law based on the interval between ovulations and a standard deviation of 1.

2.2.1.1.4 Insemination and fertility

Inseminations are considered fertile if they lead to pregnancy. This result may depend on the strategy adopted in terms of inseminations and the animal's fertility.

2.2.1.1.4.1 Insemination choice

Three modes of fertilization are proposed by the simulator:

- natural mating by a bull,
- artificial insemination in conventional semen,
- artificial insemination in sexed semen (male or female).

Bulls used for inseminations are randomly selected from the catalog for this purpose according to the procedures described in paragraph *2.2.4.1.3 Genetic value of bulls for insemination (including natural)*, depending on the breed to be used and the genetic strategy chosen by the experimenter (balanced, with priority over milk quantity or functional traits).

A mating plan is proposed to divide semen types and breed crosses (see paragraph *2.2.1.2.4 Mating plans*).

When artificial insemination occurs due to a specificity lack (see paragraph *2.2.1.1.3 Estrus detection specificity*), it is non-successful because performed "at the wrong time". However, if by chance it is performed on the ovulation day, it would then be considered "at the right time" given the related success rules.

A management parameter is used to stop inseminations under certain conditions (see section *2.2.1.2.8 Individual decision of stop inseminations related to heifer* and cow infertility).

2.2.1.1.4.2 Fertility – basic values

Success (fertility) probabilities related to fertilization methods used are estimated for insemination at the right time (during simulated ovulation). They include non-fertilization and early embryonic mortality. They are based on the results of the FertilIA study conducted between 2004 and 2007 on Holstein cows (Salvetti *et al.*, 2011).

With regard to the Normande and Montbeliarde breed heifers, the FertilIA study results were weighted to take into account the differences reported during the study conducted on sexed semen use in 2014 by the IDELE (Le Mézec, 2015).

Those relating to reproduction are based on expert testimony.

The basic fertility rates of fertilization modes, which do not take into account the harmful effects of certain factors (see paragraph *2.2.1.1.4.4 Fertility modulation*), are as follows:

		Mating	Conventional artificial insemination	Sexed artificial insemination
Normande	**Heifer**	95%	85%	69%
	Adult	90%	78%	62%
Holstein	**Heifer**	95%	83%	69%
	Adult	90%	74%	62%
Montbeliarde	**Heifer**	95%	85%	73%
	Adult	90%	80%	67%

Table 9: Basic fertility rate (not taking into account the adverse effects of certain factors) according to fertilization modes

One parameter makes it possible to adjust the fertility level of the herd (see paragraph *2.2.1.2.6 Herd-specific fertility factor*).

2.2.1.1.4.3 Grouped calvings

By default, calvings are spread throughout the campaign. However, the simulator makes it possible to group the calvings of the heifers at one time of the year, according to the parameters proposed in the paragraph *2.2.1.2.5 Grouped calvings*, which will also have an influence on the constitution of the initial herd (see paragraph *2.2.5.1.1.1 Gradual herd increase*).

Insemination of heifers is postponed if calving is likely to occur during the prohibited period.

2.2.1.1.4.4 Fertility modulation

Some factors may have a negative or positive influence on cow fertility.

2.2.1.1.4.4.1 Milk production

Milk production impacts fertility. To simulate this effect, a fertility factor linked to milk production that depends on the cow's peak production is applied to influence insemination success, as follows (Meignan, 2018):

Production at peak (in kg, rule of 3 for intermediate values)	Fertility factor related to milk production
<= 27.2	1/0.95
= 36.6	1
>= 47.2	1/1.07

Table 10: Calculation of the value of the fertility factor related to milk production at peak

2.2.1.1.4.4.2 Individual potential

Individual potential is determined by the phenotypic trait "Fer", which is set up in paragraph *2.2.4.1.2 Individual genetic value*. The principle is to apply to the success probability of an insemination (even mating) the corrected performance of the phenotypic trait (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*).

2.2.1.1.4.4.3 Ketosis effect on fertility

Fertility can be disturbed when the cow undergoes ketosis, as described in the paragraph *2.2.3.2.1.1.2.1.2 Effect of ketosis on fertility*.

2.2.1.1.4.4.4 Lameness effect on fertility

Fertility can be disturbed when the cow undergoes lameness, as described in the paragraph *2.2.3.3.1.1.3.1.3 Effect of lameness on fertility*.

2.2.1.1.4.4.5 Veterinary surveillance for fertility problems

Fertility may be impaired when the cow suffers from lameness, as described in paragraph *2.2.1.1.5 Veterinary surveillance*.

2.2.1.1.5 Veterinary surveillance

When a veterinary breeding contract is in place (see paragraph *2.2.1.2.9 Breeding contract*), non-pregnant adult cows not intended for culling are examined every 15th of the month to determine the presence of any breeding problems. Three cases are determined:

a) Cows over 60 days old and not seen in heat,

b) Cows with 3 non-fertilising artificial inseminations,

c) Cows with a negative pregnancy diagnosis at 35 days after insemination (with a sensitivity defect for 3.7% of already pregnant cows).

Depending on their classification, cows receive appropriate medical treatment with the following effects:

- The reappearance of heat (cases a, b and c, systematically leading in the latter case to an interruption of gestation in the case of a sensitivity defect), which will inevitably be detected,
- The increase in fertility (case b).

Treatments are set in paragraph *2.2.1.2.9 Breeding contract*. No milk waiting period is necessary regarding these treatments.

Furthermore, as metritis and other uterine diseases were not modelled, it was decided to apply a fertility increase of 3 percentage points (adapted[1] from (Fourichon, Seegers et Malher, 2000)) to cows that were not affected by case a.

2.2.1.1.6 Pregnancy

Pregnancy is when a cow, after having undergone a successful insemination, carries an embryo. It has a basic duration, but can undergo interruptions before term. If nothing disturbs the pregnancy, the cow gives birth to one or two calves.

2.2.1.1.6.1 Late embryonic mortality and abortion

Assuming that the risk of early embryo mortality is taken into account in fertility (see paragraph *2.2.1.1.4 Insemination and fertility*), two critical pregnancy periods remain to be defined in terms of simulation: late embryonic mortality (including fetal mortality) and abortion.

Late embryon mortality occurs between the 16th and 89th pregnancy day. Pregnancy loss probability at this stage was estimated from the results of the FertilIA study on Holstein adult cows (Salvetti *et al.*, 2011). These results' application for Normande and Montbeliarde breeds is the result of cross studies of ovulation return observations by IDELE (Le Mézec, 2015) and of progesteronemia analyzes on a large sample of individuals (Humblot, 2001).

[1] The review by (Fourichon, Seegers et Malher, 2000) indicates that cows with endometritis have a 16 % point reduction in fertility. It is considered that with reproductive monitoring they are diagnosed (1 in 5 cows concerned) and treated.

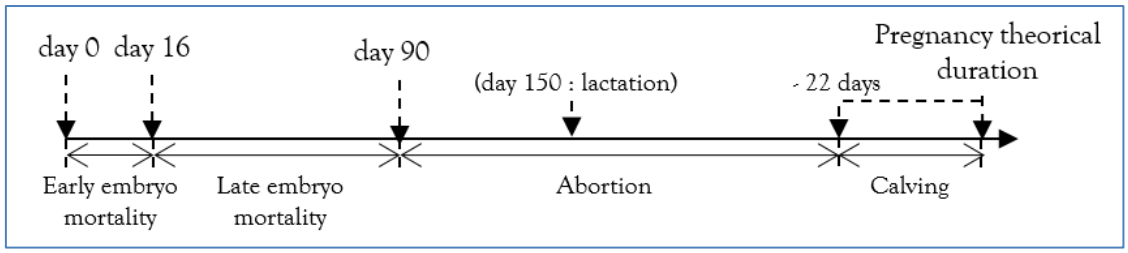


Figure 4: Periods at risk of pregnancy loss

The values used are as follows:

	Late embryonic mortality (*)
Montbeliarde	21%
Normande	23%
Holstein	21%

Table 11: Breed-specific probability of late embryonic mortality

(*) Beta-Pert distribution with 21-day peak

The late abortion period begins on the 90th day and goes until the day from which calving begins to appear according to the established distribution, that is, 22 days less than the breed's average pregnancy (see paragraph *2.2.1.1.6.2 Pregnancy duration*).

The implemented rates are based on the observation of mortality rates in the study conducted by UNCEIA (Humblot, 2001). The values used are as follows:

	Late abortion
Montbeliarde	1.6%
Normande	0.3%
Holstein	2.5%

Table 12: Late abortion probability

Depending on pregnancy stage, a lactation process may be initiated (see paragraph *2.2.2.1 Constant biological and technical values*).

2.2.1.1.6.2 Pregnancy duration

Pregnancy duration depends on the breed, parity, the sex and the number of foetuses (Bareille *et al.*, 2016).

2.2.1.1.6.2.1 Breed and parity

Nominal breed duration is determined for each cow in a stochastic manner with a standard deviation of 5 days that is applied to the following averages (Marceau *et al.*, 2014):

	Heifer average Pregnancy duration	Primiparous and multiparous cow' average pregnancy duration
Montbeliarde	286 days	287 days
Normande	285 days	286 days
Holstein	280 days	282 days

Table 13: Breed and parity-specific average Pregnancy duration

Pregnancy duration is influenced by the breed of the unborn (cross) calf however it is not taken into consideration, as well as the dam performance's repeatability, because of the low heritability of pregnancy duration...

2.2.1.1.6.2.2 Sex of the unborn calf

Regarding the unborn calf's sex, the probability of it being a female is 50% for natural insemination, 49% for conventional artificial insemination, and 93% (males) and 90% (female) for sexed artificial inseminations (Le Mézec, 2015).

When the expected calf is a male, Pregnancy duration is reduced by one day.

2.2.1.1.6.2.3 Twin pregnancy

Twin pregnancy probability is as follows:

Nulliparous	1%
Primiparous	6%
Multiparous	7%

Table 14: Twin pregnancy probability

These values are based on the 2004 observation of Holstein herds in the United States (Germain, 2009). While in reality, the cattle's twining rate depends on the breed; this factor is not integrated into the simulator.

If the calves to be born were of opposite sexes, the female would be sterile.

The simulator does not take into account the increased risk of twin pregnancies.

In reality, in case of multiple pregnancies, births occur 5 to 8.5 days in advance (Germain, 2009). Since the simulator only manages twin pregnancies, pregnancy will be reduced by 5 days.

2.2.1.1.7 Cyclicity resumption after pregnancy loss and calving

The post-parturm cyclicity recovery depends on the end of the last pregnancy: loss case or calving. It can also be affected by ketosis or lameness.

2.2.1.1.7.1 Pregnancy loss case

For cases of pregnancy loss (late embryonic mortality and abortion), the time until estrus return is proportional to the actual pregnancy duration, increasing until the 150th day of pregnancy until reaching 60 days, to gradually resume a normal cycle until the day from which calving is considered normal:

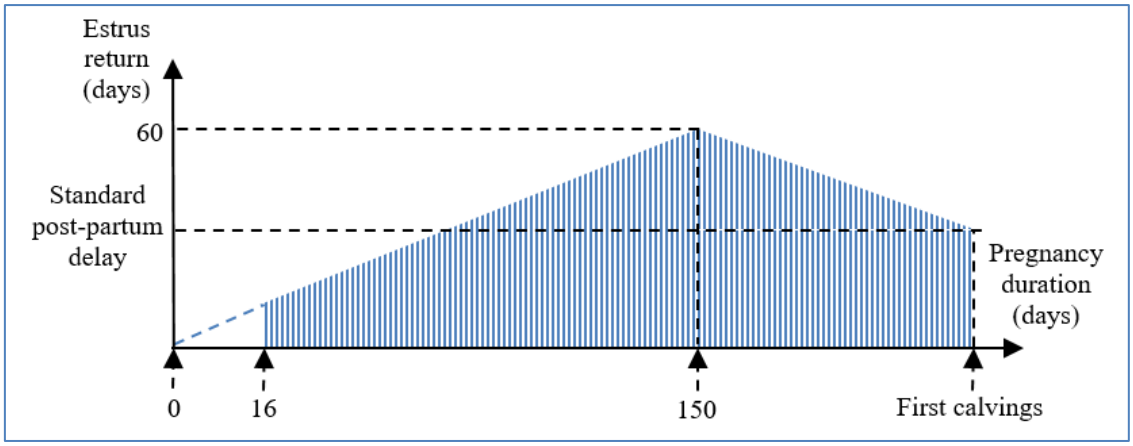


Figure 5: Delay of cyclicity resumption time after embryo or fetal mortality

The farmer chooses when to start reproduction again after a pregnancy loss (see paragraph *2.2.1.2.7 Minimum post-partum delay before breeding (waiting period)*). If a new lactation begins after pregnancy loss (pregnancy stage of at least 150 days), the delay until reproduction is the same as for calving. Otherwise, there is no latency delay.

2.2.1.1.7.2 Calving case

The recovery time of a post-calving cow cycle and the probability of a cyclical interruption are breed and parity dependent (Disenhaus *et al.*, 2008). Probability distribution is as follows:

		1st standard cycle (10 to 50 days)		1st delayed cycle (51 to 100 days)		1st cycle after 100 days (INO)
		Normal cycle	Interrupted cycle	Normal cycle	Interrupted cycle	
Montbeliarde(*)	**Primiparous**	84%	4%	11%	1%	0%
	Multiparous	87%	11%	1.4%	0.6%	0%
Normande	**Primiparous**	78%	6%	15%	1%	0%
	Multiparous	83%	15%	1.4%	0.6%	0%
Holstein	**Primiparous**	51%	19%	17%	1%	12%
	Multiparous	56%	30%	5.4%	2.6%	6%

Table 15: Post-partum cyclicity resumption by breed and parity

(*) The study used does not show the details of first-calf heifers and multiparous' cyclicity returns for the Montbeliarde breed. The values were chosen by trial and error to obtain a delay variation in setting the reproduction of Montbeliarde cows 4 days before Normande cows (Reproscope data).

The postpartum delay of ovulation of the standard and delayed cycles is distributed evenly over the period in question. When a cycle is interrupted, the second ovulation occurs until 35 days after the first one.

For the first cycle after 100 days (INO), the determined D-day of return follows this distribution:

$$D = 101 * (1+ n^2)$$

With n = uniform distribution from 0 to 1

These data are a global result. They include the distribution of the effects of the prevalence of ketosis cases as defined in the paragraph *2.2.3.2.1.1.2.1.3 Effect of ketosis on the recovery of ovarian activity* and lameness case as defined in paragraph *2.2.3.3.1.1.3.1.2 Effect of lameness on the recovery of ovarian activity*.

2.2.1.1.7.3 Treatment in case of cyclicality recovery problems

Treatment by the veterinarian can solve problems of cyclicity recovery. This is the subject of paragraph *2.2.1.1.5 Veterinary surveillance*.

2.2.1.2 Parameters for reproductive management

This paragraph describes the decision-making parameters of the farmer for aspects related to reproduction. Several options are offered to the user. Combined, they simulate different managements.

2.2.1.2.1 Breeding age

This parameter makes it possible to define the age in days at which the heifers are put to reproduction by the farmer. This results in estrus monitoring in preparation for first insemination.

The default value is 500 days.

2.2.1.2.2 Estrus detection modes

The detection mode used in the herd is configurable. The possible values are:

- embedded sensor,
- robot, with milk progesterone dosage, paid option (see table *Table 138: Default rates for miscellaneous accounting transactions)*
- farmer,
- bull, when mating.

This option will have an impact on estrus sensitivity rates (see paragraph *2.2.1.1.2 Estrus detection sensitivity*) and on lack of specificity (see paragraph *2.2.1.1.3 Estrus detection specificity*).

The default mode is detection by the embedded sensor.

2.2.1.2.3 Slippery floor

Simulation may involve accommodation conditions that could reduce estrus expression, such as a slippery floor which is a Boolean option (true or false) that will affect estrus detection rates (see paragraph *2.2.1.1.2.3.1 Slippery floors*).

By default, the option is not selected (false).

2.2.1.2.4 Mating plans

It is possible to set the choice of insemination type and breed according to AI rank and cow parity, as well as the proportion to be applied, by implementing a Bernoulli law. The complement of this proportion causes a conventional artificial insemination (not sexed) of the designated breed of the herd (see paragraph *2.2.5.2.1.1 Initial cow breed*).

The default values are:

	First insemination		**2 and 3 insemination**		**4 and more insemination**	
	Insemination type	**Breed**	**Insemination type**	**Breed**	**Insemination type**	**Breed**
Heifers	100% Female sexed artificial	100% Holstein	100% Conventional artificial	100% Holstein	100% Conventional artificial	100% Limousine
Primiparous and multiparous	100% Conventional artificial	100% Holstein	100% Conventional artificial	100% Holstein	100% Conventional artificial	100% Charolaise

Table 16: Default values for mating plans

2.2.1.2.5 Grouped calvings

The grouping of heifer calvings is possible by excluding a period from the campaign. The setting consists of indicating the first month of the exclusion of calvings as well as the last. The calvings will be spread over the remaining period of the campaign. By default, no calving period is excluded for heifers.

This setting also determines the way in which the herd is built up, see paragraph *2.2.5.1.1.1 Gradual herd increase.*

2.2.1.2.6 Herd-specific fertility factor

A multiplicative value can improve fertility (value greater than 1.0) or reduce it (value less than 1.0). This option will affect the success rates of inseminations (see paragraph *2.2.1.1.4 Insemination and fertility*). Reproduction factors that influence fertility which are not explicitly represented are therefore taken into consideration.

The default value is 1.0.

2.2.1.2.7 Minimum post-partum delay before breeding (waiting period)

This parameter makes it possible to define the delay to be respected before post-calving reproduction (pregnancy end having led to a lactation).

Besides, this parameter makes it possible to apply a strategy to extend lactations.

The default value is 55 days.

2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility

The time limits described in this paragraph make it possible to determine whether, under certain conditions, it is no longer considered necessary to carry out inseminations. When an animal fulfils these conditions, it is considered infertile and therefore generally culled (see paragraph *2.2.5.1.1.2.2 Heifer sales and adult cow*).

The evaluated period's beginning is the date of the reproduction decision for both heifers and cows.

Estrus detection absence

This parameter is used to define the delay after which the first insemination will no longer be attempted because no estrus has been detected since breeding start. The default values are 150 days for heifers and 190 days for cows.

Lack of fertility

This parameter makes it possible to define the delay after which the inseminations will be stopped because none has been successful since the cow has been set (back) to breeding. The default values are 200 days for heifers and 260 days for cows.

2.2.1.2.9 Breeding contract

A management option allows the reproduction aspects to be contracted with a veterinarian (see *Table 166: Keys and formats for farm management parameters*). This fee-based option is invoiced at the beginning of the campaign at the herd level, and is calculated by multiplying the accounting cost for one animal with the average number of cows present (see paragraph *2.2.7.1.1 Reproduction*).

This contract makes it possible to reduce the costs linked to reproduction and to carry out treatments according to the reproduction problems encountered (see § *2.2.1.1.5 Veterinary surveillance*). These treatments can be configured, and are defined by default in the following way:

Case	**Calved cow not seen in heat** (see paragraph 2.2.1.1.5 a)	**Artificial inseminations without fertilisation** (see paragraph 2.2.1.1.5 b)	**Negative pregnancy diagnosis** (see paragraph 2.2.1.1.5 c)
Type	ENZAPROST® T	RECEPTAL® (2 ml)	ENZAPROST® T
Obtained effect	Return in heat (100%)	New estrus (100%) and specific 6 percent points increase in fertility on the AI	Return in heat with embryo loose on sensibility defect (100%)
Time to effect	3 days	Immediate (at insemination)	3 days
Referency	RCP*	(Besbaci *et al.*, 2020) and (Morgan et Lean, 1993)	RCP*

Table 17: Veterinary treatment plan under the breeding contract

* Summary of Product Characteristics (RCP): http://www.ircp.anmv.anses.fr/rcp.aspx?NomMedicament=ENZAPROST+T

The cost of these treatment is set in paragraph *2.2.7.1.1 Reproduction*.

2.2.1.3 Data produced

Data are produced based on calving data, insemination data and technical reproduction data.

2.2.1.3.1 Calving-based reproductive performance

By convention, a calving is considered to be the birth of one or two calves born at term. Cases of embryonic mortality or abortion (see paragraph *2.2.1.1.6.1 Late embryonic mortality and abortion*) are therefore not considered calving. These data are generated only in the 'full results' version of the simulator.

2.2.1.3.1.1 Primiparous

Result file name: « PrimipareReproductionResultsBasedOnCalving.csv »

Production type: one-off

Information level: cow

This data is produced during a primiparous cow calving.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Successful_calving_date	Date (*)	Successful calving date
First_insemination_age	integer	Age at the first insemination
Successful_insemination_age	integer	Age at the first successful insemination
Calving_age	integer	Age at the caving
First_insemination_date	Date (*)	First insemination date
First_insemination_type	Insemination type (*)	First insemination type
First_insemination_bull_breed	Breed (*)	First insemination bull breed
Insemination_quantity	integer	Number of inseminations performed
Successful_insemination_date	Date (*)	Successful insemination date
Successful_Insemination_quantity	integer	Successful insemination number
Successful_insemination_type	Insemination type (*)	Successful insemination type
Successful_insemination_bull_breed	Breed (*)	Successful insemination bull breed
First_insemination_successful_insemination_interval	integer	Number of days between the first and the successful insemination
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 18: Structure of calving-based reproductive performance data for primiparous cows

(*) See *Table 2: Type data formats* page *15*.

2.2.1.3.1.2 Multiparous

Production type: one-off

Information level: cow

Result name: « MultipareReproductionResultsBasedOnCalving »

This data is produced during a multiparous cow calving

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Successful_calving_date	Date (*)	Successful calving date
Previous_calving_date	Date (*)	Previous calving dates
Previous_successful_calving_interval	integer	Number of days between the successful calving and the previous one
Previous_calving_rank	integer	Rank of the previous calving
First_insemination_date	Date (*)	First insemination date
First_insemination_type	Insemination type (*)	First insemination type
First_insemination_bull_breed	Breed (*)	First insemination bull breed
Previous_calving_first_insemination_interval	integer	Number of days between the previous calving and the first insemination
Insemination_quantity	integer	Number of inseminations performed
Successful_insemination_date	Date (*)	Successful insemination date
Successful_Insemination_quantity	integer	Successful insemination number
Successful_insemination_type	Insemination type (*)	Successful insemination type
Successful_insemination_bull_breed	Breed (*)	Successful insemination bull breed
Previous_calving_successful_insemination_interval	integer	Number of days between the previous calving and the first insemination
First_insemination_successful_insemination_interval	integer	Number of days between the first and the successful insemination
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 19: Structure of calving-based reproductive performance data for multiparous cows

(*) See *Table 2: Type data formats* page *15*.

2.2.1.3.2 Insemination-based reproductive performance

These data are generated only in the 'full results' version of the simulator.

2.2.1.3.2.1 Nulliparous

Result name: « NullipareReproductionResultsBasedOnInsemination »

Production type: one-off

Information level: cow.

This data is produced when a heifer calves.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
First_insemination_age	integer	Age at the first insemination
First_insemination_date	Date (*)	First insemination date
Insemination_date	Date (*)	Insemination date
Insemination_type	Insemination type (*)	Insemination type
Insemination_bull_breed	Breed (*)	Insemination bull breed
Insemination_number	integer	Number of inseminations performed
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 20: Structure of insemination-based reproductive performance data for nulliparous cows

(*) See *Table 2: Type data formats* page *15*.

2.2.1.3.2.2 *Primiparous and multiparous*

Result file name: « PrimiMultipareReproductionResultsBasedOnInsemination.csv »

Production type: one-off

Information level: cow

This data is produced during a primiparous or a multiparous cow insemination.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Previous_calving_date	Date (*)	Previous calving date
Previous_calving_rank	integer	Previous calving rank
First_insemination_date	Date (*)	First insemination date
Insemination_date	Date (*)	Insemination date
Insemination_type	Insemination type (*)	Insemination type
Insemination_bull_breed	Breed (*)	Insemination bull breed
Previous_calving_first_insemination_interval	integer	Number of days between the previous calving and the first insemination
Insemination_number	integer	Number of inseminations performed
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 21: Structure of insemination-based reproductive performance data for primiparous and multiparous cows

(*) See *Table 2: Type data formats* page *15*.

2.2.1.3.3 Technical reproduction data

This data is generated automatically, regardless of the version of the simulator.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Type of production: annual.

Information level: Herd.

This data represents the annual technical balance sheet related to breeding activities.

The available fields are the following:

Field name	Format	Value
IV_IA1	real	Herd average of calving-1st AI intervals
TRIA1	real	Herd average of percentage of successful 1st AI
IVIAF	real	Herd average of calving-fertile AI intervals
IVV	real	Herd average of calving intervals
First_calving_age	real	Age average at first calving
IA1_count	integer	Number of first AIs
IA_count	integer	Number of AIs
Reproduction_treatment_count	integer	Number of vet treatments for reproductive problems
Reproduction_treatment_per_100_cows	real	Number of vet treatments for reproductive problems per 100 cows in the herd
Reproduction_culling_per_100_cows	real	Number of culls for reproductive problems per 100 cows in the herd

Table 22: Structure of the data on technical results related to reproduction

2.2.2 Lactation

The lactation module integrates all the aspects implemented to simulate female milk production. While this phenomenon is strongly dependent on biological constraints, it is however led by the farmer.

2.2.2.1 Constant biological and technical values

The internal parameters used for lactation simulations relate to milk production in terms of duration, quantity and composition, depending on different biological and technical factors.

The simulator differentiates cows' lactation stages as follows:

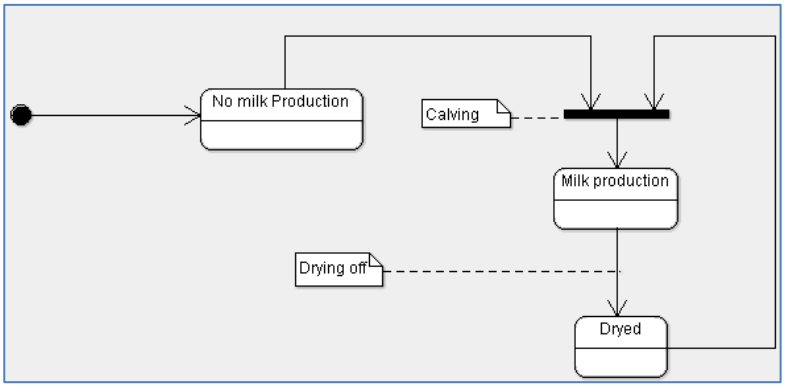


Figure 6: Lactation initiation and end steps

By convention, a lactation is considered as such when the female gives birth at the end of a pregnancy of at least 150 days, whatever the viability of new-born calf (calves).

Regarding the liter representation of milk production expressed in kg, the following coefficient is applied (Bareille *et al.*, 2017):

1 liter = 1.033 kg

Lactation duration is decided by the farmer who schedules the drying-off date. Like the quantity produced and the composition, the duration of the lactation can vary.

2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination

The quantity of milk produced and its composition varies according to the breed, as the daily production depends on the lactation stage (Bareille *et al.*, 2017). Lactation duration is set up by the farmer.

2.2.2.1.1.1 Breed impact on cumulated milk production

Milk quantity and composition depends on the cow's breed, and to a lesser extent on its genetic make-up (discussed in paragraph *2.2.4.1.1 Genetic values associated with phenotypic traits*, describing the basic performances of the gross production).

2.2.2.1.1.2 Daily production by lactation stage

Daily dairy production (DDP) is not constant over time, it depends on the lactations stage. Moreover, unlike milk quality, which is represented firstly by the fat content (FC) and secondly by the protein content (PC), the produced quantity is also linked to the parity of the cow (1st lactation, 2nd lactation and following lactations). The shape of the curves does not depend on breed, but on parity. This was demonstrated in a retrospective observational study conducted on French dairy herd data enrolled in the official Milk Recording Scheme covering the period January 2008 to December 2015. The shape of the lactation curves of non-pregnant Prim'holstein cows observed in these data for the different parities allowed modelling up to day 800 of lactation. However, production levels are differentiated by breed as modelled in paragraph *2.2.4.1.1.2 Criteria of genetic values associated with breed-dependent phenotypic traits* and modulated as described in paragraph *2.2.2.1.2 Milk production modulation*.

Thus, for each breed and to take account of parity, five curves are applied to distribute the DDP on a daily basis throughout a 305-day reference lactation. The curves obtained for DDP are as follows:

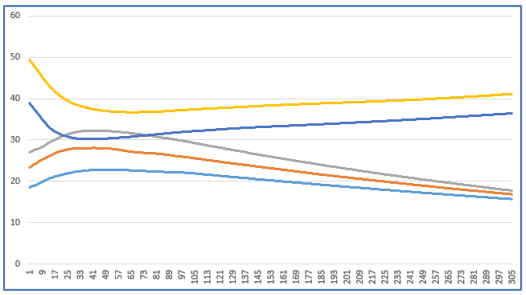


Figure 7: Daily dairy production curve for the Montbeliarde breed

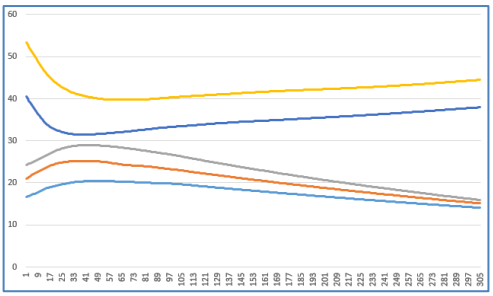
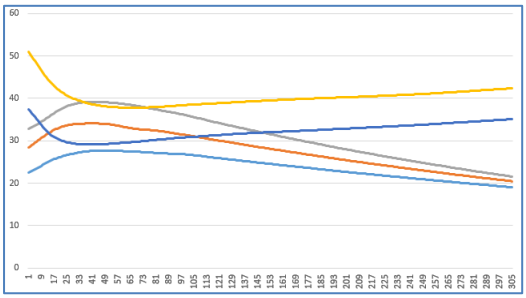


Figure 8: Daily dairy production curve for the Normande breed



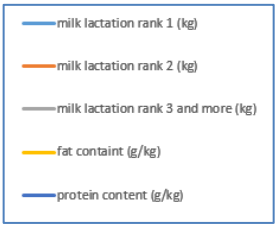


Figure 9: Daily dairy production curve for the Holstein breed

The non-pregnant effect is described in paragraph *2.2.2.1.2.3 Pregnancy*.

2.2.2.1.1.3 Milk somatic cell count in absence of infection

The level of milk somatic cell in absence of infection is dependent on the rank and stage of lactation, but not on the breed of the cow. It is accepted that the shape of the curve representing the variation due to the stage of lactation is that observed for the first lactation of non-pregnant Prim'holstein cows taken from the same data as those used for the milk curves (see previous paragraph), only the levels differ according to the lactation rank as follows:

Parity	1	2	3 and +
Mean level (1000 cell / ml)	43.3	67.7	84.7

Table 23: Basis levels of somatic milk cell count in mammary infection absence depending on the parity

Thus, the Somatic Cell count (SCC) of the milk in the absence of infection, expressed in number of 1000 cells / ml of milk, will respect the following curves:

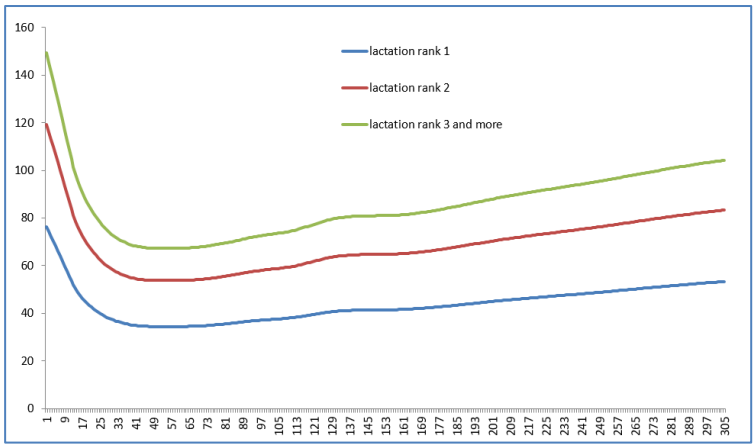


Figure 10: SCC wood curves of the udder in mammary infection absence

The inter-day-to-day variability of SCC (excluding mastitis) is defined by hazard in paragraph *2.2.2.1.2.14 Daily hazard*.

2.2.2.1.1.4 Basic lactation duration – drying-off programming

The theoretical lactation duration is decided by the farmer (drying-off). This allows him to consider the dry period he wants as part of his farm management. This duration is configurable (see paragraph *2.2.2.2.1 Drying-off*).

For this purpose, if a lactation is to be in progress, the drying-off date is programmed as soon as an insemination has been determined as successful and therefore a pregnancy begins. Calculation is done as follows:

$$Tp = Ir + Pg - Ps$$

with

Tp = planned day for drying-off

Ir = day of the successful insemination

Pg = expected duration according to the pregnancy's breed and parity

Ps = duration set up for the Dry Period.

The "farmer" estimate of Pregnancy duration is based on the average pregnancy duration based on breed and parity (see paragraph *2.2.1.1.6.2.1 Breed and parity*). It does not take into account other biological factors.

Drying-off is deprogrammed in case of embryonic mortality or abortion.

When a drying-off date has been programmed, the milk production is stopped on the planned day. In the opposite case (e.g. if the cow is destined for culling and therefore has not been bred), the production is automatically stopped as soon as the milk product level is lower than the one set (see paragraph *2.2.2.2.1 Drying-off*).

2.2.2.1.1.5 Milk destination

The production of the first days of lactation is not considered consumable (marketable) because it is colostrum (Bareille *et al.*, 2017). It will not be delivered to the dairy, but is considered as discarded milk. The simulator is used to set the time length during which this milk will be discarded by the farmer (see paragraph *2.2.2.2.3 Minimum lactation stage for delivered milk*).

The milk to be delivered produced daily is stored in the tank and is collected every three calendar days. This milk is analysed at the cooperative three times a month to determine the average SCC. The dates of these controls are not known by the farmers, the simulator carries them out on the 5th, 15th and 25th of the month, and the results are communicated the next day. Depending on the measured SCC (i.e. from the first test) and the SCC ceiling that he decides not to exceed, the farmer discards the milk that penalises him the

most, i.e. the milk from the quarter of the cow with the highest SCC since the last two milk tests (thus assuming that the milk test is not a simulation option, but a systematic subscriber).

Depending on the average SCC of the three milk checks carried out during the month, penalties are applied to the price paid for the milk delivered by the farmer, by instalments:

- above 250 (000/ml)
- above 300 (000/ml)
- above 400 (000/ml)

The amount of the penalties can be configured, see chapter *2.2.7.1.2 Production*.

2.2.2.1.2 Milk production modulation

"Real" milk production is a modulation of the theoretical production due to the circumstances described below.

2.2.2.1.2.1 Parity

Milk production MP increases with parity (Bareille *et al.*, 2017). For this purpose, the simulator uses a divisor factor of MP at adult stage, the values of which are established as follows (Institut de l'élevage, 2023):

Parity	Value of the divisor
1	1.3
2	1.12
3	1.03
4+ (adult)	1.0

Table 24: Divisor value of the milk quantity produced during adulthood according to parity

Durations remain the same, but a very slight decrease in PC with age (-0.2g / kg between the 1st and 4th lactation) is taken into account.

2.2.2.1.2.2 Drying-off

The dry period starts from the drying day (milking's end) and ends when the next lactation begins. Its reference duration is a decision of the farmer, but it can be modulated according to unpredictable biological events (abortions, variability of the pregnancy duration, ...).

The duration of the dry season influences the coming production. Indeed, the elimination of drying-off has the effect of reducing the quantity of milk produced by 15%, and a dry period of 30 days by 7%.

The principle adopted to simulate this effect is the application of a multiplicative value whose calculation is based on a proportionality implementing the actual dry period's duration (taking into account biological events) and the foreseeable decrease in quantity:

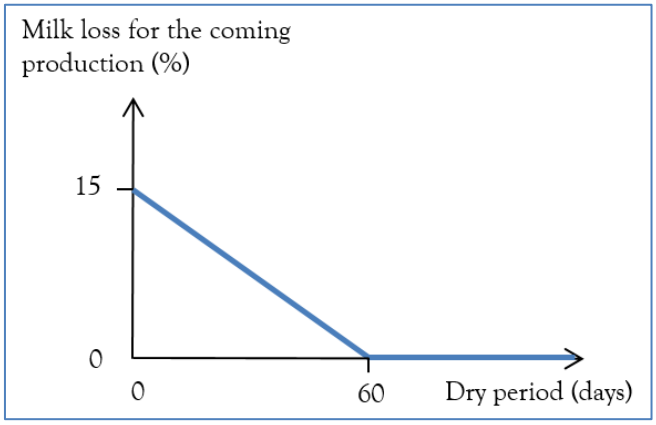


Figure 11: Effect of the decreased milk production due to reduced dry period at the next lactation

Thus the proportional multiplicative value v is calculated using the formula:

$$v = 1 - \frac{\mathrm{dp} * \left(\frac{-15}{60}\right) + 15}{100}$$

$$with \quad 0.85 \leq v \leq 1$$

dp = actual duration of the dry period.

Regarding FC and PC, according to the Breton Survey (Kerouanton et al., 1995, Designé 1966), the benefits obtained due to the omission of the previous lactation's dry period are as follows (Rémond, Kérouanton et Brocard, 1997):

Lactation	FC gain (g/kg)	PC gain (g/kg)
2nd	2.9	3.0
3rd and more	0.4	1.1

Table 25: Gain in FC and PC due to the omission of the drying up of the previous lactation

According to the same scheme as for milk production, the proportionate additive value v is calculated for FC and PC using the following formula:

$$v = g\ x\ \frac{60 - dp}{60}$$

$$with \quad v \geq 0$$

g = basic gain

dp = actual duration of the dry period

The lactation curve's shape is little or no modified by the absence of dryness (Rémond, Kérouanton et Brocard, 1997), it is not modified in the simulation.

2.2.2.1.2.3 Pregnancy

The theoretical production curves (see paragraph *2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination*) are based on the assumption that cows are not pregnant. In case of pregnancy, the following values are minored from the quantity produced (Billon, 2015):

Lactation stage	Minored value
From 242 days	1 kg
From 272 days	2 kg
From 303 days	2,5 kg

Table 26: Minored value of milk production of a cow that is pregnant according to its lactation stage

FC and PC are not changed.

2.2.2.1.2.4 Individual potential

Individual potential in adult stage (lactation 4) depends on the genetic value of the individual. It is determined in the simulation for the following phenotypic traits:

- MILK : Quantity milk (in kg)
- FC : fact content (in g/kg)
- PC : protein content (in g/kg)

These values' determination is explained in the genetic module (see paragraph *2.2.4 Genetics*).

2.2.2.1.2.5 Estrus

Milk production decreases the day the cow is in estrus from 5 to 10% (Bareille *et al.*, 2017). Therefore, the simulator uses a multiplicative value of 0.925, which affects the quantity of milk produced and corresponds to a 7.5% drop.

FC and PC do not undergo any Movements during estrus.

2.2.2.1.2.6 *Photoperiod*

The photoperiod (associated with the season) has a specific effect on the daily milk production of the cow (Coulon, Chilliard et Rémond, 1991). This additive effect is represented by the following curve (Bareille *et al.*, 2017):

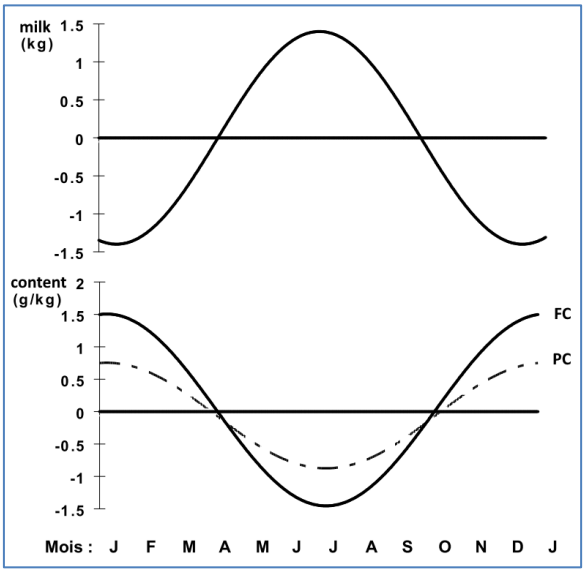


Figure 12: Specific effect of the month on the dairy production of the cow

Thus, the equation used to determine the multiplicative value v of the performance p to add to the milk production of the day (PLJ) is as follows:

$$v = p * \cos(\frac{2\pi * < day\ of\ the\ year >}{< number\ of\ days\ in\ the\ year >})$$

With as criterion value p:

p Value	Factor
Dairy production (kg)	-1.5
FC (g/kg)	1.5
PC (g/kg)	0.75

Table 27: Performance-specific seasonal multiplier factor

The photoperiod effect thus calculated is applicable to a herd located at the average latitude of metropolitan France.

2.2.2.1.2.7 *Milking frequency*

Milking frequency is usually set at twice a day. Reducing this frequency to one time leads to a 25% drop in production, with a 2.7g / kg increase in FC and a 2.2g / kg increase in PC (Rémond, Pomiès et Pradel, 2005). However, a milking carried out 3 to 4 times a day results in an increase of approximately 15%, without impacting the rates (Bareille *et al.*, 2017) nor of the SCC.

Milking frequency can be parameterized (see paragraph *2.2.2.2.2 Milking frequency*).

2.2.2.1.2.8 *Somatic cell count*

Beyond 50,000 cells / ml of milk, SCC causes a decrease in milk production depending on parity and lactation stage. This effect following the presence of mastitis is taken into account by the simulator by applying the following equations (Hortet *et al.*, 1999):

$$RMY(X) = (a * DIM^2 + b * DIM + c) * \log n(\frac{X}{50})$$

With

RMY = decrease in the milk production (kg)

χ = SCC value studied (1000 cells/ml)

DIM = lactation stage

and for each parity:

Parity	a	b	c
1	0	0	0.44
2	0.00002	-0.0019	0.5006
3+	0.00001	0.0015	0.3341

Table 28: Parameters specific to each parity for the equation of milk quantity reduction related to milk SCC

2.2.2.1.2.9 Mastitis effect on dairy production

Mastitis can occur from the beginning of the first lactation until the culling (or death) of the cow. Depending on its severity, this disease can modify milk production, both in quantity and in composition. These situations are described in paragraph *2.2.3.1.1.1.3 IMI consequences*.

2.2.2.1.2.10 Ketosis effect on dairy production

When ketosis occurs, it alters milk production, both in quantity and composition. This situation is described in the paragraph *2.2.3.2.1.1.2.2 Impact of ketosis on milk production performance*.

2.2.2.1.2.11 Lameness effect on dairy production

When ketosis occurs, it alters milk production, both in quantity and composition. This situation is described in the paragraph *2.2.3.3.1.1.3.2 Impact of lameness on milk production performance*.

2.2.2.1.2.12 Quarter loss

When one quarter of the udder is dry (for example following a severe case of mastitis, see paragraph *2.2.3.1.1.1.3.2 Important decrease in milk production*), the udder production is reduced by 20% (ECOMAST), which amounts to slightly increase the theoretical quantity of milk produced by each of the healthy quarters of the udder, according a *F* factor defined as following:

$$F = 1 + \frac{\left(\frac{1}{4} - 0.2\right)}{3} \cong +1.0167$$

2.2.2.1.2.13 Feeding

In this chapter milk production is calculated on the basis that the cow is fed in a balanced way. During production peak, it may be necessary to give some concentrate in addition. This method is detailed in paragraph *2.2.6.2.2 Production concentrate diets*.

2.2.2.1.2.14 Daily hazard

A hazard is applied to the daily milk production. This hazard meets the following character:

Criterion	Distribution
Quantity	Uniform (+ or – 2kg)
FC	N (0 ; 1.25)
PC	N (0 ; 0.5)
SCC	N (0 ; 0.1)

Table 29: Daily hazard on milk performance

2.2.2.2 Parameters for lactating farmer management

Different parameters allow the user to define the management rules related to lactation.

2.2.2.2.1 Drying-off

The simulator offers to the user to decide the drying period duration (see paragraph *2.2.2.1.1.4 Basic lactation duration – drying-off programming*). By default, this duration is set to 60 days.

2.2.2.2.2 Milking frequency

The simulator offers different daily milking frequencies:

- once a day,
- twice a day (default value),
- above twice a day,

This option may affect the amount of milk produced (see paragraph *2.2.2.1.2.7 Milking frequency*).

2.2.2.2.3 Minimum lactation stage for delivered milk

A legal lactation stage must be respected before the milk is considered marketable (see paragraph *2.2.2.1.1.5 Milk destination*). The default value applied by the simulator is a six-day delay. However, the experimenter has the possibility to set this value to decide on a different number.

2.2.2.2.4 Herd production level

The simulator makes it possible to vary the production level of the herd with respect to the average of the herds of the same breed. For each milk characteristic (quantity, TB and TP), a value expressed in kg for quantity and in g/kg for TB and TP will be added to the animal's 305 days production according to the desired adjustment of the production level of the simulated herd. The default value is 0.

2.2.2.3 Data produced

The data produced concern milk deliveries, side locks, monthly test-day results and technical production data.

2.2.2.3.1 Milk delivery to a dairy

This data is generated only in the 'full results' version of the simulator.

Result name: « DeliveredMilk »

Production type: monthly.

Information level: Herd.

This data represents the monthly assessment of milk production (sum of the daily dairy production) for the herd. This production is reduced by calves' milk consumption, if this option is to be chosen (see paragraph *2.2.6.2.1.1 Unweaned calf* feeding).

The available fields are:

Field name	Format	Value
Date	Date (*)	Monthly test-day date
Liter_quantity	real	Monthly delivered milk quantity (liters)
Liter_TB	real	Monthly average FC in milk (g/l)
Liter_TP	real	Monthly average PC in milk (g/l)
SCC (**)	real	Monthly average SCC in milk (1000/ml)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 30: Data structure of monthly results of delivered milk

(*) See *Table 2: Type data formats* page *15*.

(**) Obtaining the SCC value is detailed in paragraph *2.2.3.1.1.1.3.1 Increase in somatic cell count*.

2.2.2.3.2 Spread and discarded milk

This data is generated only in the 'full results' version of the simulator.

Result name: « DiscardedMilk »

Production type: monthly.

Information level: Herd.

This data represents the monthly assessment of discarded milk (sum of the daily quantities of milk actually discarded) for the herd. This result takes into account the possible consumption of discarded milk by calves, if this option is to be chosen (see paragraph *2.2.6.2.1.1 Unweaned calf feeding*).

The available fields are:

Field name	Format	Value
Date	Date (*)	Monthly-test day date
Liter_quantity	real	Quantity of milk discarded in the month (liters)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 31: Data structure of monthly results of discarded milk

(*) See *Table 2: Type data formats* page *15*.

2.2.2.3.3 Performance estimation by monthly test-day

This data is generated automatically, regardless of the version of the simulator.

Result name: « MilkControlResults »

Production type: monthly.

Production level: Simulation (merging of the result of all protocols and runs)

Information level: Herd.

This data represents the result of the milk controls, which is not an option but is systematically implemented by the simulator on the 15th of each month (10 cl collected on controlled cow produced milk). Although considered present in the herd, cows that have not reached the minimum stage of lactation for the milk delivered are not considered to be lactating and therefore their milk is not checked (see paragraph *2.2.2.2.3 Minimum lactation stage for delivered milk*).

The available fields are:

Field name	Format	Value
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	
Date	Date (***)	Monthly test-day date
Herd_cow_count	integer	Number of cows in the herd
Milking_cow_count	integer	Number of milking cows in the herd
Average_milk_quantity_cow	real	Average milk quantity per milking cows (checked) the monthly test-day (kg)
Average_lactation_stage	integer	Average lactation stage of the cows that aren't dried up (days)
Average_FC	real	Average milk FC of the day (g/kg)
Average_PC	real	Average milk PC of the day (g/kg)
Average_SCC (*)	real	Average SCC of the day (1000 cellules/ml)
SCC_300_prevalence	real	Ratio of milking cows whose SCC exceeds 300 000 c / ml on the monthly test-day
SCC_300_incidence	real	Incidence ratio for SCC threshold at 300 000 c / ml (**)
Detected_infectious_lameness_percent	real	Percentage of controlled cows with infectious lameness detected
Infectious_G1_lameness_percent	real	Percentage of controlled cows with G1 infectious lameness
Infectious_G2_lameness_percent	real	Percentage of controlled cows with G2 infectious lameness
Detected_non_infectious_lameness_percent	real	Percentage of controlled cows with non-infectious lameness detected
Non_infectious_G1_lameness_percent	real	Percentage of controlled cows with G1 non-infectious lameness
Non_infectious_G2_lameness_percent	real	Percentage of controlled cows with G2 non-infectious lameness

Table 32: Data structure of monthly test-day results

(*) SCC represents milk aspect. This concept is detailed in paragraph *2.2.3.1.1.1.3.1 Increase in somatic cell count*.

(**) The incidence ratio is obtained by calculation BH / (BB + BH), with BH the number of milking cows whose milk SCC produced the previous month was less than 300 000 c / ml and whose SCC exceeded 300 000 c / ml on the monthly test-day, and BB that of milking cows whose milk SCC produced the previous month was less than 300 000 c / ml and who remained with an SCC less than 300 000 c / ml on the monthly test-day.

(***) See *Table 2: Type data formats* page *15*.

2.2.2.3.4 Technical production data

This data is generated automatically, regardless of the version of the simulator.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Production type: annual.

Information level: Herd.

This data represents the annual technical balance sheet related to production activities.

The available fields are:

Field name	Format	Value
Delivered_milk_liter_quantity	real	Total quantity of milk delivered during the campaign (litres)
Delivered_milk_liter_quantity_by_cow	real	Total quantity of milk delivered during the campaign / Average number of cows present (litres)
Produced_milk_liter_quantity_by_cow	real	Total quantity of milk produced during the campaign / Average number of cows present (litres)
SCC	real	Average tank milk cell count over the campaign (1000 cells/ml)
TB_liter	real	Tank milk TB level over the campaign (g/litre)
TP_liter	real	Tank milk TP level over the campaign (g/litre)

Table 33: Structure of data on technical production results

2.2.3 Health

This module deals with production diseases that can have an economic impact, both in terms of production loss and in terms of health costs related to their treatment.

The diseases that are implemented by the simulator and described in this chapter are mastitis (i.e. intra-mammary Infections), ketosis and lameness.

2.2.3.1 Intramammary infection (IMI)

In the lactation phase, somatic cells are naturally present in the milk produced, at a limited concentration even if there is no infection. IMIs are infections caused by the proliferation of different types of bacterium. They impact the immune defence system of the cow, so significantly increasing the concentration of these somatic cells in the milk. They can appear in the four quarters of the udder. These IMIs have consequences on the quantity and the quality of the produced milk cows and on their reproduction. These consequences can go as far as cullinging the cow. Depending on their severity, IMIs may require treatment for recovery.

2.2.3.1.1 Constant biological and technical values for IMI

2.2.3.1.1.1 IMI description

The chapter's purpose is to describe the different types of mastitis, their severity level, their relation to the lactation stage, and their impact on milk production and animal health.

2.2.3.1.1.1.1 IMI types

The IMIs implemented by the simulator are of five different types, which makes it possible to take into account the diversity of the current epidemiological-clinical entities:

Bacterium name	Short name
Staphylococcus aureus	StaphA
Streptococcus uberis	StreptU
Gram Negative bacterium	G-
Coagulase Negative Staphylococcus	CNS
Corynebacterium bovis	CB

Table 34: Bacterium responsible for IMI

2.2.3.1.1.1.2 IMI severity levels

When it occurs, each IMI can begin as subclinical or clinical mastitis, varying in different severity levels, and with various frequencies.

2.2.3.1.1.1.2.1 Definition of IMI severity levels

Severity levels were defined as follows:

Name	Definition
G0	Subclinal IMI
G1	IMI with slight milk modification (clinical)
G2	Local IMI (clinical)
G3	Systemic IMI (clinical)

Table 35: IMI severity levels

2.2.3.1.1.1.2.2 Severity levels by IMI type and by lactation stage/cow pregnancy stage at infection time

Three degrees of severity can be differentiated according to the stage and lactation number of the cow (Robert-Briand, 2006). In the simulator, they are distributed as follows:

Lactation stage (*)	Lactation number		
	Primiparous	2 lactations	3 lactations et +
Peri-partum and early lactation	increased	increased	increased
Lactation	basic	basic	increased
Dry period	decreased	increased	increased

Table 36: Modulation in IMI severity by lactation stage and rank

(*) the duration of the periods is defined in paragraph 2.2.3.1.1.2.1 Periods at risk page 46.

Thus, when the cow is infected, the IMI initial severity (possibly increased or decreased) of the IMI is evaluated as follows (Ecomast):

IMI type	Risk level (%) basic (decreased- increased)			
	G0	G1	G2	G3
StaphA	85 (87 – 86)	9 (7 – 3)	5 (4 – 7)	1 (2 – 4)
StreptU	45 (45 – 25)	25 (30 – 13)	23 (23 – 49)	7 (1 – 13)
G-	15 (10 – 15)	33 (38 – 20.5)	36 (41 – 23.5)	16 (6 – 41)
CNS	90 (90 – 90)	5 (7 – 4)	5 (3 – 5.5)	0 (0 – 0.5)
CB	98 (98 – 98)	1.5 (1.8 – 1.3)	0.3 (0.2 – 0.4)	0.2 (0 – 0.3)

Table 37: Risk levels according to IMI type and severity

2.2.3.1.1.1.3 IMI consequences

Depending on their type, IMI can have consequences on the production as well as on the cow's health condition.

2.2.3.1.1.1.3.1 Increase in somatic cell count

IMI occurrence increases the concentration of somatic cells, so the SCC evolves in the following way (ECOMAST):

IMI type	Severity	Decreased SCC (1000/ml)	Increased SCC (1000/ml)
StaphA	G0	1320	3800
	G1	1000	27000
	G2	7700	47500
	G3	27000	55000
StreptU	G0	2760	6160
	G1	2000	26000
	G2	7500	47500
	G3	26000	55000
G-	G0	2430	6700
	G1	2500	26000
	G2	7500	47500
	G3	26000	55000
CNS	G0	530	2080
	G1	700	27000
	G2	7500	47500
	G3	27000	55000
CB	G0	310	1980
	G1	500	20000
	G2	6000	34000
	G3	20000	40000

Table 38: IMI occurrence impact on quarter SCC

This variability is implemented by the daily application of a Beta-pert law delimited by the lowest and highest values thus determined and shifted to the left, possibly cumulative if several mastitis (thus of different bacterium) simultaneously were to occur in the same quarter.

According to the SCC resulting from the IMI, the quarter milk can be dismissed by the farmer. The strategy implemented under these circumstances is detailed in paragraph *2.2.2.1.1.5 Milk destination*.

2.2.3.1.1.1.3.2 Important decrease in milk production

The quantity of milk produced naturally reduces with the increase in somatic cell count (see paragraph *2.2.2.1.2.8 Somatic cell count*). With regard to clinical mastitis, milk production loss during the severe phase is specifically modified in the following way (Robert-Briand, 2006):

IMI type	Severity	Milk loss in the quarter		
		Highest loss (%)	Lowest duration (j)	Highest duration (j)
StaphA	G1	20	8	10
	G2	40		
	G3	75		
StreptU	G1	25	5	10
	G2	40		
	G3	75		
G-	G1	1	5	15
	G2	4		
	G3	110 [1]		
CNS	G1	0	2	10
	G2	40		
	G3	60		
CB	G1	20	2	10
	G2	40		
	G3	60		

Table 39: Consequences of IMI clinical cases on quarter milk production

The variability of a mastitis duration is implemented by the application of a uniform law delimited by the decreased and increased values thus determined. This is also the case for the variability of the percentage of milk loss associated with it. If the quarter has multiple infections (i.e. different bacterium), the highest percentage of milk loss will be applied.

In extreme cases of G3 severity mastitis, a permanent loss of the quarter may be possible. It is represented the following probabilities:

IMI type	Probability of quarter permanent loss (%)
StaphA	2
StreptU	6
G-	2
CNS	2
CB	1

Table 40: Probability of quarter loss in G3 mastitis

This eventual loss occurs at the expected end of the infection period and has an effect on milk production in the neighbouring quarters (see paragraph *2.2.2.1.2.12 Quarter loss*).

2.2.3.1.1.1.3.3 Impact on feeding

Because of the reduction in the quantity of milk produced in the event of mastitis, feed consumption is reduced as follows: a reduction of 8 kg of milk leads to a reduction in consumption of 1 kg (divided proportionally between forage and concentrate), except for cases of quarter loss for which this effect is divided by 2.

2.2.3.1.1.1.3.4 Impact of mastitis on susceptibility to other diseases

Mastitis has an effect on susceptibility to other diseases. The diseases concerned in DHM are ketosis (see paragraph *2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes*) and lameness (see paragraph *2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases*).

[1] The loss is total for the quarter, and impacts 10% of the neighbouring quarter

2.2.3.1.1.1.3.5 Mortality and culling risk related to G3 severity

G3 severity IMI can have an impact on the animal's fate according to the following probabilities (Robert-Briand, 2006):

IMI type	Probability (%)	
	Mortality	Culling
StaphA	2	2
StreptU	1	1
G-	5	8
CNS	0	0
CB	0	0

Table 41: Mortality and culling risk related to G3 severity

2.2.3.1.1.2 IMI incidence

The occurrence or not of an IMI on a quarter of a given cow depends on the combination of a risk specific to the cow, its environment and the effectiveness of the prevention methods. Thus, the basic probability of IMI onset depends on the incidence of mastitis on the udder per lactation cycle, corresponding to the use of basic means of prevention.

The udder of a cow (or of a heifer at the approach of the first calving) is likely to contract an IMI according to the following epidemiological model:

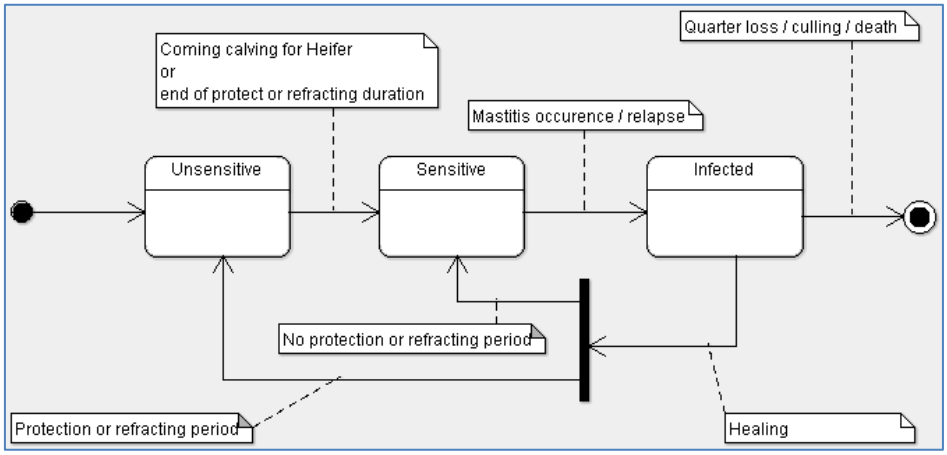


Figure 13: IMI epidemiological model

This model presented here is simplified. The dynamics of infection evolution applied for each quarter and for each type of bacterium is detailed in paragraph *2.2.3.1.1.4 Evolution and cure*. Not all bacteria are equivalent in terms of impact. The share of incidence that each one is led to take is configurable, this is the subject of the paragraph *2.2.3.1.2.3 Share of bacterial type in incidence*.

A quarter is likely to contract multiple IMIs simultaneously if they were to be caused by different bacterium. For each quarter, a refractory period of 7 days follows the occurrence of an IMI, preventing the appearance of a new infection. At the end of this period, the quarter is again exposed to IMI. Only one mastitis case can occur on a given day in neighbouring quarters. However, in case of several mastitis cases (for different bacterium) the least common disorder is considered. The ranking order is as follows (from least to most frequent):

- Gram Negative
- Streptococcus Uberis
- Staphylococcus Aureus
- Coagulase Negative Staphylococcus
- Corynebacterium Bovis

The udder is considered infected by a bacterium when one of its quarters is in the infected state for this bacterium.

2.2.3.1.1.2.1 Periods at risk

The risk of onset of the disease depends especially on biological periods and production activities, particularly those related to lactation (Robert-Briand, 2006). It therefore depends on the cow's (re) productive periods, whose sequence and reference duration are defined as follows:

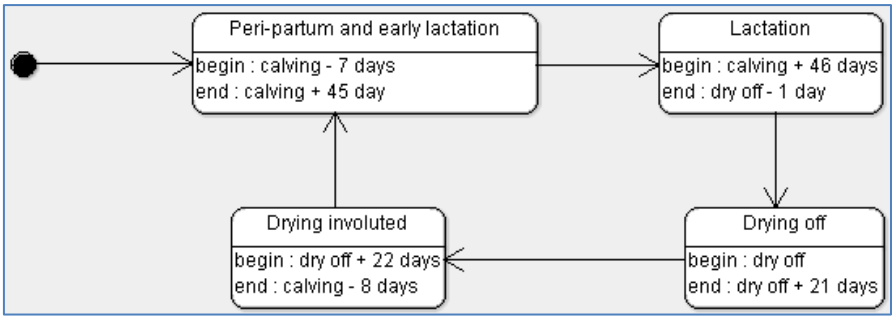


Figure 14: Sequence and duration of (re)productive periods at IMI risks

Note : The peripartum period is also triggered at the time of an abortion if it has resulted in lactation (see paragraph *2.2.1.1.6.1 Late embryonic mortality and abortion*).

According to the cow's pregnancy/lactation stage, based on lactation after 305 days and a dry period of 60 days (so for a cycle of 365 days), each IMI type occurrence's basic distribution is the following (ECOMAST):

IMI type	**Periods**			
	Peri-partum and lactation beginning	Lactation	Drying-off	Drying involuted
StaphA	0.42	0.31	0.2	0.07
StreptU	0.51	0.22	0.2	0.07
G-	0.615	0.235	0.1	0.05
CNS	0.825	0.025	0.1	0.05
CB	0.3	0.55	0.08	0.07

Table 42: Distribution of each IMI type occurrence according to pregnancy and lactation stage over a year

Thus, relying on two Beta-Pert distributions with respectively a peak on the calving day and a lambda value of 10 for one, and a peak 5 days after drying-off and a lambda value of 4 for the other, the probabilities of IMI occurrences are distributed as follows:

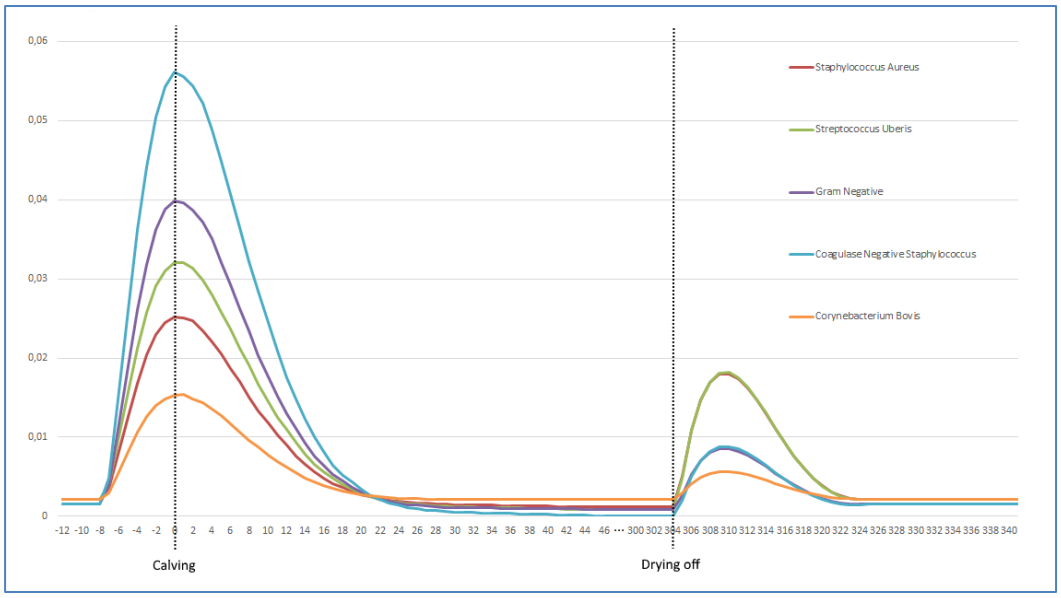


Figure 15: Distribution of each IMI type occurrence according to pregnancy-lactation stage over a year

2.2.3.1.1.2.2 Incidence risk modulation

The risk of mastitis incidence can be modulated according to individual situations and husbandry conditions.

2.2.3.1.1.2.2.1 Individual modulation of incidence risk

The risk of developing basic mastitis cases can be weighted by particular conditions. Indeed, certain driving practices, and in particular those implemented in the context of prevention, can modulate this risk, which is simulated by taking into account a global factor of individual prevention, which can be parameterised according to the methods defined in the paragraph *2.2.3.1.2.5 Prevention factor for mastitis at the individual level*. For the others, they are defined in the following paragraphs.

2.2.3.1.1.2.2.1.1 Dairy production

IMI incidence may change according to the amount of milk produced during a lactation. If milk quantity decreases, the risk is attenuated (Billon, 2015). On the contrary, during peak production, the risk increases:

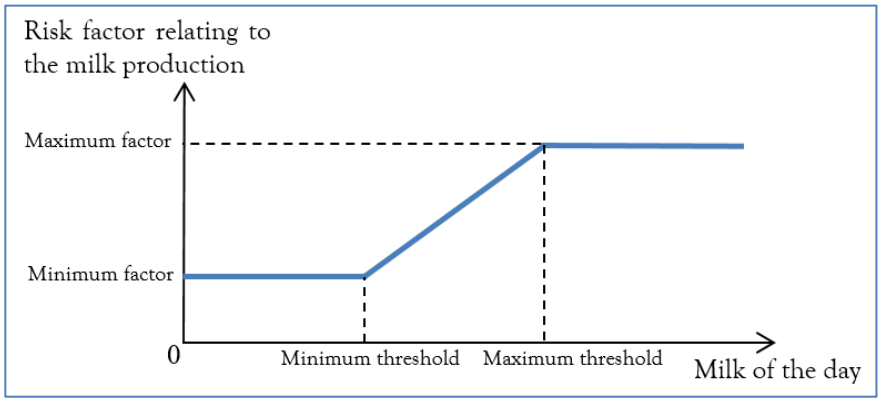


Figure 16: Risk factor for mastitis incidence according to milk production

The threshold values of the udder production and of the afferent risk, depending on the bacterium studied, are defined in the following way (ECOMAST):

IMI type	Decreased risk		Increased risk	
	Production threshold (kg)	Risk factor	Production threshold (kg)	Risk factor
StaphA	25	0.50	50	1.5
StreptU	25	0.45	50	2.0
G-	25	0.45	50	1.8
CNS	25	0.50	50	1.5
CB	25	0.50	50	1.5

Table 43: Risk factor values for mastitis incidence according to udder milk production and bacterium presence

2.2.3.1.1.2.2.1.2 Lactation rank

IMI incidence may be different depending on parity, it tends to increase throughout its productive life (Billon, 2015). In order to take this effect into account in the simulator, a risk factor related to this lactation rank is applied. Without distinction of bacterium type, this risk is determined in the following way (ECOMAST):

Number of lactations	Risk factor
1	0.75
2	1
3	1
4 et +	1.5

Table 44: IMI risk depending on lactation rank

2.2.3.1.1.2.2.1.3 Potential milk

The milk potential influences IMI incidence during lactation phases. The more milk the cow is able to produce, the higher the risk of developing mastitis is (Billon, 2015). Therefore, the simulator applies a risk factor based on the following values, without distinction of bacterium type (ECOMAST):

	Decreased risk	Increased risk
Potential milk	4000 kg	12000 kg
Associated risk	0.8	1.5

Table 45: IMI risk related to potential milk

The milk potential implemented here is the individual's corrected milk performance P, based on the corrected lactation production (cumulative over 305 days and adult level) of the breed, described in paragraph *2.2.4.1.1 Genetic values associated with phenotypic traits*.

2.2.3.1.1.2.2.1.4 Individual character

Individual susceptibility to mastitis is determined by the phenotypic trait "MACL", described in paragraph *2.2.4.1.2 Individual genetic value*. The principle adopted for its consideration at the simulation level is to apply to the risk the factor represented by the corrected performance of this phenotypic trait (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*).

2.2.3.1.1.2.2.1.5 IMI risk related to pre-existing SCC level

Pre-existing high SCC in the udder may have a beneficial effect on the incidence of IMI during lactation. Conversely, a low level may favour its appearance (Billon, 2015). The simulator produces these effects by applying a risk factor based on the following values (ECOMAST):

IMI type	Risk factor		
	SCC < 75 (1000/ml)	SCC ≥ 75 (1000/ml) and SCC ≤ 750 (1000/ml)	SCC > 750 (1000/ml)
StaphA	1	1	0.8
StreptU	1	1	0.8
G-	1.1	1	0.8
CNS	1	1	0.8
CB	1	1	0.8

Table 46: Risk factor values for mastitis incidence according to the pre-existing level of SCC

2.2.3.1.1.2.2.1.6 Quarter interdependence

The risk of mastitis occurring in one area is increased by the presence of mastitis of the same type (same bacterium) on another area of the udder. These complementary risk factors are defined in the following way (ECOMAST):

IMI type	Risk factor
StaphA	3.2
StreptU	3.2
G-	3.2
CNS	3.2
CB	3.2

Table 47: IMI risk related to quarter interdependence

2.2.3.1.1.2.2.1.7 Modulation of mastitis incidence due to competition from other disease episodes

The presence of certain diseases may increase the risk of developing mastitis. Mastitis susceptibility refers to all types of IMI, which are clinically severe (G1, G2 and G3). The following relative risks are associated:

Disease	Relativ risk	Risk duration	References
Ketosis	1,61	Concomitant with the disease	G1 : (Raboisson, Mounié et Maigné, 2014) Other severities: Extrapolation of risk from expert opinion
Lameness	1,44	Concomitant with the disease	(Peeler, Otte et Esslemont, 1994)

Table 48: Relative risk of mastitis occurrence due to competition with other disease episodes

2.2.3.1.1.2.2.2 Modulation of the incidence risk related to herd management

The risk of basic mastitis cases may also be modulated by certain circumstances or management practices, particularly those implemented in the context of herd prevention. The seasonal risk and the risk of contagion of the batch are simulated precisely in the following paragraphs. For other effects, an overall prevention factor for the population is used, which can be parameterised according to the methods defined in paragraph *2.2.3.1.2.6 Prevention factor for mastitis at* herd level.

2.2.3.1.1.2.2.2.1 Seasonal risk (housing effect)

Depending on the season, mastitis incidence increases (or even decreases). The simulator reproduces this effect by taking into account a factor that modulates the probability of mastitis occurrence depending on the simulation month and the bacterium studied. This configurable factor is described in paragraph *2.2.3.1.2.2 Seasonal impact on IMI incidence*.

2.2.3.1.1.2.2.2.2 Batch contagion

Mastitis presence in a batch can have a contagion effect to the whole batch. Therefore, the simulator makes it possible to define, by bacterium, the relation between the number of cases encountered over the last seven days, at the scale of a quarter, and the incidence of the simulated day, by taking into account a factor f used as follows:

$$f = 1 + \langle contagion\ effect \rangle * \langle prevalence\ of\ the\ previous\ week \rangle$$

The effect per bacterium is defined as such (Billon, 2015):

Bacterium	Contagion effect
StaphA	0.15
StreptU	0.08
G-	0.05
CNS	0.10
CB	0.15

Table 49: IMI contagion effect in the batch

2.2.3.1.1.3 IMI detection

The clinical IMI of G2 severity to G3 is systematically detected, however it is not necessarily the case of G1 severity IMI. The sensibility of mastitis detection for those levels can be modified, it is described in paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis.*

2.2.3.1.1.4 Evolution and cure

The evolution dynamics of a quarter's infection by a bacterium type is defined according to the following model:

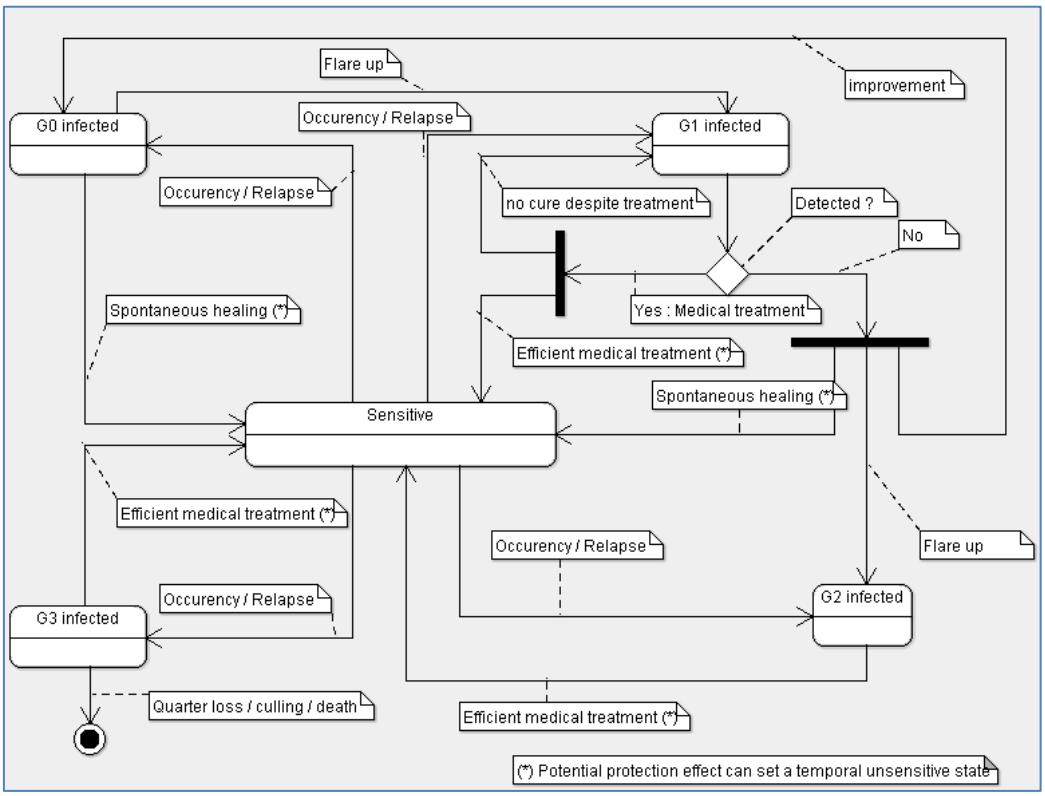


Figure 17: IMI evolution dynamics

2.2.3.1.1.4.1 Spontaneous healing

While healing usually requires treatment, it can be spontaneous (Billon, 2015).

2.2.3.1.1.4.1.1 Basic spontaneous healing

Subclinical G0 IMIs, if they do not turn into clinical mastitis (see paragraph *2.2.3.1.1.4.2.1 Clinical recurrence of persistent subclinical infection*), can heal spontaneously after 50 days, and if not, their duration is extended to 200 days. A G1 severity IMI, if it has not been detected, will not benefit from the appropriate medical treatments, it can nevertheless heal spontaneously or regress to G0. The conditions for spontaneous recovery from undetected G0 and G1 severity mastitis are as follows:

IMI type	During lactation (from peri-partum until drying-off)	At drying-off	Dry period
StaphA	0.2	0.35	0.2
StreptU	0.3	0.45	0.3
G-	0.9	0.9	0.9
CNS	0.2	0.7	0.65
CB	0.2	0.6	0.5

Table 50: Baseline rate of spontaneous cure of a G1 seriousness IMI not detected according to the pathogen

2.2.3.1.1.4.1.2 Cure induced by the cure of a new infection in the quarter

Mastitis cure (caused by a bacterium) that occurs after a mastitis already on the quarter (so due to another bacterium) can trigger the cure of the latter. The survival probability of pre-existing mastitis in this case is determined under the following conditions (ECOMAST):

Current healed IMI	Pre-existing IMI in the quarter				
	StaphA	StreptU	G-	CNS	CB
StaphA		1.0	0.5	0.5	0.5
StreptU	1.0		0.5	0.1	0.3
G-	1.0	1.0		0.1	0.3
CNS	1.0	1.0	0.5		0.7
CB	1.0	1.0	0.5	0.7	

Table 51: Probability of pre-existing mastitis during the cure of a previous mastitis

For G3 severity mastitis, they will heal according to this modality only if it was expected that they heal. This excludes those for which a quarter loss, a culling or a mortality was foreseen (see paragraph *2.2.3.1.1.1.3.2 Important decrease in milk production* and paragraph *2.2.3.1.1.1.3.5 Mortality and culling risk related to G3 severity*).

2.2.3.1.1.4.2 Mastitis worsening

Under certain conditions, mastitis may worsen. This may be the case of a persistent subclinical mastitis or an undetected G1 severity mastitis.

2.2.3.1.1.4.2.1 Clinical recurrence of persistent subclinical infection

Persistent subclinical infections are at risk of clinical recurrence, the probability of which is defined as follows (ECOMAST):

IMI type	Probability (%)
StaphA	30
StreptU	60
G-	90
CNS	10
CB	0

Table 52: Clinical recurrence of persistent subclinical infection depending on bacterium type

Thus, at the end of the period initially defined for each G0 severity mastitis, a random draw is carried out, making it possible to determine whether the mastitis has worsened (thus becoming G1 severity) or if it has been the subject of spontaneous cure.

2.2.3.1.1.4.2.2 Worsening of undetected clinical mastitis

When a G1 severity mastitis is undetected (see paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis*), it evolves in 10% of the cases and after 2 days in a G2 severity, and if it does not heal spontaneously (see paragraph *2.2.3.1.1.4.1.1 Basic spontaneous*), it evolves to G0 severity mastitis after 5 days.

2.2.3.1.1.4.3 Healing following treatments

When an IMI is detected, it is systematically and immediately subjected to a medical treatment provided by the farmer or a veterinary. The effectiveness of this treatment will be different according to the mastitis treatment plan that will be implemented and the individual's character. This treatment is carried out over a given period of time and its effects may require a certain delay. This may lead to not marketing the milk of

the infected udder, during treatment but also beyond. Other mastitis (including subclinical) present in the quarter also benefit from the treatment caused by the detection of clinical mastitis, under the same conditions as those set in the treatment plan.

Under certain conditions, this treatment may have a protective effect against the occurrence of new mastitis, regardless of the bacterium. This eventual effect is applied as soon as the treatment is taken.

The criteria for defining treatments are configurable according to the procedures described in paragraph *2.2.3.1.2.4 Treatment plans*.

2.2.3.1.1.4.4 Relapses

The probability of a clinical relapse of persistent (unhealed) mastitis is defined, depending on the pathogen, as follows (Robert-Briand, 2006):

Pathogen	**Relapse probability** (%)
StaphA	50
StreptU	50
G-	10
CNS	10
CB	10

Table 53: Pathogen-related relapse probability

This probability corresponds to the potential risk of clinical relapse in the 245 days following the start of an untreated IMI (G0 and G1 severity not detected) but healed spontaneously. It is simulated according to a beta law shifted to the left ($\alpha = 2$, $\beta = 4$) so that the probability of relapse is maximal within 60 days post IMI. This relapse is effective only if the affected area is susceptible to this mastitis at the scheduled time.

2.2.3.1.2 Parameters for IMI management

Various parameters enable the user to change breeding's sanitary conditions, according to the simulation's needs.

2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis

The experimenter has the possibility of setting the probability of detection by the farmer of G1 clinical mastitis. The default value is 50%.

On the other hand, if the veterinary care contract is taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), G1 mastitis detection sensitivity can be increased to 100% from 6 months after its implementation, whatever the value of the G1 mastitis detection sensitivity parameter defined at the start of the simulation (Beaugrand, personal data).

2.2.3.1.2.2 Seasonal impact on IMI incidence

The experimenter can define the seasonal impact on IMI incidence. It assigns a factor that decrease or increase the basic value (neutral value equal to 1) for each bacterium and each month of the year.

In order to highlight the increase in IMI incidence in summer and winter for certain bacterium, the default values proposed by the simulator were defined as follows (ECOMAST):

IMI type	Worsening factor		
	Summer (from july to august)	Winter (indoor period, from december to february)	Rest of the year
StaphA	1	1	1
StreptU	1.2	1.2	1
G-	1.5	1.5	1
CNS	1	1	1
CB	1	1	1

Table 54: Defaults values for IMI incident change factors by seasons

2.2.3.1.2.3 Share of bacterial type in incidence

The experimenter can adjust the importance of the type of bacteria in the incidence. The standardised default values are as follows (ECOMAST):

IMI type	Incidence part
StaphA	0.283
StreptU	0.351
G-	0.027
CNS	0.226
CB	0.113

Table 55: Share of bacterial types in mastitis incidence

2.2.3.1.2.4 Treatment plans

During the lactation, when a mastitis is detected by the farmer (clinical mastitis), it is treated with a treatment set up for that period. The curative treatment of mastitis causes unplanned activity on the part of the farmer, which is reinforced by the unplanned arrival of the vet in the case of G3 severity for a cow care (see *Table 110: Structure of data on technical heath results*). When the cow is dry, if she is pregnant and if her cell count measured at the last milk control exceeds 200,000 c/ml, she will undergo a systematic preventive treatment set for this period, farmer's scheduled activity (see *Table 110: Structure of data on technical heath results*). The default values are as follows (Billon, 2015):

	Lactation period (peri-partum until drying-off)			Drying-off and dry period		
Name	Default Mastitis wide range treatment			Default Mastitis AB BP treatment		
Delay before effect (d)	2			1		
Waiting time milk (d)	4			14		
Bacterium	**Cure probability**	**Relative risk of protective effect**	**Protection duration (d)**	**Cure probability**	**Relative risk of protective effect**	**Protection duration (d)**
StaphA	0.45	0.00	0	0.65	0.589	72
StreptU	0.70	0.00	0	0.92	0.586	72
G-	0.95	0.00	0	1.00	0.895	72
CNS	0.85	0.00	0	0.95	0.943	72
CB	0.90	0.00	0	1.00	0.781	72

Table 56: Default values of mastitis treatment plan according to the period and the bacterium

The veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) can improve the success rate of mastitis treatments by 5% during the lactation period.

Treatment costs are set in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.1.2.5 Prevention factor for mastitis at the individual level

A multiplicative value makes it possible to improve the prevention of mastitis (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it makes it possible to include the individual effect of farm management factors which have an influence on the incidence but are not explicitly represented (see paragraph *2.2.3.1.1.2.2.1 Individual modulation of incidence risk*). By default, the value is 1.0.

Note: Where a veterinary care contract is in place, a flat-rate annual cost for mastitis prevention on one cow is added at the end of the financial year based on the average number of adult cows present (see *Table 134: Default rates for health-related accounting transactions* and *Table 140: Structure of the economic balance sheet data expressed in euros*).

2.2.3.1.2.6 Prevention factor for mastitis at herd level

A multiplicative value makes it possible to improve the prevention of mastitis (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it makes it possible to include the herd effect of husbandry factors which have an influence on the incidence but are not explicitly represented (see paragraph *2.2.3.1.1.2.2.2 Modulation of the incidence risk related to herd management*). By default, the value is 1.0.

The effects of this parameter can be modulated according to the terms of the veterinary care contract. Indeed, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), the veterinary care contract makes it possible to improve herd mastitis prevention over time. This level of prevention is then modulated to improve by 25% after 24 months, and by a further 25% after 42 months. This modulation achieves the following progression in terms of clinical incidence (Beaugrand, personal data):

Number of effective months of veterinary care contract	**Clinical incidence obtained depending on the prevention parameters value** (see paragraphs *2.2.3.1.2.5* and *2.2.3.1.2.6*)		
	0.4	**1.0**	**1.7**
0	76.5%	35%	22.7%
24	61%	26.4%	13.6%
42	46%	21%	11.3%

Table 57: Clinical incidence of mastitis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract

For intermediate values of parameterised prevention, progress is weighted. For marginal values, the closest modelled level of progress is used.

2.2.3.1.2.7 Veterinary care contract option

A parameter allows to simulate a veterinary care contract whose effects are felt on mastitis (and also on the other diseases modelled), in terms of prevention, detection, intervention time and cure. This contract also entails preventive visits scheduled twice a month in the first year of the contract, then once a month in subsequent years (this visit also involves a planned activity for the farmer). The number of visits carried out is shown in the results produced (see paragraph *2.2.3.6 General health produced data*).

In addition, the veterinary care contract also helps to reduce mortality from diseases that are not modelled (see paragraph *2.2.5.1.1.3 Mortality*).

Three modalities are available:

- based on the average number of cows present during the previous campaign,

- according to the average number of calving in the previous campaign,

- according to the quantity of milk delivered during the previous campaign (per 1000 liters).

Technically, the implementation of the veterinary care contract begins when the simulation produces results (i.e. after the simulator warm-up period), and is not retained by default.

2.2.3.1.3 Specific IMI produced data

General technical data relating to IIMs are generated automatically; they are described in section *2.2.3.6 General health produced data*. The specific data generated concerning IIMs described below relate to the estimation of udder health; they are generated only in the 'full results' version of the simulator:
IMI produced data are the estimation of teat health.

Result name: « AnnualMastitisResults »

Production type: annual.

Information level: Herd.

This data makes it possible to know the mammary health of the herd, on the basis of the observation of clinical mastitis detected and the average of the present cows.

The available fields are:

Field name	Format	Value
Clinical_mastitis_per_100_cows	integer	Number of clinical cases occurring for 100 cows present (*)
First_clinical_mastitis_per_100_cows	integer	Number of first clinical cases for a cow lactation occurring for 100 present cows
Herd_SCC	integer	SCC average (1000 cells / ml) (**)
Under_300_SCC_per_100_controls	integer	Percentage of SCC controls not exceeding 300 000 cells / ml (***)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 58: Structure of annual outcome data for clinical mastitis

(*) Severity G1 (theoretically clinical) mastitis that has not been detected is not counted here.

(**) Average SCC measured during monthly dairy checks.

(***) Records at monthly dairy checks.

2.2.3.2 Ketosis (or acetonaemia)

Ketosis is a metabolic disease that reflects an energy deficiency. It is accompanied by acetonaemia, which is the increase in the blood concentration of ketone bodies (Vincent, 2019). Cases of ketosis affect different aspects of the cow's life and production. These effects can go as far as culling or even the death of the animal. Different options allow for increased detection, which offers the opportunity to improve health awareness.

2.2.3.2.1 Biological and technical constant values for ketosis

The purpose of this chapter is to describe ketosis, its incidence, the detection of cases and their evolution.

2.2.3.2.1.1 Description of ketosis

The occurrence of ketosis in cows results in the appearance of specific physiological phenomena that can be observed under certain conditions. It is also the cause of zootechnical consequences.

2.2.3.2.1.1.1 Ketosis severity levels

In addition to the external manifestation of its effects in its clinical form, ketosis, from its subclinical form, causes in cows an increase in the level of Beta-HydroxyButyrate (BHB) and acetone in their milk, which can be interpreted by expert systems as soon as they are implemented.

The blood BHB threshold generally used to detect a dairy cow suffering from subclinical ketosis corresponds to a concentration higher than 1.2 mmol/L (Benedet *et al.*, 2019).

There are three levels of severity with regard to the disease:

Severity	Definition
G0	Healthy ketosis status
G1	Cow with subclinical ketosis
G2	Cow with clinical ketosis

Table 59: Ketosis Severity Levels

2.2.3.2.1.1.2 Zootechnical consequences of ketosis

Cases of ketosis affect reproduction, production and susceptibility to other diseases, and then on culling decisions and mortality. The accounting effect of the change in feeding behaviour induced by the occurrence of ketosis is not significant and is therefore not simulated.

2.2.3.2.1.1.2.1 Effect of ketosis on reproductive performance

The occurrence of ketosis disrupts the reproductive cycle, affecting the resumption of ovarian activity, the sensitivity of heat detection and fertility and ultimately fertility. As information, robust data from the literature gives us the following impacts on fertility:

Effect	Severity	Impact	Reference
Lengthening of the IA 1 – IA f interval (days)	Untreated G1	+ 11	Adapted regarding (Fourichon, Seegers et Malher, 2000) and (Raboisson *et al.*, 2015)
	Treated G2	+ 5,5	
Lengthening of the calving-calving interval (days)	Untreated G1	+ 21	(Raboisson *et al.*, 2015)
	Treated G2	+ 8	Adapted regarding (Fourichon, Seegers et Malher, 2000)

Table 60: Impacts of ketosis on fertility

Only the impacts on the resumption of ovarian activity, on the sensitivity of heat detection and on fertility are represented and simulated.

2.2.3.2.1.1.2.1.1 Effect of ketosis on estrus detection sensitivity

The impact of ketosis on the detection of heat is linked to a lower expression of the behaviour associated with estrus by the cow (Rutherford, Oikonomou et Smith, 2016). It is neglected in the model because it is estimated to be insignificant on the overall effect of ketosis on reproduction.

2.2.3.2.1.1.2.1.2 Effect of ketosis on fertility

Fertility is disturbed when the cow has undergone ketosis (see paragraph *2.2.1.1.4.4.3 Ketosis effect on fertility*). The relative risk of insemination failure is 1.66 when the cow has had subclinical ketosis (Raboisson, Mounié et Maigné, 2014) during lactation. However, if the cow has had less than 30 days of ketosis in early lactation and a subclinical ketosis treatment has been given and has been effective, the relative risk of failure is reduced to 1.3.

In order to remain within the general scope of the *Table 9: Basic fertility rate (not taking into account the adverse effects of certain factors) according to fertilization modes* of the paragraph *2.2.1.1.4.2 Fertility – basic values*, a risk weighting is carried out for cows affected by a case of ketosis during insemination as well as for cows that are not.

As a result, ketosis during lactation will mechanically result in a longer calving - fertilizing insemination interval (IVIAF).

2.2.3.2.1.1.2.1.3 Effect of ketosis on the recovery of ovarian activity

The resumption of ovarian activity may be altered if the cow suffers from postpartum ketosis (see paragraph *2.2.1.1.7.2 Calving case*). First oestrus is delayed by 9 days when the cow has had at least one episode of subclinical ketosis since calving (Rutherford, Oikonomou et Smith, 2016). It is recognised that this also applies to cases of clinical ketosis. In simulation, this translates for the first postpartum oestrus into a weighted distribution of extra days due to ketosis cases and fewer days due to the absence of ketosis to obtain proportionally and globally the following results in the *Table 15: Post-partum cyclicity resumption by breed and parity* in the paragraph *2.2.1.1.7.2 Calving case*.

Furthermore, in case of ketosis during the last lactation, it can be considered that there are interruptions of cyclicity after the 1st cycle, the associated risk is 0.67 (Shin *et al.*, 2015). To take this into account in the simulator, the risk of cycle interruption between the post-partum ovulation of the standard cycle and the next ovulation is increased when the cow is affected by ketosis since calving. Conversely, a proportionate decrease in this risk is calculated when the cow has not experienced ketosis. Consequently, ketosis during lactation may result in a longer calving to first insemination interval (IVIA1).

2.2.3.2.1.1.2.2 Impact of ketosis on milk production performance

Ketosis has an effect on milk production (see paragraph *2.2.2.1.2.10 Ketosis effect on dairy production*) that depends on the cow's production level and the ketosis severity. The effects are simulated as follows:

Severity	Impacted feature	Effect on milk production		Reference
		Difference	Impact duration	
G1	Quantity	1.12%	55 days	Adapted regarding (Raboisson, Mounié et Maigné, 2014) and (Bareille *et al.*, 2003)
	TB	+1‰	during disease	(Vanholder *et al.*, 2015)
	TP	-1‰		
G2	Quantity	2.01%	55 days	Adapted regarding (Raboisson, Mounié et Maigné, 2014) and (Bareille *et al.*, 2003)
	TB	+3.1‰	during disease	(Vanholder *et al.*, 2015)
	TP	-2.2‰		

Table 61: Effect on milk production as a function of ketosis severity level compared to healthy cows (G0)

(*) the effect on production continues, even if the ketosis has been cured.

As far as the distribution of the daily loss of milk quantity is concerned, it follows a sinusoidal curve (angle $\pi/2$). The following example graph shows the daily loss at D0 of G1 and G2 ketosis for a cow producing 10000 kg of milk per lactation on 305 days:

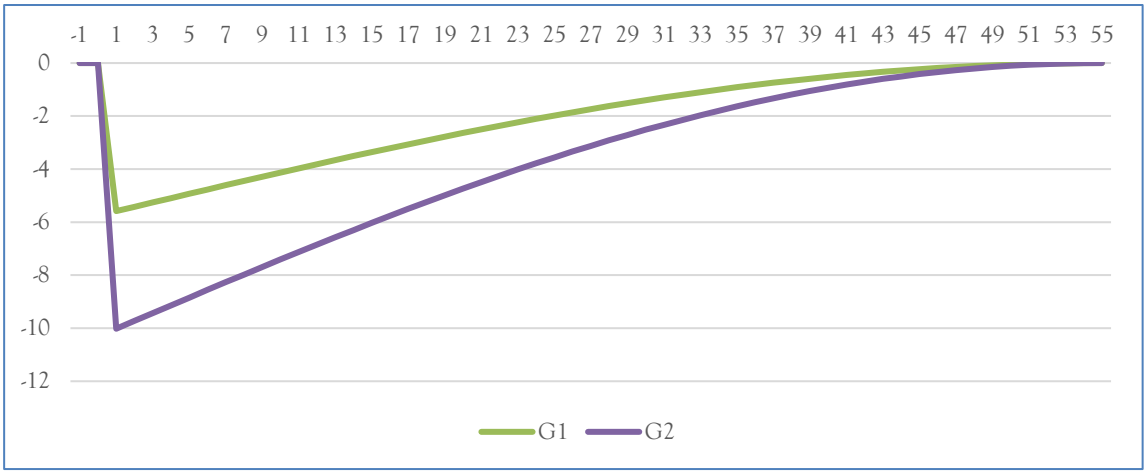


Figure 18: Distribution of the loss of milk quantity (Kg) over 55 days for a cow producing 10000 kg of milk during a lactation period of 305 days

2.2.3.2.1.1.2.3 Feeding impact

Because of the reduction in the amount of milk produced in ketosis, feed consumption is reduced as follows: a reduction of 2 kg of milk results in a reduction of 1 kg of feed consumption (divided proportionally between forage and concentrate).

2.2.3.2.1.1.2.4 Effect of ketosis on susceptibility to other diseases

Ketosis has an effect on susceptibility to other diseases. The diseases considered in DHM are mastitis (see paragraph *2.2.3.1.1.2.2.1.7 Modulation of mastitis incidence due to competition from other disease episodes*) and lameness (see paragraph *2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases*). As the movements of the abomasum are not simulated, their ketosis effect is not taken into account.Ketosis culling and mortality

When a cow develops ketosis, she is at direct and indirect risk of mortality and culling.

For the risk of culling, the causes directly related to ketosis are negligible compared to the frequency of indirect causes for poor reproductive performance or for lameness. As the simulator already takes into account culling related to these health disorders, only the risk of lethality is represented here:

		Lactation rank				Reference
		1	2	3	≥4	
Lethality percent	**G1**	0%	0,63%			Used regarding (McArt, Nydam et Overton, 2015) and (McArt, Nydam et Oetzel, 2012b) ; (Roberts *et al.*, 2012)
	G2	0%	0,7%	1,7%	2,5%	Used by (Mostert *et al.*, 2017) ; Used regarding (Bar *et al.*, 2008)

Table 62: Percentage lethality for an episode of ketosis based on severity and lactation rank of the affected cow

This risk is taken into account through a weighting of the basic risk identified in the *Table 120: Mortality risk among the herd* of the paragraph *2.2.5.1.1.3 Mortality*.

2.2.3.2.1.2 Incidence

There are two dimensions to the incidence: the basic incidence based on a standard management and feeding causing only spontaneous cases, and modulation to incorporate additional elements and management conditions that may encourage the occurrence of additional cases (or possibly reduce the basic incidence).

2.2.3.2.1.2.1 Basic incidence

The basic incidence is to be determined for standard feeding and nominal prevention methods. It therefore only reflects the spontaneous occurrence of the disease in the herd. Given the lack of epidemiological evidence for clinical ketosis in the literature, it will be described as an aggravation of subclinical ketosis (see

paragraph *2.2.3.2.1.4 Evolution and healing of ketosis*). Thus, only the basic incidence of subclinical ketosis is described here.

Ketosis is mainly observed during the first two months of lactation (Duffield, 2000).

Most studies describe the prevalence of subclinical ketosis during the first two weeks of lactation or during the first month of lactation. A prevalence of around 20% during the first two weeks of lactation has been described in a large number of herds in North America (Duffield *et al.*, 2009), as well as in Europe (Suthar *et al.*, 2013). The same 20% prevalence level has been described, this time during the first month of lactation, in Canada (Santschi *et al.*, 2016), (Tatone *et al.*, 2017). From the second month of lactation onwards, the prevalence of ketosis drops below 10% according to (van der Drift *et al.*, 2012).

Prevalence takes into account both the duration of ketosis evolution and ketosis recurrence for the same lactation. However, no study clearly estimates the recurrence rate of ketosis.

Incidence, defined as the percentage of lactations affected for the first time in a given time interval, is poorly described in the literature because it requires repeated measurements over time on the same sample of cows. The study of (McArt, Nydam et Oetzel, 2012b) shows a lactational incidence of 43.2% between 3 and 16 days postpartum in 4 large American herds. (Kaufman *et al.*, 2016) finds a similar incidence (44%) in 4 Canadian herds.

Thus, for a lactation, the baseline incidence of subclinical ketosis by breed is as follows:

	Baseline incidence
Montbeliarde	35%
Normande	25%
Prim'Holstein	45%

Table 63: Baseline incidence of subclinical ketosis by breed

The incidence curve of subclinical ketosis as a function of the stage of lactation implemented by the simulator is as follows:

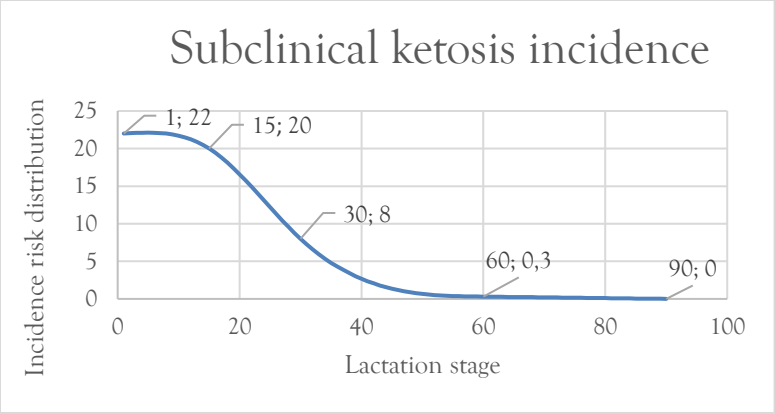


Figure 19: Incidence curve of subclinical ketosis as depending on lactation stage

2.2.3.2.1.2.2 Incidence risk modulation

The risk of ketosis incidence can be modulated according to individual situations and farming conditions.

2.2.3.2.1.2.2.1 Modulation of the ketosis incidence depending on genetics

Several authors describe the BHB level in milk or blood as heritable traits.

The genetic parameters of the 'BHBlait' trait are therefore taken into account in the simulator to represent the modulation of the incidence of G1 ketosis.

The 'BHBlait' index approximates the genetic risk of subclinical ketosis for a cow going through the risk period of the defined disease.

This trait is quantitative but for modelling purposes will be implemented as a qualitative risk trait for G1 in chapter *2.2.4 Genetics*.

2.2.3.2.1.2.2.2 Modulation of the ketosis incidence depending on lactation rank

A cow's lactation rank determines her likelihood of developing ketosis within two months of calving. The relative risk presented here takes into account both the effect of age itself and the effect of a cow producing more milk as her lactation rank increases and therefore being more at risk for ketosis.

	Lactation rank			Reference
	1	2	≥3	
Relative risk	0,8	1	1,6	Adapted regarding (Tatone *et al.*, 2017), (Santschi *et al.*, 2016)

Table 64: Relative risk of ketosis according to lactation rank

2.2.3.2.1.2.2.3 Modulation of the ketosis incidence depending on production level

The level of the cow's milk production influences its risk of developing ketosis: the higher the cow's milk production, the more sensitive it is. However, as a cow's milk production potential is linked to its genetics and parity, this effect is not represented here in order to avoid double counting.

2.2.3.2.1.2.2.4 Modulation of the ketosis incidence depending on season

Several studies note an influence of the season on the incidence of ketosis (Berge et Vertenten, 2014), (Tatone *et al.*, 2017), (Vanholder *et al.*, 2015) and (Santschi *et al.*, 2016), but they do not have significant data for all periods of the year. There would seem to be more ketosis in spring than in summer and autumn, with no consensus on what happens in winter. The biological explanations put forward by the authors are hypothetical, but a priori they reside in the management and feeding of the herd. (Vanholder *et al.*, 2015) believes that silages consumed at the end of winter are the oldest and therefore at risk for the development of butyric acid, which would favour ketosis.

Given these uncertainties, the effect of the season on the incidence of ketosis is not taken into account.

2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes

The risk of subclinical ketosis may be increased if the cow has or has had episodes of disease. Currently only mastitis is taken into account in the simulator, as follows:

	Risk	Temporality	Reference
Clinical mastitis in progress	1,9 (OR)	Met since the beginning of the current lactation	(Gröhn *et al.*, 1989)
Lameness	1,7 (RR)	Concomitant with the disease	(Peeler, Otte et Esslemont, 1994)

Table 65: Modulation of the incidence of ketosis related to competition from other disease episodes

The effect of the history of ketosis is taken into account in determining the probability of aggravation described in paragraph *2.2.3.2.1.4.2 Aggravation of an episode of subclinical ketosis*.

2.2.3.2.1.2.2.6 Modulation of the incidence of ketosis, in multiparous women, linked to the duration of the previous lactation

Cows with a moderate to high fattening status before calving are more likely to develop ketosis in early lactation, due to rapid and massive mobilization of accumulated fat. This is why cows in the herd with a delayed start to reproduction, whose lactation or dry-off has been prolonged are indirectly at risk because they have benefited from a positive energy balance for a longer period of time, which has allowed them to significantly increase their fattening status.

The risks associated with the duration of the calving interval, adapted from (Tatone *et al.*, 2017), are as follows:

Calving to calving interval	12-13 months	14-15 months	>15 months
Risk of ketosis at the beginning of the next lactation (OR)	0,86	1	1,4

Table 66: Risk of ketosis depending on the calving to calving interval

2.2.3.2.1.2.2.7 Modulation of the incidence of ketosis, in primiparous females, related to age at first calving

Similarly, heifers with moderate to high fatness prior to calving are more likely to develop ketosis in early first lactation. This is why heifers in the herd with a later age at first calving present an additional risk of ketosis according to (Tatone *et al.*, 2017) (OR = 1.41 for a calving between 25 and 33 months, compared to a calving before 25 months in Prim'Holsteins). However, this observation depends on the growth objective of the pre-herd depending on the breed and the breeding system under consideration. Thus, this risk could be significant for heifers with a strong delay in insemination, which can occur during group calving rearing. This risk is not currently implemented in the simulator, but will be sized and modelled on the basis of the analysis of the initial results obtained by comparing the different types of management.

2.2.3.2.1.2.2.8 Modulation of the incidence of ketosis by the use of intra-ruminally administered monensin boluses (Kexxtone®)

According to the meta-analysis by (Duffield, Rabiee et Lean, 2008), the preventive use of monensin boluses during dry-off is associated with a 0.75 reduction in the risk of clinical ketosis in the next lactation. If this option is chosen, the bolus is taken 30 days before the next calving date and its effect lasts for the next 95 days. The choice of using this preventive treatment is the subject of the parameter defined in paragraph *2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®).*

2.2.3.2.1.3 Ketosis detection

In its clinical form, ketosis causes phenomena that can be systematically observed externally (e.g. weight loss, decreased production level, feeding behaviour, constipation, characteristic breath, nervous disorders, etc.). The detection of a ketosis in its subclinical form would require the implementation of specific means.

2.2.3.2.1.3.1 Subclinical ketosis

Two methods can be used to estimate the level of ketosis risk that will lead the farmer to take sanitary action related to the detection of subclinical ketosis: methods Cetodetect ® and Herd Navigator ®. The use of these detection tools can be parameterized according to the methods defined in the paragraph *2.2.3.2.2.2 Detection options*.

When a sub-clinical ketosis has been detected, the cow is given the appropriate treatment for ketosis of severity G1 (see paragraph *2.2.3.2.2.3 Treatment plan*), even in the case of a false positive. It would then have no curative effect but could nevertheless be protective if necessary.

2.2.3.2.1.3.1.1 Cetodetect ®

Optional method to quantify the risk of ketosis monthly during milk control by an assay of BHB and acetone in milk in combination with other zootechnical data in a way that is not known (Vincent, 2019). If cases of clinical ketosis are systematically detected by the breeder, the use of the Cetodetect ® option is interesting for the detection of sub-clinical cases. Thus, if this system is implemented (resulting in costs, see paragraph *2.2.7.1.7 Other accounting items*), a case of subclinical ketosis (G1) can be detected on a spot sample analysed during the monthly milk control, under the following conditions (Vincent, 2019):

Sensibility	91%
Specificity	88%

Table 67: Sensitivity and specificity of the Cetodetect ®test

The error of specificity can only occur during the period at risk of ketosis.

2.2.3.2.1.3.1.2 Herd Navigator ®

This optional tool allows the precise analysis of each cow's milk, every 3 days of milking, and to design an action plan based on the results obtained. The detection of ketosis cases requires the BHB to be measured

in combination with other zootechnical data in a way that is not known. The tool does not assign a score; it alerts the breeder when the significant level of risk is reached. It is therefore accepted that with this tool, a cow suffering from ketosis will necessarily have a BHB dosage in her milk. Sensitivity and specificity data have not been communicated by the company, however those of a biochemical analysis with optical reading are respectively 86% and 82% (Vincent, 2019). It can be assumed that the Herd Navigator® algorithm optimises the sensitivity and specificity results in order to reach at least those of the Cetodetect® tool, which is what is implemented by the simulator.

The cost of the initial investment in this tool is not taken into account in the simulation accounting data. As for the operating cost (defined in paragraph *2.2.7.1.7 Other accounting items*), it includes the dosage of progesterone and LDH in milk.

2.2.3.2.1.3.1.3 Blood test

This method is only used if a breeding contract has been signed with a veterinarian (see paragraph *2.2.3 Health*) and is not invoiced. It consists of taking a blood sample on the 15th of the month for any cow that calved the previous month. Thus, a case of subclinical ketosis (G1) may be detected under the following conditions (Macmillan *et al.*, 2017):

Sensibilité	98%
Spécificité	95%

Table 68: Sensitivity and specificity of the blood test for ketosis

2.2.3.2.1.3.2 Clinical ketosis (detected)

Cases of clinical ketosis are those detected (by the farmer himself or by the detection options chosen, with a negligible effect on the sensitivity of detection and confirmation by the veterinarian), on the basis of the signs noticed on a daily basis during his driving actions without the use of detection means other than his own perception. These cases systematically lead to taking the appropriate treatment for ketosis of G2 severity, the plan of which is defined in paragraph *2.2.3.2.2.3 Treatment plan*.

2.2.3.2.1.4 Evolution and healing of ketosis

The dynamics of disease progression are defined according to the following model:

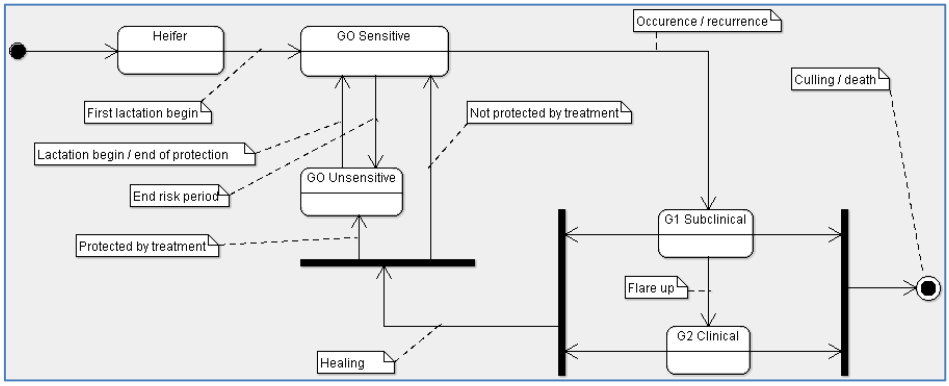


Figure 20: Dynamics of ketosis evolution

The principle implemented by the simulator is to trigger, when the conditions are met (age of the animal, risk periods, etc.) and stochastically from the incidence described in paragraph *2.2.3.2.1.2 Incidence*, a case of sub-clinical ketosis which, depending on the elements involved, will heal spontaneously or with the taking of one or more treatments, will worsen (thus becoming a case of clinical ketosis), or will lead to culling or even death.

2.2.3.2.1.4.1 Duration of ketosis

According to the 16-day observations of (McArt, Nydam et Oetzel, 2012a), subclinical ketosis develops over a period of 2 to 14 days, with a median of 4 to 5 days. Approximately 85% of cases are resolved after 14 days. The duration of a subclinical ketosis implemented by the simulator therefore varies over time according to a triangular law between 2 and 20 days with a peak at 5 days.

For clinical ketosis cases, it is agreed that the duration of an episode (G2) is to 5 days.

2.2.3.2.1.4.2 Aggravation of an episode of subclinical ketosis

The risk of worsening from G1 subclinical ketosis to G2 clinical ketosis is 5% for a primiparous cow and 7% for a multiparous cow (McArt, Nydam et Overton, 2015). This risk is multiplied by 3 when the cow has experienced at least one episode of ketosis during the previous lactation (Østergaard, Sørensen et Houe, 2003). Aggravation occurs at the end of the initially planned subclinical duration of the episode (see paragraph above).

2.2.3.2.1.4.3 Detection of a case of clinical ketosis, treatment

While cases of clinical ketosis are systematically detected by the farmer, cases of sub-clinical ketosis can only be detected by the implementation of specific means (see paragraph *2.2.3.2.1.3 Ketosis detection*). They shall then give rise to one or more treatments under the conditions set out in paragraph *2.2.3.2.2.3 Treatment plan*. In the case of subclinical ketosis, if the treatment given was not effective, it will have the advantage of reducing the original duration by one day. In the case of clinical ketosis, if the first treatment was not effective, the cow is given a second treatment with a 100% success rate.

2.2.3.2.1.4.4 Recurrence of ketosis

Two days after the end of an episode, the cow is again susceptible to ketosis if she is still in the risk period, whether she has been treated or not. According to data from (Bareille *et al.*, 2003), about 40% of affected cows show a recurrence (modalities: N = 1050 VL in experimental farm, definition of ketosis as "cow with a decrease in milk production and intake between 1 week and 1 month of lactation, having a favourable response to propylene glycol administration"). In simulation, cases of recurrence are triggered by taking into account this probability, weighted by the genetic value of the cow's BHBlait index. They can be consecutive and are triggered on average 15 days after the first day of the sensitivity period following the case of subclinical ketosis (normal distribution with a standard deviation of 5).

2.2.3.2.2 Ketosis-related husbandry parameters

The simulator's parameterization makes it possible to define the overall prevention factor, the detection options and the treatment plan.

2.2.3.2.2.1 Prevention factors

Significant relationships are observed between the level of milk production of one farm compared to another farm, and the prevalence of ketosis within these farms (Tatone *et al.*, 2017). However, these links are trends related to indirect effects, because from one farm to another, the difference in production level is explained by a multitude of factors that directly influence the level of ketosis prevalence (reproductive efficiency, feeding of heifers, dry cows, early lactation cows, genetic level of the herd, etc.), some of which are already accounted for. This is why this modulation of incidence according to the production level of the herd is not developed in the simulator.

2.2.3.2.2.1.1 Global prevention factor

A multiplicative value improves ketosis prevention (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it allows for the effect of husbandry factors that influence the incidence but are not explicitly represented (see paragraph *2.2.3.2.1.2.2 Incidence risk* modulation). This is the case, for example, for prevention related to dry period management, the feed system and lifestyle. The default value is 1.0.

The effects of this parameter can be modulated according to the terms of the veterinary care contract. If taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), the veterinary care contract makes it possible to improve the prevention of ketosis in the herd over time. This level of prevention is then modulated to improve by 25% after 24 months, and by a further 25% after 42 months. This modulation achieves the following progression in terms of clinical incidence (Beaugrand, personal data):

Number of effective months of veterinary care contract	Clinical incidence obtained depending on the prevention parameter (see paragraph *2.2.3.2.2.1.1 Global prevention factor*)		
	0.4	**1.0**	**1.7**
0	27.2%	14.1%	7.5%
24	22.8%	10.6%	5.2%
42	16.9%	7.6%	4.3%

Table 69: Clinical incidence of ketosis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract

For intermediate values of parameterised prevention, progress is weighted. For marginal values, the closest modelled level of progress is used.

Note: Where a veterinary care contract is in place, a flat-rate annual cost for mastitis prevention on one cow is added at the end of the financial year based on the average number of adult cows present (see Table 134: Default rates for health-related accounting transactions and Table 140: Structure of the economic balance sheet data expressed in euros.

2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®)

The option of using monensin preventive treatment to reduce the incidence in the next lactation can be set (see paragraph *2.2.3.2.1.2.2.8 Modulation of the incidence of ketosis by the use of intra-ruminally administered monensin boluses*). This is an activity scheduled by the farmer (see *Table 110: Structure of data on technical heath results*), it is not retained by default.

2.2.3.2.2.2 Detection options

Different detection options are offered to the experimenter.

2.2.3.2.2.2.1 Cetodetect ® option during milk control

The simulator systematically implements monthly milk control.

The paid option Cetodetect ® (see paragraph *2.2.7.1.7 Other accounting items*) is not retained by default. However, it is compulsory in the case of a veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*).

2.2.3.2.2.2.2 Herd Navigator ® option of the milking robot

This option incurs an employment cost (see paragraph *2.2.7.1.7 Other accounting items*), it is not retained by default.

2.2.3.2.2.3 Treatment plan

When a ketosis is detected by the breeder, the latter provides treatment. The recommended treatment for subclinical ketosis is based on oral administration of 300 grams of propylene glycol per day for 5 days (Gordon, LeBlanc et Duffield, 2013). This treatment reduces the duration of ketosis progression by one day, and has beneficial effects on the risk of worsening subclinical ketosis to clinical ketosis, as well as on fertility and milk production (McArt *et al.*, 2011), (McArt, Nydam et Oetzel, 2012a).

The treatment of G2 clinical ketosis is controversial depending on the suspected majority etiological origin:

Type 1 ketosis: Hyper-acetonaemia linked to the massive mobilisation of ketone bodies for use in the face of an energy deficit in high-producing dairy cows at the time of peak lactation, without associated hepatic steatosis. This form of ketosis generally appears between 3 and 6 weeks of lactation and is characterised by hypoglycaemia associated with hypoinsulinemia (Vanholder *et al.*, 2015), (Douart, 2015). The use of glucocorticoids is indicated here because it helps to boost the appetite and promote gluconeogenesis and therefore the use of proteins by the liver as an energy substrate (Douart, 2015).

Type 2 ketosis: Hyperacetonaemia exacerbated by a dysfunction of the hormonal adaptation of the metabolism due to a phenomenon of primitive hepatic steatosis. This ketosis is characterised by sub-normal blood glucose levels associated with hyperinsulinemia. Hepatic steatosis is favoured by poor feed management during the dry period and occurs in animals with a high fat content. This type of ketosis appears in early lactation (Douart, 2015), (Han van der Kolk *et al.*, 2017). The use of glucocorticoids is controversial here

because glucocorticoids also have a lipolytic effect which theoretically risks accentuating the phenomenon of hepatic steatosis (Seifi *et al.*, 2007). However, the randomised therapeutic trial of (van der Drift *et al.*, 2015) did not demonstrate a lipolytic effect associated with the use of dexamethasone in the treatment of clinical ketosis.

We therefore consider that the treatment of clinical ketosis is unique, because the boundary between these two etiological tables is not always so distinct in practice (only liver biopsies would make it possible to sort type 1 ketosis from type 2 ketosis (Bobe, Young et Beitz, 2004)), because the epidemiological elements distinguishing the two ketoses in animal husbandry are not known to us, and because the difference in treatment between the two is controversial. Thus, the default treatment plan, which can be parameterised, is as follows:

	G1 Ketosis treatment	G2 Ketosis treatment
Name	Propylène glycol PO 300g SID 5days	500 mL glucose 30% IV lente Niacine (vitB3), carnitine, méthionine, vitB12, Cobalt
Delay before effect (d)	5	0
Milk waiting delay (d)	0	3
Healing probability	0,5	0,42
Flareup to G2 risk	0,54	
References	(McArt *et al.*, 2011) (McArt, Nydam et Oetzel, 2012a)	(Foster, 1988), (Douart, 2015), (van der Drift *et al.*, 2015)

Table 70: Default values for ketosis treatment plan

The curative treatment of ketosis requires unplanned activity on the part of the farmer, compounded by the unscheduled arrival of the vet to treat the cow in the event of G2 severity (see *Table 110: Structure of data on technical heath results*). The veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), improves the success rate of treatments for G2 ketosis by 5%.

It should be noted that no protective effects are expected for ketosis treatments. The cost of processing is set up in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.2.3 Specific produced ketosis data

The data produced concern cases of ketosis (clinical and non-clinical) encountered in the herd.
General technical data relating to ketosis (clinical and non-clinical) encountered in the herd are generated automatically; they are described in section *2.2.3.6 General health produced data*. The specific data generated described below are generated only in the 'full results' version of the simulator:

Result name: « AnnualKetosisResults »

Type of production: annual.

Information level: Herd.

The available fields are as follows:

Field name	Format	Value
Clinical_ketosis_per_100_cows	integer	Number of clinical cases treated per 100 cows present
First_subclinical_ketosis_per_100_cows	integer	Number of first subclinical cases for a one-cow lactation occurring per 100 cows present
First_clinical_ketosis_per_100_cows	integer	Number of first clinical cases for a lactation of one cow occurring per 100 cows present
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 71: Data structure for annual results of subclinical and clinical ketosis

2.2.3.3 Lameness

Lameness is a clinical sign of pain when the animal moves. Except for sporadic accidents, lameness in cattle is caused by foot lesions of various origins, both infectious and non-infectious. Foot conditions therefore have an effect on the development of lameness, which in turn has an impact on the productive life of the cow. Different husbandry parameters vary the risk of lameness developing and persisting.

2.2.3.3.1 Biological and technical constant values for lameness

The purpose of this chapter is to describe lameness, its incidence, the detection of cases and their evolution.

2.2.3.3.1.1 Description of lameness

The occurrence of lameness in cows can be due to different foot lesions and has zootechnical consequences. A cow can have lesions on all four feet, but it is more often the hind feet that are affected. There is little information on the relationship between lesions on each of the hind legs of the same cow, but often both feet are affected by the same or different lesions and at different levels of severity (Manske, Hultgren et Bergsten, 2002a). Therefore, we only represent an overall condition of the cow's feet.

Furthermore, we consider that it is the lameness that causes the technical and economic impacts and not the presence of a lesion. The latter can still affect a cow's lying behaviour when the cows are not lame (Berry *et al.*, 1998). Furthermore, only 21% of cows with a lesion show lameness (van Huyssteen *et al.*, 2020).

2.2.3.3.1.1.1 Lameness types

Several foot lesions are at risk of causing lameness. To simplify, they are represented by 2 types:

Non-infectious lameness: Sole ulcers, bleeding and white line lesions are considered as non-infectious lameness. It refers to all diseases that affect the hoof.

Infectious lameness: Mortellaro's disease or digitis dermatitis, Fourchet's disease or interdigital dermatitis, interdigital hyperplasia or slugs, sole panic and sole abscess are of infectious origin. They affect the skin of the bovine foot. Here we only consider dermatitis.

These two types of lameness, which can be concomitant, are managed in the simulator by two different epidemiological systems.

2.2.3.3.1.1.2 Lameness severity levels

Only the clinical forms are represented, with 2 levels of severity:

Severity	Definition
G0	Healthy lameness status
G1	Mild to moderate lameness
G2	Severe lameness

Table 72: Lameness Severity Levels

These two levels of severity have been distinguished because in most recent publications lameness is graded according to its intensity with locomotion scores that vary according to several scales: from 1 to 5 (Sprecher, Hostetler et Kaneene, 1997), from 1 to 3 (Walker *et al.*, 2008) and even from 0 to 3 ((Barker *et al.*, 2010).

The most commonly used locomotion score is the 1-5 scale. In this case, a cow can be considered lame when her locomotion score is equal to or higher than 2 or 3 depending on the publications. In addition, authors choose the scores they assign to mild to moderate lameness and severe lameness.

2.2.3.3.1.1.3 Zootechnical consequences of lameness

Lameness affects reproduction, milk production, feeding and susceptibility to mastitis and ketosis, and even culling decisions and mortality.

As a cow can be affected by both types of lameness simultaneously, the consequence that applies in this case will be that of the disease with the greatest impact on the effect under consideration.

2.2.3.3.1.1.3.1 Effect of lameness on reproductive performance

The occurrence of lameness can disrupt the reproductive cycle by affecting heat detection sensitivity. Ovarian recovery and fertility are also affected but these are a consequence of poor heat detection in a lame cow.

2.2.3.3.1.1.3.1.1 Effect of lameness on estrus detection sensitivity

When lameness affects the cow, her sensitivity to heat detection is immediately affected (see paragraph *2.2.1.1.2.3.4 Effect of lameness on estrus detection sensitivity*). Indeed, a lame cow lies down more often, walks less and overlaps less with other conspecifics (Gaude *et al.*, 2017). This is modelled in the simulator as follows for severity G1 and G2 lame cows:

	Risk of detection of 1st postpartum estrus for G1 and G2 lameness	**Risk of detecting the following estrus for G1 and G2 lameness**
Sensor	1	0,98
Farmer	0,45	0,70
Robot	1	1
Bull	1	1

Table 73: Effect of lameness on heat detection sensitivity (Gaude *et al.*, 2017)

The risk is factorised when the cow has both infectious and non-infectious lameness (Risk(I) x Risk(NI)).

2.2.3.3.1.1.3.1.2 Effect of lameness on the recovery of ovarian activity

The effects on heat detection are so strong that they largely explain the delay in first insemination. As a result, the effect of lameness on the resumption of ovarian activity is not directly modelled.

2.2.3.3.1.1.3.1.3 Effect of lameness on fertility

As in the previous paragraph and for the same reasons, the effect of lameness on fertility is not directly modelled.

2.2.3.3.1.1.3.2 Impact of lameness on milk production performance

Lameness has an effect on milk production (see paragraph *2.2.2.1.2.11 Lameness effect on dairy production*). The amount produced as well as the composition (TB and TP) are affected throughout the lameness episode to a degree that depends on the type of lameness and its severity. According to (O'Connor *et al.*, 2020) and (Kofler *et al.*, 2021), lameness has little effect on TP, but the average TB over a full lactation is increased according to the severity and duration of the lameness. The effects apply as soon as the cow is lame and are cancelled out when the cow is cured. The effects are simulated as follows:

Severity	Impacted feature	Effect on milk production		Reference
		Infectious lameness	Non-infectious lameness	
G1	Quantity (kg/day)	Stabling(*): -0.7 Pasture: 0	-1,8	Infectious: (Relun, Lehebel, Chesnin, *et al.*, 2013) Non-infectious: Adapted from (Chesnin et Bareille, 2011)
	TB (g/kg)	+0,30		Adapted from (O'Connor *et al.*, 2020) and (Kofler *et al.*, 2021)
	TP (g/kg)	0		
G2	Quantity (kg/day)	Stabling(*): -0.7 Pasture: 0	55 days	Infectious: (Relun, Lehebel, Chesnin, *et al.*, 2013) Non-infectious: Adapted from (Chesnin et Bareille, 2011)
	TB (g/kg)	+1,5		Adapted from (O'Connor *et al.*, 2020) and (Kofler *et al.*, 2021)
	TP (g/kg)	0		

Table 74: Effect on milk production as a function of severity of lameness compared to healthy cows (G0)

(*) Effect halved in case of mixed stall/pasture system.

2.2.3.3.1.1.3.3 Feeding impact

Because of the reduction in the quantity of milk produced in the event of lameness, feed consumption is reduced as follows: a reduction of 2 kg of milk leads to a reduction in consumption of 1 kg divided proportionally between forage and concentrate (Bareille *et al.*, 2003).

2.2.3.3.1.1.3.4 Effect of ketosis on susceptibility to other diseases

Lameness has an effect on susceptibility to other diseases. The diseases considered in DHM are intramammary infections (see paragraph *2.2.3.1.1.2.2.1.7 Modulation of mastitis incidence due to competition from other disease episodes*) and ketosis (see paragraph *2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes*). These are discussed in the relevant chapters.Lameness-related culling and mortality

For hoof disease mortality, the figures from (Ettema, Østergaard et Kristensen, 2010), were adapted from the HR of (Bicalho *et al.*, 2007). In addition, in this publication the HR of moderate lameness included severe lameness so it was modified by taking the weighting 2/3 moderate and 1/3 severe. Thus, the risk is modelled as follows:

	Infectious		Non-infectious	
	G1	G2	G1	G2
Mortality	0,16 % (*)		3,6 % (**)	4,2 % (**)
Culling	0,14 % (*)		2,5 % (***)	4,5 % (***)

Table 75: Culling and lameness-related mortality

(*) (Ettema, Østergaard et Kristensen, 2010)

(**)Adapted from (Ettema, Østergaard et Kristensen, 2010) and (Bicalho *et al.*, 2007)

(***)Adapted from (Ettema, Østergaard et Kristensen, 2010)

The time of exit, whether for culling or mortality, is fairly linear between 15 days after the onset of lameness and its theoretical end. The model implemented in the simulator, adapted from (Booth *et al.*, 2004), removes the animal from the herd after a period of time that is uniformly within the 15 to 30 day window.

The presence of a non-infectious lameness lasting 5 months or more (150 days) and not cured at the time of drying off leads the farmer not to inseminate the cow during the next heat. She will be culled at the end of her last extended lactation. Cows culled for uncured lameness have a "cull cow" value, i.e. half the value of a healthy cow.

2.2.3.3.1.2 Incidence

The incidence has two dimensions: the basic incidence based on a basic behaviour causing only spontaneous cases, and a modulation allowing to integrate individual characteristics of the cows that may favour the appearance of additional cases (or if necessary to reduce the basic incidence).

2.2.3.3.1.2.1 Basic incidence

The baseline incidence is to be determined for nominal prevention methods. It therefore only reflects the spontaneous occurrence of the disease in the herd. Two risk periods are identified: peak lactation and dry period. The incidence is therefore set when the cow is lactating or drying off. And given the lack of epidemiological evidence for severe lameness, the G2 severity level is described as a G1 aggravation (see paragraph *2.2.3.3.1.4.2 Aggravation of a lameness episode*). Thus, only the baseline incidence of G1 lameness is described here for both types of lameness.

And so the incidence of all lameness combined is 20.3 cases/100 cows/year. In France, the incidence of digitis dermatitis lesions is 48 cases/100 feet/year (Relun, Lehebel, Bruggink, *et al.*, 2013) but only 20% of cows with lesions are lame (van Huyssteen *et al.*, 2020). In the dry period, only one author looked at the incidence of lameness, which is 8.2/100 cows/week, but the farming system is not representative of the one simulated. Based on this and on expert opinion, it was possible to model the reference incidence as follows:

Risk period	Basic incidence of infectious lameness	Basic incidence of non-infectious lameness
Lactation	20 cases/100 dairy cows/year (Relun, Lehebel, Bruggink, *et al.*, 2013)	15 cases/100 dairy cows/year Adapted from (Afonso *et al.*, 2020)
Dry off	4 cases/100 dairy cows/year Adapted from (Daros *et al.*, 2019)	

Table 76: Baseline incidence of infectious and non-infectious lameness according to risk periods

The daily risk curve is shown in the following figure:

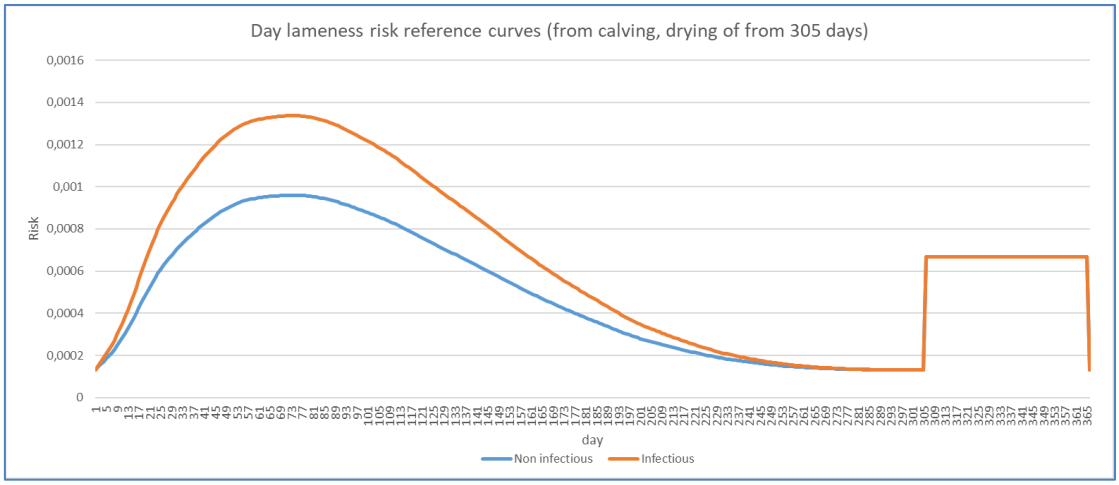


Figure 21: Basic daily risk curve for the incidence of lameness, starting from calving and for a 305-day lactation

For long lactations, this risk is extended beyond day 305 in a uniform manner.

2.2.3.3.1.2.2 Incidence risk modulation

The risk of lameness incidence can be modulated according to individual situations and farming conditions.

2.2.3.3.1.2.2.1 Individual modulation of impact risk

2.2.3.3.1.2.2.1.1 Modulation of the ketosis incidence depending on genetics

Foot health in dairy cows can be improved through genetic selection. Indeed, two indexes have been developed as a result of recording lesions during trimming and genotyping of trimmed animals. These indices are: "RLi" for resistance to infectious lesions and "RLni" for resistance to non-infectious lesions. As the simulator only takes lameness into account, these two indexes are called "RBi" and "RBni". These indices are discussed in section *2.2.4.1 Biological and technical constants related to genetics*.

2.2.3.3.1.2.2.1.2 Modulation of the lameness incidence depending on lactation rank

A meta-analysis (Oehm *et al.*, 2019) modulates the incidence of lameness according to cow parity, i.e. a cow's chance of lameness increases as her lactation rank increases. As a result, the base incidence is modulated as follows:

Lactation rank	Infectious lameness	Non-infectious lameness
1	1	1
2	1	1
3	1,1	1,8
≥4	1,3	2,7
Reference	Adapted from (Relun, Lehebel, Chesnin, *et al.*, 2013)	Adapted from (Oehm *et al.*, 2019)

Table 77: Risk of lameness according to lactation rank

2.2.3.3.1.2.2.1.3 Modulation of the lameness incidence depending on production level

Based on the analysis of the results of different publications (O'Connor *et al.*, 2020), (Solano *et al.*, 2015), (Green *et al.*, 2014) and (Relun, Lehebel, Chesnin, *et al.*, 2013), we decide not to include the level of milk production in the modulation of the incidence. Indeed, when an effect was observed, the statistical analysis did not take into account parity, which is likely to explain the effect on lameness risk by itself. Furthermore, the indexes "RBi" and "RBni" show a genetic correlation with milk production (see *Table 112: Genetic correlation ρ between each phenotypic trait*).

2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases

A cow is more likely to develop lameness in a given time interval when she develops another disease. Depending on the nature of the disease, the associated relative risk is as follows:

	Mastitis (G1 à G3)	Subclinical and clinical ketosis (G1 et G2)
Relative risk	2	2
Risk duration	Concomitant with the disease	Concomitant with the disease
References	From (Dohoo *et al.*, 1983) and (Peeler, Otte et Esslemont, 1994)	Based on (Raboisson, Mounié et Maigné, 2014) and (Dohoo *et al.*, 1983)

Table 78: Relative risk of occurrence of lameness due to competition from other diseases

2.2.3.3.1.2.2.2 Modulation of the risk of incidence linked to herd management

2.2.3.3.1.2.2.2.1 Modulation of the incidence of infectious lameness due to batch contagion

A cow in a batch with a certain prevalence of infectious lameness has a higher risk of becoming lame itself from infectious lameness (Relun, Lehebel, Bruggink, *et al.*, 2013). This applies in the following ways:

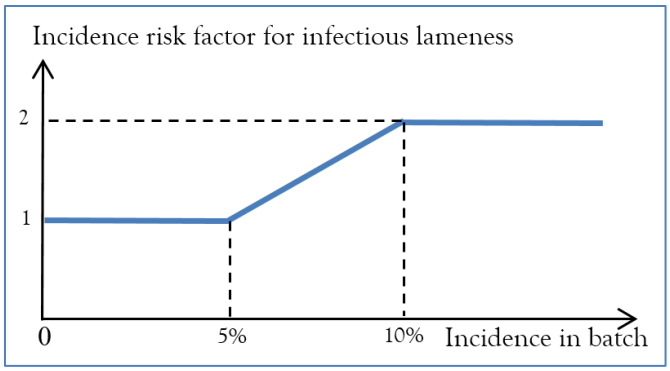


Figure 22: Risk of becoming lame from an infectious disease as a function of batch prevalence

2.2.3.3.1.2.2.2.2 Modulation of the incidence of season-related lameness (housing effect)

A cow that stays in a building for a long period of time is more likely to become lame from an infectious disease in the following ways:

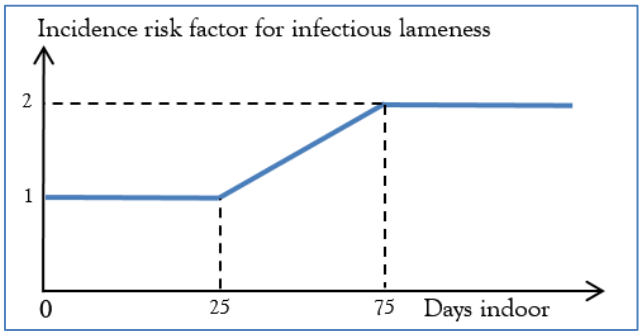


Figure 23: Risk of becoming lame from an infectious disease by staying in a building for a certain period of time

This effect is halved in the case of a mixed grazing/stabling season.

2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures

Foot trimming of cows allows prevention of non-infectious (Hernandez *et al.*, 2007) and (Manske, Hultgren et Bergsten, 2002b), and infectious diseases (Relun, Lehebel, Chesnin, *et al.*, 2013) and to treat cases that would not have been detected routinely. In addition, the use of a foot bath treats infectious lameness cases in short (Relun, Lehebel, Bruggink, *et al.*, 2013) and (Ariza *et al.*, 2017). Thus, trimming and the use of a foot bath are the two available prevention options.

The costs of trimming, foot bath operation and associated care are set in the accounting module (see paragraph *2.2.7.1.3 Health*).

Trimming:

The preventive trimming of a group of cows involves scheduled activity for the vet, and un scheduled activity in the case of group curative trimming of cows detected as lame (see *Table 110: Structure of data on technical heath results*). It also generates activity for the farmer under the same conditions.

Actions of collective preventive trimming on non-infectious lameness:

Trimming prevents non-infectious lameness. The simulator applies the latest recommendations by preventively trimming the cows concerned at the rate defined by the experimenter. This rate can be set (see paragraph *2.2.3.3.2.1.4 Option to prevent infectious and non-infectious lameness through trimming*).

The risk of non-infectious lameness in trimmed cows is presented in the table below:

	Non-infectious lameness prevention for a trimmed cow	Non-infectious lameness prevention and untrimmed cows	References
Incidence risk	0,7	1	(Hernandez *et al.*, 2007) and (Manske, Hultgren et Bergsten, 2002a)
Risk duration	2 months	0	Expert opinion

Table 79: Risk of incidence of non-infectious lameness in trimmed cows

Cows that have been recently trimmed, i.e. closer than the duration of the protection offered by a non-infectious curative trim, are not preventively trimmed.

Actions of collective preventive trimming on infectious lameness:

Incidentally, trimming also prevents infectious lameness. The risk of infectious lameness in trimmed lactating cows is shown in *Table 80: Risk of incidence of infectious lameness in trimmed cows*. The risk was lower according to (Relun, Lehebel, Chesnin, *et al.*, 2013) and was lower than the preventive effect of trimming on non-infectious lameness. It was therefore decided to increase it to the same level as for non-infectious lameness. The risk of infectious lameness in trimmed cows is shown in the table below:

	Infectious lameness prevention for a trimmed cow	Infectious lameness prevention and untrimmed cows	References
Incidence risk	0,7	1	Adapted from (Relun, Lehebel, Chesnin, *et al.*, 2013)
Risk duration	3 weeks	0	Expert opinion

Table 80: Risk of incidence of infectious lameness in trimmed cows

Curative actions on infectious and non-infectious lameness during collective preventive trimming:

During trimming, lame cows, which have not been detected by the farmer but are detected by the trimmer, are also treated as they are inspected individually. Their collective curative treatment is the same as when the farmer detects lameness and is outlined in paragraph *2.2.3.3.2.4 Treatment plan*.

Foot bath:

Collective preventive actions of the foot bath on infectious lameness:

The foot bath helps to prevent the occurrence of infectious lameness (Relun *et al.*, 2012). The risk of incidence of infectious lameness in cows that have passed through a foot bath is presented in the table below:

	Prevention of infectious lameness for a cow in the foot bath	Prevention of infectious lameness in a cow that has not passed through the foot bath	Reference
Incidence risk	0,89	1	(Ariza *et al.*, 2017)

Table 81: Risk of incidence of infectious lameness of cows in a foot bath

The operating procedures for the foot bath can be configured (see paragraph *2.2.3.3.2.1.3 Foot bath frequency option*).

Curative actions on infectious lameness when using the foot bath:

The foot bath can be used to treat infectious lameness. When the foot bath is used, dairy cows with infectious lameness, not yet detected, are treated as follows:

	Treatment of infectious lameness for a cow in the foot bath		References
	G1	G2	
Healing risk	Factor 1.3 of the spontaneous recovery rate (see paragraph 2.2.3.3.1.4)		Adapted from (Ariza *et al.*, 2017) and (Relun *et al.*, 2012)
Duration before effect (days)	5	9	Expert opinion

Table 82: Risk of recovery from infectious lameness of cows in a foot bath

This data is not shown in paragraph *2.2.3.3.2.4 Treatment plan* as it is derived from a collective treatment. The risk of recovery is reduced to the day by a ratio of the duration of the effectiveness of the foot bath.

2.2.3.3.1.3 Lameness detection

In its clinical form, lameness causes phenomena that are easier to observe externally. Cows move slower, shift their weight to the unaffected foot, have a bent back and a rocking effect of their head.

Two means of detection are available: the farmer or an on-board sensor. Breeders generally have difficulty detecting G1 severity lameness but are better at detecting G2 severity lameness according to (Cutler *et al.*, 2017), (Whay, Main et Green, 2003) and (Wells *et al.*, 1993). A distinction in case detection is made between a sensitive and a less sensitive breeder as described in the table below.

An on-board sensor is being researched that will detect a lame cow based on their approach. Ideally, this data should be coupled with milking, feeding and body condition data.

The means of detection can be set up as defined in paragraph *2.2.3.3.2.2 Detection options*.

	Infectious and non-infectious lameness		References
	G1	G2	
Sensitive farmer	40%	95%	Adapted from (Thomsen, 2009) and expert opinion
Less sensitive farmers	20%	70%	
Sensor	90%	100%	Expert opinion

Table 83: Sensitivity of detection of lame cows

The veterinary care contract may change the farmer's sensitivity during the simulation (see paragraph *2.2.3.3.2.2 Detection options*). Lameness cases, when detected, systematically lead to the implementation of an adapted treatment according to the cause of the lameness, the plan of which is defined in paragraph *2.2.3.3.2.4 Treatment plan*. Detection occurs with a uniform law from day 5 to day 10 of lameness.

2.2.3.3.1.4 Evolution and healing of lameness

The dynamics of disease progression are defined according to the following model:

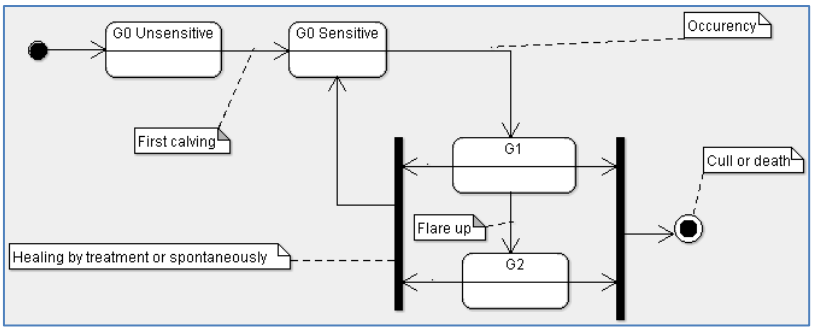


Figure 24: Dynamics of lameness evolution

The principle implemented by the simulator is to trigger, when the conditions are met (in lactation or at drying off, parity, competition with the episode of another disease, etc.) and in a stochastic manner from the incidence described in paragraph *2.2.3.3.1.2 Incidence*, a case of G1 lameness, whether infectious or non-infectious, which, depending on the factors involved, will heal following collective preventive treatment or with the introduction of one or more treatments, worsen (thus becoming a case of G2 lameness), or lead to culling or even death.

G1 lameness can heal spontaneously according to the values described in the table below. Spontaneous recovery of G2 severity lameness is neglected.

Severity lameness G1		**Reference**
Infectious	**Non-infectious**	
50% healed by day15	5% healed by day 20	Adapted from (Relun *et al.*, 2012)

Table 84: Spontaneous healing from G1 severity lameness

Spontaneous healing of G2 severity lameness is overlooked.

2.2.3.3.1.4.1 Duration of lameness

When undetected, lameness goes untreated and can last for a long time. The duration of lameness is not defined as it depends on the circumstances described in the following lines.

2.2.3.3.1.4.2 Aggravation of a lameness episode

All G1 severity lameness that is not cured spontaneously or by treatment will worsen to G2 severity lameness. The time to aggravation depends on the type of lameness. For infectious lameness it is 30 to 90 days spread according to a uniform law, and for non-infectious lameness it is 70 to 170 days spread in the same way.

2.2.3.3.1.4.3 Recurrence of lameness

Infectious lameness may not recur until 3 weeks after recovery (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009), and 2 months for non-infectious lameness (by expert opinion). These durations are modelled in the simulator as temporary periods of insensitivity.

2.2.3.3.2 Lameness-related husbandry parameters

The simulator settings allow you to define the overall prevention factor, the prevention and detection options, and the treatment plan.

2.2.3.3.2.1 Prevention factors

2.2.3.3.2.1.1 Global prevention factors

A multiplicative value is used to improve the prevention of lameness (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), and allows the effect of management factors that influence incidence but are not explicitly represented (see paragraph *2.2.3.3.1.2.2 Incidence risk modulation*). A global prevention factor is described for lameness of infectious origin and another for lameness of non-infectious origin. The default value is 1.0.

2.2.3.3.2.1.2 Option to prevent infectious lameness by using a foot bath

The use of preventive treatment by using a foot bath to reduce the incidence of infectious lameness can be set (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures). The option to use the foot bath is not selected by default. When selected, the protection, which can be parameterised, defaults to 21 days (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009).

2.2.3.3.2.1.3 Foot bath frequency option

When the foot bath is used for lactating cows, it is possible to set the frequency of its use (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures), differently for the three housing systems (see paragraph *2.2.5.2.2.1 Stabling and grazing*). The default value for each of the grazing, stabling and mixed housing systems is 21 days (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009).

2.2.3.3.2.1.4 Option to prevent infectious and non-infectious lameness through trimming

Different trimming methods are proposed to reduce the incidence of infectious and non-infectious lameness (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures), they are as follows:

- No trimming,

- Systematic and grouped preventive trimming of the batch of lactating cows the first day of autumn (default),

- Systematic and grouped preventive trimming of the batch of lactating cows the first day of spring and the first day of autumn,

- Preventive trimming of lactating cows in small groups after calving (enrolled after 60 days) and at dry-off (enrolled immediately)

For the last option, trimming is carried out when the list of registered cows contains enough individuals for the trimming workshop to be set up and group trimming to be carried out. The size of the small group of cows to be trimmed preventively is the same as for curative trimming, which can be configured (see paragraph *2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment*).

The application of a veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), may modify the preventive trimming option initially chosen during the simulation. The practical effect in this case is to recommend preventive trimming twice a year, regardless of the option initially chosen. This option is put into practice after one year of contract.

Preventive trimming activities are a planned veterinary activity included in the results (see paragraph *2.2.3.6 General health produced data*).

2.2.3.3.2.2 Detection options

Three detection options are offered to the experimenter: visual detection by the sensitive farmer, by a less sensitive farmer and detection using a sensor.

Visual detection by a less sensitive farmer is chosen by default as described in paragraph *2.2.3.3.1.3 Lameness detection*. However, the application of a veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), can change the breeder's sensitivity over the course of the simulation. Indeed, the advice given to the farmer by the veterinarian under this contract, as well as his proximity to the farmer, means that a farmer initially set as "not very sensitive" can become "sensitive" after 6 months.

2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment

Cows found to be lame are treated in small groups. This is also the case when the option of preventive trimming by small groups is selected (differentiated group). The size of these small groups is configurable, the default value is 10.

The veterinary care contract option (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) can reduce the time taken to process cases by reducing the size of these groups during simulation. In this case, if the trimming group size initially set was larger, it is reduced to 5 cows after 6 months, which reduces the time taken to treat cases.

2.2.3.3.2.4 Treatment plan

This section only covers individual treatments resulting from routine detection of a lame cow. The treatment of cows detected as lame through the use of collective preventive measures such as trimming or the use of a foot bath is described in paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures.

When lameness is detected by the farmer (alone or with the means of detection available to him), he will only treat when there are a certain number of lame cows in this case, whether infectious or not. This number of cows to be treated can be set (see paragraph *2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment*), which can be reduced during the simulation in the event of a veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) to ensure that it is taken into account more quickly. It performs a curative trimming, it provides veterinary care for the cow (see *Table 110: Structure of data on technical heath results*).

The treatment plan applied is configurable, its default values are as follows:

	All periods			
	Non-infectious lameness		**Infectious lameness**	
Severity	**G1**	**G2**	**G1**	**G2**
Name	Fitting a heel pad		Dressing with disinfectant	
Delay before effect (d)	3 to 7 (*)	7 to 14 (*)	3	7
Milk waiting delay (d)	0			
Healing probability 1st treatment	55%	55%	90%	85%
Healing probability if 1st treatment failure	45%	25%	90%	85%
References	(Thomas *et al.*, 2015) and expert opinion		Expert opinion	

Table 85: Valeurs par défaut du plan de traitement de la boiterie

(*) uniform distribution

The same curative treatment is carried out when a cow is found to be lame during preventive collective trimming. If it was not effective at the first attempt, the treatment of a G2 lameness is repeated every 40 days until it is cured.

The cost of the treatment is set in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.3.3 Specific data produced on lameness

General technical data relating to lameness (non-infectious, infectious, severity 1 or 2) encountered in the herd are generated automatically; they are described in section *2.2.3.6, 'General health data generated'*. The specific data generated described below are generated only in the 'full results' version of the simulator:

Result names: « AnnualNonInfectiousLamenessResults » and « AnnualInfectiousLamenessResults ».

Type of production: annual.

Information level: Herd.

The available fields are as follows:

Field name	**Format**	**Value**
G1_lameness_per_100_cows	real	Number of cases of G1 severity lameness / number of cows present (percentage)
G2_lameness_per_100_cows	real	Number of cases of G2 severity lameness / number of cows present (percentage)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 86: Structure of the data on annual lameness results

2.2.3.4 Neonatal infectious gastroenteritis (GENNI)

During their first days of life, calves are susceptible to infection by viral, bacterial, or parasitic pathogens responsible for neonatal gastroenteritis. The severity of the infection varies depending on the pathogen involved and can lead to the death of the animal in the short, medium, or long term. These infectious gastroenteritis conditions have consequences for growth, reproduction, and milk production during the first lactation and can lead to premature culling of the animal.

2.2.3.4.1 Biological and technical constant values for GENNI

2.2.3.4.1.1 GENNI description

2.2.3.4.1.1.1 GENNI types

The simulator takes into account four different types of GENNI, representing the four main pathogens encountered in livestock farming that cause GENNI during the first 30 days of life:

Pathogen name	Abbreviated name
Escherichia coli entérotoxinogène	ETEC
Cryptosporidium parvum	Crypto
Rotavirus	Rota
Bovine coronavirus	Corona

Table 87: Pathogens responsible of GENNI

2.2.3.4.1.1.2 GENNI severity levels

GENNI can occur with varying degrees of severity and frequency depending on the pathogen involved.

2.2.3.4.1.1.2.1 GENNI severity levels definition

The severity levels were determined as follows:

Name	Definition
G0	Healthy animal
G1	Infected animal with mild to moderate diarrhea
G2	Infected animal with severe diarrhea and systemic involvement

Table 88: GENNI severity levels

2.2.3.4.1.1.2.2 Distribution of severity levels according to GENNI type

The distribution of severity levels depends on the causative agent and whether it is the first occurrence of the disease. If the calf has not yet been affected by a GENNI, the probability of severity being G2 is as follows (Bartels *et al.*, 2010):

Pathogen	G2 probability
ETEC	0,6
Crypto	0,7
Rota	0,6
Corona	0,6

Table 89: Distribution of the risk of severity of the first GENNI

This probability can be adjusted according to the calf's protection status and the mother's vaccination status (see paragraph *2.2.3.4.1.2.2.2.2 Vaccination of the dam*). If the calf was already infected with at least one GENNI at the time a new one appeared, the probability that the latter will be of severity G2 is 100%. A pathology of severity G1 may be detected by the farmer (see paragraph *2.2.3.4.1.3 GENNI detection*).

2.2.3.4.1.1.3 GENNI consequences

Depending on their severity, GENNI can have consequences for the animal's health and production. Subsequently, they can indirectly influence the decision to cull the animal (see paragraph *2.2.5.1.1.2.2.2 Culling for population regulation*).

2.2.3.4.1.1.3.1 Delay in the sale of the calf

Calves intended for sale (male calves, sterile females, beef crossbreeds, surplus heifers) cannot be sold when they are suffering from clinical GENNI, but only once they have recovered.

2.2.3.4.1.1.3.2 Decrease in average growth

During an episode of GENNI, the calf is weakened and does not feed or feeds very little, causing a serious nutritional deficiency during a period of significant growth. If this episode is classified as severity G2, the calf does not feed for two days. Following GENNI, it has been found that average daily gain (GMQ) is reduced throughout the animal's growth. In the simulator, this translates into a delay in the age at first calving in the following proportions (adapted from (Goh, House et Rowe, 2024) and (Abuelo, Cullens et Brester, 2021):

Delay in first calving (days) (*)	
G1	G2
+4	+6

Table 90: Delay in first calving caused by GENNI

(*) In the event of infection by multiple pathogens, the simulator will implement the maximum delay.

2.2.3.4.1.1.3.3 Decrease in milk production during first lactation

The milk production of a cow that contracted GENNI during its first days is reduced during its first lactation. There is a decrease of 1.07 kg per day of lactation (adapted from (Abuelo, Cullens et Brester, 2021)). This production returns to normal in the second lactation.

As a result, and depending on the farmer's strategy for managing surplus calves, a female calf may be sold because it has been affected by GENNI if its genetic value does not protect it (see paragraph *2.2.5.1.1.2.1 Sale of female calves*).

2.2.3.4.1.1.3.4 Mortality

Mortality linked to GENNI occurs at two levels: mortality directly linked to calf disease, and mortality linked to increased susceptibility to unmodeled diseases, which can ultimately cause the death of the animal throughout its growth.

2.2.3.4.1.1.3.4.1 Mortality linked to GENNI pathogens affecting calves

Calf mortality linked to a GENNI pathogen concerns G2 cases in the event of treatment failure according to the probability described in paragraph *2.2.3.4.2.9 Treatment plan*, and subclinical G1 cases if they do not heal spontaneously (see paragraph *2.2.3.4.1.4.1 Spontaneous healing*) and do not worsen to G2 severity according to the probability described in paragraph *2.2.3.4.1.4.3 GENNI flare up*. Only the ETEC pathogen can cause calf death in the case of subclinical GENNI G1, with a probability of 0.1 (adapted from (Virtala, 1996)). Clinical G1 cases never lead to direct calf death as they recover following treatment or worsen to G2.

The risk of mortality may be increased if the calf has not benefited from immunity transfer (see paragraph *2.2.3.4.1.2.2.2.1 Passive transfer of immunity*). The risk factor applied in this case is 9.12 (adapted from (Lora *et al.*, 2020)).

In all cases, death occurs at the end of the episode duration defined for the sick calf as described in paragraph *2.2.3.4.1.4.2 GENNI duration*.

2.2.3.4.1.1.3.4.2 Effect of GENNI on animal mortality related to unmanaged diseases

GENNI increases the risk of various diseases developing during the animal's growth, most of which are not managed in the simulator. To represent this effect, a risk factor for animal death following a GENNI episode is applied, linked to the age of infection and not to the causative agent (Goh, House et Rowe, 2024):

Age at onset of first GENNI	Associated mortality risk	
	1 to 20 days after the end of the last episode	21 to 100 days after the end of the last episode
1-7j	HR 2,00	HR 1,54
8-14j	HR 2,83	HR 2,27
15-21j	HR 8,22	HR 2,90
>22j	HR 1,19	HR 1.0

Table 91: Effect of GENNI on animal mortality related to unmanaged diseases

The cause of death is not classified as "GENNI" in this case, but as "otherDeathReason".

2.2.3.4.1.2 GENNI incidence

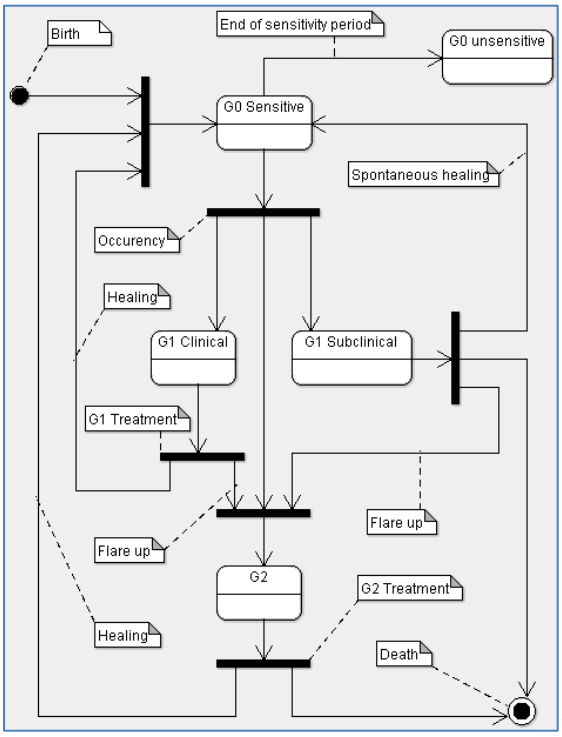


Figure 25: GENNI epidemiological model

*Proportion of each type of pathogen in the incidence**GENNI incidence*

Figure 26: GENNI risk periods

2.2.3.4.1.2.2 Incidence modulation

2.2.3.4.1.2.2.1 Incidence modulation

Lactation rank	Risk factor
1	1,75
2	1,33
3 and +	1

Table 92: Modulation of GENNI incidence linked to maternal parity

2.2.3.4.1.2.2.2 Herd modulation

2.2.3.4.1.2.2.2.1 Passive transfer of immunity

Passive transfer of immunity	Risk factor
Success	1
Failure	3.18

Table 93: Effect on the incidence of colostrum intake failure on the incidence of GENNI

Vaccination of the damMortality linked to GENNI pathogens affecting calves $I(x, \varepsilon) = \varepsilon + (100 - \varepsilon) * \frac{e^{2,9529x}}{100}$ %

$$I(x, \varepsilon) = \varepsilon + (100 - \varepsilon) * \frac{e^{2,9529x}}{100} \%$$

$x = x1 * x2$

$\varepsilon\varepsilon = 100 - \varepsilon'$

Control modality	Risk factor	
	Good colostrum management practices	Poor colostrum management practices
No colostrum bank neither controls	1	
Colostrum weighing	0,41	0,861
Refractometer	0,07	0,805

Table 94: Risk factors for immunity failure induced by the type and quality of colostrum management

Quality control of colostrum and colostrum bank management

Colostrum modality	Risk factor	
	Less than 4 liters	At least 4 liters
Under the mother or without special attention	1	
Before4 hours	0,5704	0,4588
After 4 hours	1,1408	0,9176

Table 95: Risk factors for immunity failure induced by the time elapsed before colostrum intake and the amount received

*Time spent for colostrum and quantity received**ε**Proportion of calves receiving colostrumVaccination of the dam*

Vaccination of pregnant cows

Concerned pathogen	Risk factor					Reference
	Incidence	Episode length	G1 healing	G1 flare up to G2	G2 probability	
		§ 2.2.3.4.1.4.2	§ 2.2.3.4.1.4.1 § 2.2.3.4.2.9	§ 2.2.3.4.1.4.3	§ 2.2.3.4.1.1.2.2	
ETEC	0.5	1	1,3	0,5	0,5	Adapted from (Viidu et Mõtus, 2022)
Corona	0.5	1	1,1	0,5	0,5	
Rota	0.5	1	1,1	0,5	0,5	
Crypto	0,46	0,49	1	1	1	According to (Timmermans *et al.*, 2024)

Table 96: GENNI risk factors related to dam vaccination

Vaccination of pregnant cowsThermal comfort of calves

Position of the calf pen	Risk factor (for all pathogens)
Indoor	0,57
Outdoor	1

Table 97: Modulation of GENNI incidence related to calf thermal comfort

Position of the calf penManagement of calf living environment hygiene

Hygiene is important in combating the onset of GENNI in dairy farming. Effective hygiene measures can drastically reduce the risk of infection, particularly in the calf's environment. This applies to the various areas where the calf will live, namely the calving pen or calf pen. In practice, this means, for example, keeping the maternity ward clean, where the mother is isolated during calving, or cleaning the calf pens before the arrival of a new calf. In the simulator, hygiene management is reflected in a score ranging from 1 to 5, with 1 representing a farm where there is no control of hygiene in the calf's living areas, and 5 representing impeccable hygiene in these areas. This is considered as follows:

Hygiene management score	**Risk factor (for all pathogens)**	**Reference**
1	2	Expert opinions
2	1.7	
3	1	Adapted from (Klein-Jöbstl, Iwersen et Drillich, 2014), (Klein-Jöbstl, Iwersen et Drillich, 2014) and (Bartels *et al.*, 2010)
4	0,6	
5	0.2	

Table 98: Modulation of GENNI incidence related to environmental hygiene

This option can be configured as defined in paragraph *2.2.3.4.2.8 Hygiene score*.

2.2.3.4.1.2.2.2.5 Global prevention factor

Overall GENNI prevention factorGENNI detection

Sensitivity of detection of minor GENNIGENNI progression and recovery

2.2.3.4.1.4.1 Spontaneous healing

GENNI flare upMortality linked to GENNI pathogens affecting calvesVaccination of the damGENNI durationGENNI duration

Figure 27: Beta distribution of GENNI durations

Vaccination of the GENNI flare up

Pathogen	**Probability**
ETEC	0,35
Crypto	0,15
Rota	0,15
Corona	0,15

Table 99: Probability of flare up of undetected GENNI G1 to G2

Vaccination of the damTreatments

*Treatment planVaccination of pregnant cowsTreatment planHealthTable 110: Structure of data on technical heath results*GENNI-related husbandry parameters

2.2.3.4.2.1 Sensitivity of detection of minor GENNI

2.2.3.4.2.2 Proportion of each type of pathogen in the incidence

It is possible to adjust the importance of the pathogen type in the incidence. The default values for infections caused by a single pathogen are defined according to the following graph (based on (Bartels *et al.*, 2010)):

Pathogen	Main profil (%)			
	Mean profile (default)	**ETEC profile**	**Crypto profile**	**ROTA profile**
ETEC	**6**	50	3	10
Crypto	**59**	20	80	25
Rota	**31**	25	14	60
Corona	**4**	5	3	5

Table 100: Setting the proportion of pathogens in incidence

2.2.3.4.2.3 Quality control of colostrum and colostrum bank management

*Passive transfer of immunity**Time spent for colostrum and quantity received***

*Passive transfer of immunity**Proportion of calves receiving colostrum***

This parameter determines the proportion of calves receiving colostrum at birth (*Passive transfer of immunity*). The value must be between 0 and 100. The default value is 100.

2.2.3.4.2.6 Vaccination of pregnant cows

Vaccination of the

Pathogen target	**Vaccination modality**			**Cost incurred** (see *2.2.7.1.3 Health*)	
	Vaccination of pregnant cows when a case of GENNI is detected in a calf	Systemic vaccination of all pregnant cows		Primiparous	Multiparous
		Scattered calving	Grouped calving		
ETEC + Rota + Corona	1 unplanned activity, upon detection	6 planned activities / an	2 planned activities / year	1 vaccine / animal	
Crypto		12 planned activities / year due to primiparous presence		2 vaccines / animal	1 vaccine / animal
Tous				3 vaccines / animal	2 vaccines / animal

Table 101: Breakdown of the breeder's activities relating to GENNI vaccination of future dams and associated costs

2.2.3.4.2.7 Position of the calf pen

*Thermal comfort of calves**Hygiene score***

*Management of calf living environment hygiene Health*Paratuberculosis*Treatment plan*

Table 102: Default values for the GENNI processing plan, general case

		G1				G2 (provided by the vet*)			
Name		G1 GENNI treatment for <pathogen>				G2 GENNI treatment for <pathogen>			
Effect delay (d)		3				4			
Pathogen		ETEC	Crypto	Rota	Corona	ETEC	Crypto	Rota	Corona
Healing probability	**Targeted**	0.80	0.95	0.50	0.50	0,90	0,98	0,95	0,85
	No targeted	0,70	0,85	0,50	0,50	0,85	0,95	0,95	0,85

Table 103: Effectiveness of treatment of severity G2

ETEC	Crypto	Rota	Corona
0.70	0.90	0.90	0.80

provided by the breeder to males in cases

*Vaccination of the dam**Veterinary care contract option**Overall GENNI prevention factor*

*Global prevention factor*Specific data produced relating to GENNI

General technical data relating to lameness (non-infectious, infectious, severity 1 or 2) encountered in the herd are generated automatically; they are described in section *2.2.3.6, 'General health data generated'*. The specific data concerning the daily status of GENNI calves by pathogen described below are generated only in the 'full results' version of the simulator:

Result name: « GenniCalfSituation<*pathogen*>Results »

Production type: on time at 30 days for the calf.

Information level: Calf.

The available fields are:

Field name	**Format**	**Value**
Id	integer	Identifiant de l'animal concerné
Day_<day number>	Infection status (*)	Day state
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 104: Structure of data relating to the daily status of GENNI calves

(*) See *Table 2: Type data formats page 15.*

2.2.3.5 Paratuberculosis

2.2.3.5.1 Biological and technical constant values for paratuberculosis

2.2.3.5.1.1 Paratuberculosis description

Bovine paratuberculosis (or Johne's disease) is a chronic granulomatous enteritis caused by Mycobacterium avium subsp. paratuberculosis (MAP). It mainly affects domestic ruminants, causing progressive weight loss, chronic diarrhoea and a decline in milk production. Transmission occurs predominantly via the faecal-oral route through the ingestion of MAP present in the environment; the second most significant route of infection is vertical transmission in utero; and, finally, transmission via colostrum or milk, although less common, is possible (Whittington *et al.*, 2019). The pathogen multiplies slowly and persists for a long time in the external environment, which helps it to persist on livestock farms (Kirkeby *et al.*, 2016).

Type C (cattle type) strains predominate in European cattle and are more resistant in the environment than type S (sheep type) strains (Whittington *et al.*, 2019). The only strain type modelled in the simulator is type C.

2.2.3.5.1.1.1 Stages of infection

Stage	Description
S	Susceptible to MAP, not infected
IT	Transiently infected: recent infection, no excretion
IL	Latent infection: persistent infection, negligible excretion
IM	Subclinical infection: moderate excretion, positive serology
IC	Clinically infected: significant or massive shedding, clinical signs
R	Animal over 1 year old that can no longer be infected

Table 105: Definition of the stages of paratuberculosis infection

Individual contribution (excretion)Sensitive (S)

The sensitive (S) stage corresponds to an animal that is not infected with MAP. It is serologically negative and shows no signs of clinical illness.

2.2.3.5.1.1.1.2 Refractory (R)

The refractory stage (R) is associated with animals that have remained susceptible until the age of 1 year. They then become refractory, making it impossible for the disease to progress to any other stage.

2.2.3.5.1.1.1.3 Transiently infected (IT)

The transiently infected (IT) stage is assigned to an animal that has just become infected. At this stage, it shows no clinical signs. The progression will inevitably be to the latent infected (IL) stage. The transition from transiently infected (IT) to latent infected (IL) is modelled on a daily basis using a Bernoulli draw with a probability of 1/Vt, where Vt is the average duration of the transiently infected phase: here, Vt = 168 days (van Roermund *et al.*, 2007). Otherwise, a heifer in the transiently infected (IT) stage who has not yet progressed to the latent infected (IL) stage will do so at the time of her first calving. Thus, genetics only serves to maximise the chances of avoiding infection; however, once an animal is infected, it has an equal chance of progressing to the next stage, regardless of its genetic makeup.

2.2.3.5.1.1.1.4 Latent infection (IL)

The latent infection (IL) stage follows the transient infection (IT) stage. An animal cannot progress beyond this stage until it is one year old. At this stage, the animal shows no clinical signs and is almost impossible to detect. This stage will inevitably progress to the subclinical infected (IM) stage. The transition is modelled daily from the animal's first birthday onwards, using a Bernoulli draw with a probability of 1/Vl, where Vl is the average duration of the latent phase; here, we have set Vl = 730 days (Nielsen et Ersbøll, 2006). An animal may remain latently infected (IL) for its entire life if it does not spontaneously progress to the subclinical infected stage (IM).

2.2.3.5.1.1.1.5 Subclinical infection (IM)

The subclinical stage (IM) follows the latent infection stage (IL). At this stage, the animal shows a slight reduction in milk production as well as a minor impact on its slaughter value (see paragraph *2.2.3.5.1.1.2.3 Impact on slaughter value*). This stage will inevitably progress to the clinically infected (IC) stage. The transition from subclinical infection (IM) to clinical infection (IC) is modelled daily using a Bernoulli draw with a probability of 1/Vm. Here, Vm represents the average duration of the subclinical phase, and we have set Vm = 728 days (Nielsen et Ersbøll, 2006).

2.2.3.5.1.1.1.6 Clinically infected (IC)

The clinically infected (IC) stage follows the subclinically infected (IM) stage. At this stage, the animal shows a significant drop in milk production as well as a major impact on its slaughter value (see paragraph *2.2.3.5.1.1.2.3 Impact on slaughter value*).

The outcome of this stage is systematic culling.

2.2.3.5.1.1.2 Consequences of paratuberculosis

2.2.3.5.1.1.2.1 Culling increase

MAP infection and the incurable disease it causes mean that farmers must cull cows that test positive in serological tests (see paragraph *2.2.3.5.1.1.2.5 Mortality and culling risk*) or cows with genetic indices that increase their susceptibility to paratuberculosis. The current recommendations regarding the culling strategy to be adopted are set out below and may be used for simulations (Synetics, 2024):

- Infected or highly susceptible females (if genotyped) are culled to prevent transmission.

- Healthy but susceptible females are inseminated with a beef crossbreed bull to avoid the risk of producing susceptible offspring if the scenario includes genotyping and a paratuberculosis crossbreeding strategy.

- Genetically standard or resistant healthy females are inseminated with suitable paratuberculosis-resistant (PTR) bulls, using sexed semen, Fertimax or conventional semen, where genotyping is included in the scenario and in accordance with the insemination strategy in place

- A few lines of high genetic merit but which are susceptible can be preserved by strictly using RPTB bulls to produce more resistant offspring.*Further decline in milk production*

Depending on the stage of infection, cows may experience a decline in milk production that varies according to the stage of the disease (L. Smith *et al.*, 2016):

Stage	Decrease in milk production in kilograms per day
IT, IL	No reduction (*)
IM	−1.4 – 0.09 × MthP (**)
IC	−4.0 – 0.7 × MthP (**)

Table 106: Decrease in milk production according to the stage of paratuberculosis infection

2.2.3.5.1.1.2.3 Impact on slaughter value

The disease does not directly affect appetite, but causes intestinal malabsorption linked to granulomatous enteritis. The animal eats normally but gradually loses weight, reflecting a loss of digestive efficiency (Whittington *et al.*, 2019). This leads to a loss of carcass weight, and therefore of slaughter value, and sometimes, in the case of clinically affected animals, to total rejection at the abattoir. As the animal's weight is not modelled in the simulator, the consequences will only be visible in the slaughter value.

A latent animal has not yet experienced any weight loss. For a subclinically infected (IM) animal, the impact is estimated at 15 per cent of the slaughter value. This figure rises to 47.6 per cent for a clinically infected (IC) cow (Kudahl et Nielsen, 2009).*Impact on susceptibility to other diseases*

Paratuberculosis causes progressive immunosuppression (Th1/Th2 imbalance), which promotes opportunistic infections, particularly mastitis and metritis (Sweeney, 1996). However, due to the lack of quantitative and literature-based data on a correlation between the impact of paratuberculosis infection and susceptibility to other diseases, this impact will not be modelled.*Mortality and culling risk*

Cows at the clinical stage (IC) have a probability of culling or mortality of nearly 100 per cent within 6 to 12 months of the onset of symptoms (Marcé, 2010). In this model, clinically affected animals are culled rapidly within one month of a positive result for paratuberculosis. Assuming that a PCR test is routinely carried out in the event of a negative ELISA result, it is assumed that the diagnosis suffers from no sensitivity issues and is 100 per cent reliable in the event of a positive result. Consequently, clinical cases will not remain in the herd long enough for their mortality to be considered.

Nevertheless, we have set a culling limit in the simulator for cows at an advanced stage of gestation. Beyond this stage, culling can only take place after calving. Although European regulations (Regulation (EC) No 1/2005) prohibit the transport of animals during the final tenth of their gestation (252 days), we have set this limit at 210 days. Indeed, this limit is often adopted by farmers and abattoirs to prevent the risks of unexpected calving, dystocia and significant physiological stress. This decision is in line with the scientific recommendations of the EFSA (2022) on the transport of cattle Conversely, animals clinically identified as pregnant for less than this period will be culled in accordance with the GDS recommendations for paratuberculosis control plans, i.e. within 2 weeks to 30 days (applied in the simulator using a uniform distribution). This will also apply to animals found to be subclinically positive during routine preventive screening (see section 2.2.3.5.1.4.2 Practical use of tests) if they are not pregnant. For subclinically positive pregnant animals, culling will only take place after calving.*MAP quantity*

To model the transmission of paratuberculosis to animals as accurately as possible, we needed to add an environmental compartment that had not previously existed in the simulator. We can therefore now model environmental contamination with MAP by adult excreting individuals at different stages. We therefore chose to model a single compartment comprising an overall livestock environment within which all animals would be in contact with one another, regardless of their age. This choice is based both on the simplification required for computer simulation and on situations that may be encountered on farms affected by paratuberculosis.

The equation used to calculate the level of contamination in the overall environment on day Eg(t) is as follows:

$$Eg(t) = Eg(t-1) * (1-\mu) + \sum_{i \in infectious} Excretion$$

Where:

- Excretion: the individual animal's contribution
- μ: the spontaneous breakdown of MAPs over time

2.2.3.5.1.2.1 Individual contribution (excretion)

To estimate the quantity of MAP emitted by an animal, we assign everyone a level of excretion per kilogram of faeces produced, which remains constant throughout the duration of the disease stage. Then, knowing the amount of faeces produced each day (see paragraph *2.2.6.1.2 Faeces produced*), it will be possible to determine its contribution to the overall environment and thus the level of contamination, by multiplying the two figures.

The excretion rate depends on the stage of the disease:

Stage	Excretion rate per kilogram of faeces
S	No excretion
IT	No excretion(*)
IL	No excretion
IM	Probability distribution: $10^{(4+10*beta(2.65,17))}$ with a minimum of 10^4 and a maximum of 10^{15} MAP (Marcé, 2010)
IC	Probability distribution: $10^{(8+10*beta(2,17))}$ with a minimum of 10^8 and a maximum of 10^{15} MAP (Marcé, 2010) (**)
R	No excretion

Table 107: MAP excretion levels depend on the stage of the disease

(*) The literature indicates that animals in the transiently infected stage may excrete the pathogen (van Roermund *et al.*, 2007). However, we estimated that transiently infected animals account for a negligible proportion of total MAP excretion into the wider environment. Indeed, R modelling has enabled us to estimate this proportion as between 10^{-4} and 10^{-5} of the herd's total excretion. The excretion from these animals will therefore not be taken into account.

(**) We chose not to treat clinically infected super-shedders as a separate stage, but rather to define the shedding level of super-shedders as exceeding a threshold (see table below). The excretion levels of clinically infected (IC) animals show a distribution consistent with the literature regarding the proportion of super-shedders (Aly *et al.*, 2012).

In terms of classifying individuals according to their excretion levels, we estimate that the categories are determined according to the following ranges of values:

Excretor category	Range of values (in CFU MAP/kg of faeces)	Reference
Non-shedder or undetectable	0 to 31 CFU/kg	(Magombedze, Eda et Koets, 2016)
Low excretor	31 to 10^3 CFU/kg	(Magombedze, Eda et Koets, 2016) (Field, Mee et McAloon, 2022)
Moderate excretor	10^3 to 10^{10} CFU/kg	(Corbett *et al.*, 2018) (Laurin *et al.*, 2015)
High excretor	Over 10^{10} CFU/kg	(Corbett *et al.*, 2018) (Aly *et al.*, 2012)

Table 108: Classification of individuals according to their level of excretion

2.2.3.5.1.2.2 Spontaneous decomposition (μ)

Daily environmental contamination takes into account the spontaneous breakdown of MAPs on a day-to-day basis, that is, the gradual elimination of MAPs from the environment μ (Jørgensen, 1982), and adds to the residual contamination in the environment the new excretions of MAPs that have occurred during the day. According to (Gao *et al.*, 2025), the decay rate μ is estimated at 0.150 per week and therefore approximately 0.021 per day, which corresponds to a half-life of MAPs of approximately 4.61 weeks in the environment.

2.2.3.5.1.3 Incidence of paratuberculosis

In all the simulations we carry out, we assume that calves are separated from their mothers at birth and are unable to suckle from their mothers. They are fed colostrum from a colostrum bank and subsequently on powdered milk.

2.2.3.5.1.3.1 Routes of contamination and periods of risk

Several routes of transmission occurring at different times may be considered to pose a risk of paratuberculosis infection.

2.2.3.5.1.3.1.1 Orofecal route

The neonatal period (0–6 months) is the most critical stage. During this period, calves are extremely susceptible to faecal-oral infection, which is the main route by which an animal becomes infected with MAP through contact with its environment (including, where applicable, suckling from an infected dam and contact with the faeces of infected adults) (Kirkeby *et al.*, 2016). As the risk is negligible after one year, it is treated as non-existent in the simulator; therefore, individuals over one year old cannot become infected in our model ((Camanes *et al.*, 2018), (Marcé, 2010)), and they are thus assigned the status 'R'. Furthermore, to

reflect this trend, we have used the following basic distribution: $\exp(-0.01 * a_{days})$ (Kirkeby, Græsbøll et Halasa, 2018). This equates to 2.6 per cent at one year (Kirkeby *et al.*, 2016).

The overall equation used to calculate the daily probability of an individual becoming infected with MAP during their first year of life via this major route of transmission—which incorporates the probability of infection via suckling and the probability of infection via their environment is as follows:

$$P_i(t) = 1 - \exp\left(-\exp(-0.01 * a_{days}\right) * S_i * \frac{\beta_{day} * E(t)}{\alpha N(t)} * H)$$

Where:

- $P_i(t)$ is the probability of an individual becoming infected via the faecal-oral route
- $\exp(-0.01 * a_{days})$: Susceptibility term, which decreases with age
- β_{day}: Transmission rate if an infectious dose is present in the environment. It had been estimated at 5×10^{-5} per day for the local environment and at 9.5×10^{-7} per day for the global environment (van Roermund *et al.*, 2007). As our model only includes a global environment, this value was determined to be 7×10^{-7} following calibration.
- $E(t)$: Number of bacteria (Map) in the general environment
- $N(t)$: Number of animals in this general environment
- α: Infectious dose = 10^6 Map (Sweeney, 2006).
- H: The hygiene-related risk factor (see paragraph *2.2.3.5.1.3.2.2 Modulation linked to farm management*)
- S_i: the individual potential relating to susceptibility to paratuberculosis, depending on the corrected performance of the RPTB index for the animal in question (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*).

This equation is applied daily to each 'S' (Susceptible) animal.

2.2.3.5.1.3.1.2 In utero route

Paratuberculosis is a disease for which in utero transmission has been demonstrated. It is the second most important route of transmission. It was therefore essential to include this in our model. For practical reasons, and based on the available literature on the subject, in utero transmission is modelled as a fixed probability at the time of calving: 9 per cent for subclinically infected (IM) and latently infected (IL) individuals, and 39 per cent for clinically infected (IC) individuals (Windsor et Whittington, 2010).

Thus, for each birth, a Bernoulli draw with replacement is carried out to determine whether the calf is infected or not, depending on its dam's status. Births are treated as a sequence of independent events.

The genes identified as playing a role in resistance to paratuberculosis are primarily involved in the local (intestinal) immune response to faecal-oral exposure (Sanchez *et al.*, 2020). In the case of in utero paratuberculosis infection, transmission occurs via the exchange of blood between the dam and the foetus, without the involvement of the intestinal tract.

To date, no studies have been carried out on the link between the foetus's genomic index and its impact on the probability of in utero infection. Therefore, due to the lack of available information, we have hypothesised that the genomic index of the unborn calf will not determine its likelihood of in-utero infection. This likelihood depends solely on the dam's status regarding the disease.

2.2.3.5.1.3.1.3 Route via milk and colostrum

A calf can also become infected via the milk or colostrum it drinks. This is less common, and infection via these routes alone is rare but does occur.

This route of infection has long been overestimated; whilst MAP is indeed excreted in milk and colostrum, a calf fed contaminated colostrum is no more likely to become infected than any other calf (Pithua, Wells et Godden, 2011).

Furthermore, this route of transmission can be considered negligible if the dam-calf pair is separated within 2 hours of calving, the calves are fed milk powder, and the colostrum provided comes solely from healthy mothers (Kirkeby *et al.*, 2016).

We have therefore chosen not to model the transmission of infection to calves via milk and colostrum.

2.2.3.5.1.3.1.4 Direct transmission from calf to calf

Contamination from calf to calf via inhalation was demonstrated in a study carried out by (Eisenberg *et al.*, 2012). However, it remains very low and can therefore be considered a minor factor in our model. Furthermore, we are dealing with a situation in which we model only a single general compartment, namely the overall environment (see paragraph *2.2.3.5.1.2 MAP quantity*). Contamination of this environment by MAP is therefore largely driven by infected adults (both subclinical and clinical). We have therefore decided not to model calf-to-calf transmission.

2.2.3.5.1.3.2 Modulation of the risk of incidence

2.2.3.5.1.3.2.1 Genetic modulation

As described in paragraph *2.2.3.5.1.3.1.1 Orofecal route*, an animal's genetics influence its resistance to the disease via its RPTB index. This index is explained in detail in section *2.2.4 Genetics*.

2.2.3.5.1.3.2.2 Modulation linked to farm management

The risks increase with the stocking density in the building, the cohabitation of calves and adults, the failure to separate calving areas, the recycling of unpasteurised milk or contaminated colostrum, and poor manure management. The lack of precise literature data on this subject prevents us from describing the effect of each adjustment. Given that there is already a parameter in the GENNI section relating to hygiene levels (see paragraph *2.2.3.4.2.8 Hygiene score*), and to avoid creating a new parameter, the factor relating to the level of hygiene to be applied for the PTB will be the inverse of the values described as risk factors in *Table **98**: Modulation of GENNI incidence related to environmental hygiene*.

2.2.3.5.1.3.2.3 Seasonal impact on incidence

Calving concentrated in winter promotes calf-to-calf and adult-to-calf transmission through confinement. Dry summer periods reduce the environmental survival of MAP (Whittington *et al.*, 2019). However, these variations are not modelled in the simulator.

2.2.3.5.1.3.2.4 Veterinary care contract

The management of paratuberculosis is based on comprehensive health monitoring (testing, biosecurity, culling) which does not depend on taking out a veterinary care policy. Paratuberculosis plans are therefore put in place by the various animal health protection groups (GDS), which vary from department to department; these plans cover part of the costs incurred by screening, whether as a preventative measure or when a case is suspected. The rates are set out in *Table **134**: Default rates for health-related accounting transactions*.

2.2.3.5.1.3.3 Calibration

According to (Marcé *et al.*, 2011), in an infected herd (without a veterinary care contract), approximately:

- 70–80 per cent of infected animals is in the latent stage (IL),
- 15–20 per cent is moderately infected (IM),
- 5–10 per cent reach the clinical stage (IC).

These proportions depend on the level of hygiene, stocking density and the dynamics of MAP introduction (Kirkeby *et al.*, 2016).

The prevalence of apparent intra-herd paratuberculosis varies greatly between farms: in France, it ranges from 2.7 per cent to a maximum of 22 per cent (Nielsen et Toft, 2009). This prevalence is underestimated due to the poor sensitivity of the ELISA tests used in the field: the actual prevalence is thought to range between 0 and 60 per cent (Camanes *et al.*, 2018). With an intra-herd prevalence of 5 per cent, the proportion of super-

shedders among clinically affected individuals in Clara Marce's model is consistent with the prevalence of 0.5 per cent estimated in the literature (Aly *et al.*, 2012).

The simulator's default settings should allow these trends to be reproduced.

2.2.3.5.1.4 Detection of cases of paratuberculosis

Screening for paratuberculosis involves a range of different tests.

2.2.3.5.1.4.1 Description of the tests used

The tests are tailored to the animal's clinical stage and, where genotyping is carried out, to its genetic profile; they include ELISA and PCR tests. These tests are predominantly used in the field. Their sensitivity varies considerably depending on the stage of infection, which prevents highly effective screening for the disease and leads to an underestimation of the actual prevalence in livestock herds (Clark *et al.*, 2008).

2.2.3.5.1.4.1.1 Serum ELISA test

The characteristics of this type of test are as follows (Nielsen et Toft, 2009):

Clinical stage	**Sensitivity** (%)(*)	**Specificity** (%)
IT, IL	15	98
IM	50	
IC	88(**)	
IC super-excretors(***)	97	

Table 109: Characteristics of the ELISA test

(*) Estimation of the sensitivity of serological ELISA tests by establishing a link between MAP excretion and the clinical stage of the disease, based on studies by (BRUGEL, 2014) and (Roussel *et al.*, 2005)

(**) possibility of supplementing with a PCR test if the individual is clinically ill but has tested negative (Se=100%)

(**) see paragraph *2.2.3.5.1.2.1 Individual contribution (excretion)*

2.2.3.5.1.4.1.2 Faecal PCR test

In our simulator, sensitivity and specificity will not be considered. This is because a PCR test is only carried out on a clinically ill animal that has already been screened using ELISA, with a negative result. In this context, we assume that the animal's viral shedding is already significant and therefore that the sensitivity is 1.

2.2.3.5.1.4.2 Practical use of tests

Various screening strategies can be used within this model. Practices can be configured (see paragraph *2.2.3.5.2 Herd management practices relating to paratuberculosis*), enabling these different strategies to be implemented. Screening is systematically carried out as part of a 'paratuberculosis plan' or, at the very least, within an incentive-based framework, which allows for reduced test prices through partial reimbursement by the GDS.

2.2.3.5.1.4.2.1 Testing strategy for clinically affected cows

The first strategy does not involve prophylaxis: only animals showing clinical signs are tested, where applicable (serum ELISA followed by quantitative PCR culture if the ELISA test is negative). Screening takes place one month after the onset of clinical signs (IC); this is the time required for the farmer to develop clinical suspicion. This procedure is treated as an unplanned activity on the part of the farmer and the vet for each animal screened. This strategy is implemented from the start of the simulation, as and when clinical cases are encountered.

2.2.3.5.1.4.2.2 Regular screening strategy

A second strategy involves supplementing the first by carrying out regular screening, consisting of annual testing of all non-clinical cows in the herd aged over 24 months using ELISA testing only, carried out on the first day of the financial year. This procedure counts as a single, comprehensive planned activity on the part

of the farmer and the vet if at least one animal is screened. This preventive screening is implemented from the moment the PTB genetic strategy begins (see paragraph *2.2.4.2.2 Genetic strategy*).

2.2.3.5.1.4.2.3 Strategy for regular and infrequent screening

A third strategy is equivalent to the second, except that testing is carried out only every two years for resistant animals. It therefore requires genomic testing at birth, which is always the case when the genetic strategy prioritises the RPTB index.

The resistance threshold is determined by a true genetic value greater than 0.5. This value is justified by the fact that when calculating the relative risk for an individual (equal to the disease susceptibility factor), the risk of infection is halved for individuals with a true genetic value of 0.5.

NB: It is important here to consider how performance is calculated. We do this by taking the index value and adding to it the average of the genomic indices for the population of Prim'Holstein cows born in France from 2020 onwards. This is consistent with the fact that the distribution of genomic indices within the population follows a normal distribution centred on M = 0.1901 (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*). Thus, in the calculation of relative risk, a true genetic value of 0.5 corresponds to an index value of 0.69 when the mean is added to the calculation.

Once adopted, this strategy is implemented within the same timeframe as the previous strategy.

2.2.3.5.1.5 Progression and recovery from paratuberculosis

The various stages of the disease associated with tuberculosis follow one another as shown in the diagram below:

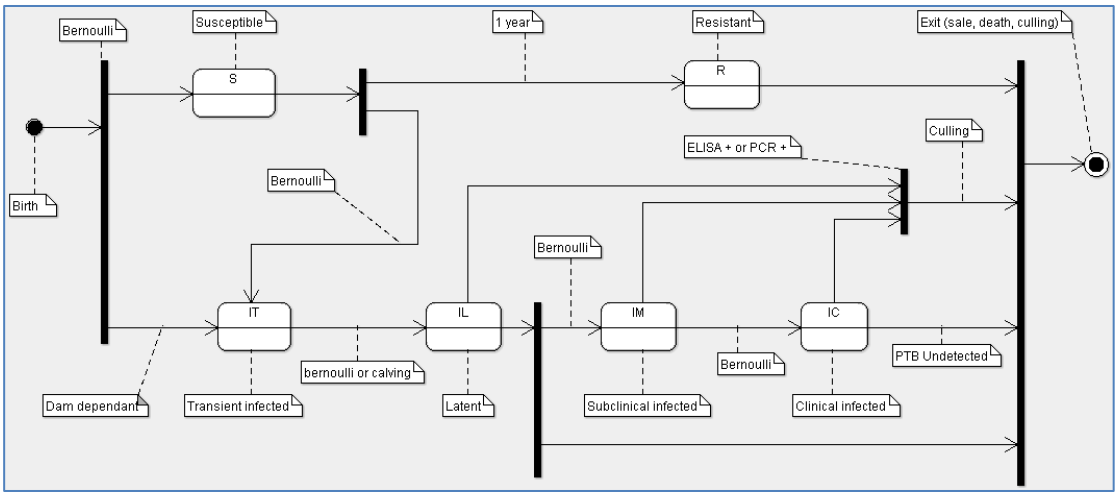


Figure 28: States and transitions in the epidemiological model of paratuberculosis

2.2.3.5.1.5.1 Spontaneous healing

Rare cases of early immune control (effective Th1 phase) leading to partial elimination of the pathogen (Whittington *et al.*, 2019) have been reported in the literature. As regards recovery induced by controlled superinfection, no clear data are available, although some models incorporate a 'cross-immunity' effect that reduces susceptibility to reinfection (Marcé, 2010).
We considered these cases to be too isolated and therefore chose not to include them in the modelling.

2.2.3.5.1.5.2 Flareup

Metabolic stress or co-infections can reactivate a persistent subclinical infection, leading to a transition from latent infection (IL) to moderated infection (IM) (Marcé, 2010).
The probability of transitioning from the latent state to the subclinical state is 1/vl, and from one state to the other is 1/vt, where vl is the average duration of the latent period. We therefore use a binomial distribution with a probability of 1/vl and a draw with replacement every day. An animal cannot emerge from the latent phase until it has reached 1 year of age.

Furthermore, subclinical cows may be high excretors without showing any visible signs, thereby facilitating the hidden spread of MAP (Kirkeby *et al.*, 2016). This is considered in the excretion by subclinical cows described in paragraph *2.2.3.5.1.2.1 Individual contribution (excretion)*.

2.2.3.5.1.5.3 Recovery following treatment

There is currently no effective treatment. Anti-mycobacterial antibiotics (clarithromycin, rifabutin) are ineffective in the long term and are prohibited in dairy production (Whittington *et al.*, 2019).

2.2.3.5.2 Herd management practices relating to paratuberculosis

2.2.3.5.2.1 Occurrence of cases of paratuberculosis

This parameter is an integer value that allows the disease to be introduced into the herd at the start of the simulation by forcing a stochastic proportion of the susceptible animals present to transition to the IT state.
The default value is 0, with a maximum of 10.

2.2.3.5.2.2 Hygiene

The parameter relating to herd hygiene management is described in paragraph *2.2.3.4.2.8 Hygiene score*.

2.2.3.5.2.3 Genotyping

As regards the genotyping option, this depends on the genetic strategy adopted, which is described in paragraph *2.2.4.2.2 Genetic strategy*.

2.2.3.5.2.4 Test strategy

This setting determines the testing strategy adopted (see paragraph *2.2.3.5.1.4.2 Practical use of tests*). The available options are:

- Clinical cows only (default),
- Regular screening.
- Regular screening at intervals. This last option is only implemented if the genetic strategy is set to RPTB priority, as this is the strategy that enables genotyping to be carried out. Otherwise, simple regular screening is implemented.

2.2.3.5.3 Data generated relating to paratuberculosis

The data produced relating to paratuberculosis is generated automatically, regardless of the version of the simulator. They are described in section *2.2.3.6 General health produced data*.

2.2.3.6 General health produced data

The general health data produced relates to annual technical data concerning the diseases managed. It is generated automatically, regardless of the simulator version.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Production type: annual.

Information level: Herd.

The available fields are:

Field name	Format	Value
G1_ketosis_occurency_by_cow	real	Number of subclinical ketosis cases / number of cows calving in the campaign (percentage)
G2_ketosis_occurency_by_cow	real	Number of clinical ketosis cases / number of cows calving in the campaign (percentage)
Subclinical_mastitis_occurency_by_cow	real	Number of subclinical mastitis cases / number of cow present (percentage)
Clinical_mastitis_occurency_by_cow	real	Number of clinical mastitis cases / number of cows present (percentage)
G1_non_infectious_lameness_occurency_by_cow	real	Number of non-infectious subclinical lameness cases / number of cow present (percentage)
G2_non_infectious_lameness_occurency_by_cow	real	Number of non-infectious clinical lameness cases / number of cow present (percentage)
G1_infectious_lameness_occurency_by_cow	real	Number of infectious subclinical lameness cases / number of cow present (percentage)
G2_infectious_lameness_occurency_by_cow	real	Number of infectious clinical lameness cases / number of cow present (percentage)
Mastitis_mortality_by_cow	real	Number of mastitis dead cows / number of cow present (percentage)
Ketosis_mortality_by_cow	real	Number of ketosis dead cows / number of cow present (percentage)
Non_infectious_lameness_mortality_by_cow	real	Number of non-infectious lameness dead cows / number of cow present (percentage)
Infectious_lameness_mortality_by_cow	real	Number of infectious lameness dead cows / number of cow present (percentage)
Undetected_G1_genni_occurency_by_calve	real	Number of undetected cases of GENNI severity G1 / number of births (percentage)
Detected_G1_genni_occurency_by_calve	real	Number of GENNI cases of severity G1 detected / number of births (percentage)
G2_genni_occurency_by_calve	real	Number of GENNI cases of severity G2 / number of births (percentage)
Genni_occurency_by_calve	real	Number of GENNI cases / number of births (percentage)
Genni_death_calve_by_calve	real	Number of dead calves from GENNI / number of births (percentage)
PTB_IT_occurency_count	integer	Number of instances of the PTB status during the campaign (incidence)
PTB_IL_occurency_count	integer	
PTB_IM_occurency_count	integer	
PTB_IC_occurency_count	integer	
PTB_S_count	integer	Number of animals with the corresponding PTB status at the end of the campaign (prevalence)
PTB_R_count	integer	
PTB_IT_count	integer	
PTB_non_adult_IL_count	integer	
PTB_adult_IL_count	integer	
PTB_IM_count	integer	
PTB_IC_count	integer	
PTB_positive_preventive_elisa_test_count	integer	Number of positive screening tests carried out during the campaign on animals before the onset of clinical signs
PTB_current_MAP_quantity	float	Current MAP at the end of the campaign
PTB_S_state_by_animal	float	Number of animals with PTB status as at the end of the financial year / number of animals at the end of the campaign (percentage)
PTB_R_state_by_animal	float	
PTB_IT_state_by_animal	float	
PTB_IL_state_by_animal	float	
PTB_IM_state_by_animal	float	
PTB_IC_state_by_animal	float	
PTB_IT_by_calve	float	Number of calves born with PTB from IT / number of births (percentage)
Health_treatment_count	integer	Number of treatments carried out for health trouble
Curative_clinical_ketosis_vet_treatment_count	integer	

Curative_subclinical_ketosis_farmer_treatment_count	integer	Number of treatments carried out for each heatlh trouble class
Curative_clinical_mastitis_vet_treatment_count	integer	
Curative_clinical_mastitis_farmer_treatment_count	integer	
Preventive_ketosis_farmer_treatment_count	integer	
Preventive_mastitis_farmer_treatment_count	integer	
Curative_clinical_lameness_vet_treatment_count	integer	
Preventive_lameness_vet_treatment_count	integer	
Curative_clinical_genni_farmer_treatment_count	integer	
Curative_clinical_lameness_vet_treatment_count	integer	
Curative_clinical_genni_vet_treatment_count	integer	
Unscheduled_cow_vet_care_count	integer	Number of unplanned cow treatments carried out by the vet
Scheduled_cow_farmer_care_count	integer	Number of planned cow treatments carried out by the farmer
Unscheduled_cow_farmer_care_count	integer	Number of unplanned cow treatments carried out by the farmer
Scheduled_vet_activity_count	integer	Number of planned veterinary interventions (contractual visits care and presence at preventive triming sessions)
Unscheduled_vet_activity_count	integer	Number of unplanned veterinary interventions (over contractual visits care and presence at curative triming sessions)
Scheduled_farmer_activity_count	integer	Number of planned farmer interventions
Unscheduled_farmer_activity_count	integer	Number of unplanned farmer interventions
Mastitis_culling_by_cow	real	Number of cows culled due to mastitis / Average number of cows present (percentage)
Non_infectious_lameness_culling_by_cow	real	Number of cows culled due to non-infectious lameness / Average number of cows present (percentage)
Infectious_lameness_culling_by_cow	real	Number of cows culled due to infectious lameness / Average number of cows present (percentage)
PTB_culling_by_cow	real	Number of cows culled due to paratuberculosis / Average number of cows on the farm (percentage)
Healthy_cows	real	Number of cows without health problems present for at least 8 months during the year / Number of cows present for at least 8 months during the year
Clinical_case_cows	real	Number of cows that have had at least one clinical case of disease and have been present for at least 8 months during the year / Number of cows present for at least 8 months during the year

Table 110: Structure of data on technical heath results

2.2.4 Genetics

The simulator makes it possible to consider values specific to each individual that affect its different performances (production, reproduction and health).

2.2.4.1 Biological and technical constants related to genetics

All animals are endowed with a genetic heritage from their creation. This heritage brings together the genetic value of each of their phenotypic traits. Three cases are to be differentiated for the assignment of individual genetic values:

- animals bought during the simulation,
- bulls whose semen is used for inseminations (including natural),
- calves born from an identified dam and sire.

The environment effect is not dealt within this chapter; however, it is dealt in each of the modules concerned.

2.2.4.1.1 Genetic values associated with phenotypic traits

The genetic value of each phenotypic trait consists of the following values:

- the true genetic value A,
- the corrected performance P.

These genetic values are calculated in the simulator by the application of three common criteria of the dairy breeds (heritability, heterosis and genetic correlation), and two others that are breed-dependant (reference phenotypic mean and genetic standard deviation).

2.2.4.1.1.1 Common criteria of genetic values associated with phenotypic traits

Phenotypic trait's name	Definition	Performance trait	Unity	Heritability (h^2) [1]	Heterosis (H) [2]
Milk	Milk quantity	Production [3]	kg	0.30	510
FC	Fat content		g/kg	0.50	0.15
PC	Protein content		g/kg	0.50	0
Fer	Fertility	Functional [3]	Standard deviation	0.02	0.07
MACL	Mastitis resistance		Standard deviation	0.02	0
BHBlait	BHB level in milk	Functional	Standard deviation	0.15 [4]	0 [7]
RBi	Resistance to infectious limping		Standard deviation	0.04 [5]	0 [7]
RBni	Resistance to non-infectious limping		Standard deviation	0.03 [5]	0 [7]
RPTB	Resistance to paratuberculosis		Standard deviation	0.14 [6]	0 [7]

Table 111: Common parameters of genetic values associated with phenotypic traits

[1] (Dezetter, 2015) Holstein basis, [2] ECOMAST, [3] France génétique Elevage – index des races bovines laitières – 2018, [4] (Benedet *et al.*, 2019), [5] Adapted from (Pérez-Cabal et Charfeddine, 2015) and (Croué *et al.*, 2017), [6] (Sanchez *et al.*, 2022), [7] Data not available.

With regard to the genetic correlation ρ that can exist between the true genetic values of each phenotypic trait, it is the following:

ρ	Milk	FC	PC	Fer	MACL	BHBlait	RBi	RBni
FC	-0.45 [1]							
PC	-0.4 [2]	0.6 [2]						
Fer	-0.23 [2]	0.1 [2]	0.1 [2]					
MACL	0.26 [2]	-0.1 [2]	-0.1 [2]	-0.24 [2]				
BHBlait	0.03 [3]	0.035 [4]	-0.29 [4]	0.0 [12]	0.23 [5]			
RBi	0.26 [6]	-0.07 [7]	-0.02 [7]	0.23 [8]	0.37 [9]	0.09 [5]		
RBni	0.26 [6]	-0.07 [7]	-0.02 [7]	0.23 [8]	0.37 [9]	0.09 [5]	-0.01 [10]	
RPTB	0.00 [11]	0.012 [11]	0.03 [11]	0.02 [11]	0.034 [11]	0.0 [12]	0.0 [12]	0.0 [12]

Table 112: Genetic correlation ρ between each phenotypic trait

[1] (Beaudeau *et al.*, 2016), [2] (ECOMAST), [3] adapted from (Benedet *et al.*, 2019), [4] (Belay *et al.*, 2017), [5] (Oliveira Junior *et al.*, 2021), [6] adapted from (Koeck *et al.*, 2014), (Khansefid, Haile-Mariam et Pryce, 2021) and (Van Dorp *et al.*, 1998), [7] (Gernand *et al.*, 2012), [8] (Khansefid, Haile-Mariam et Pryce, 2021), [9] adapted from (Pritchard *et al.*, 2013), (Koeck *et al.*, 2012) and (Oliveira Junior *et al.*, 2021), [10] Idele 2021 data, [11] Expert opinion, [12] Data not available.

Remarque : les corrélations génétiques entre la résistance aux boiteries et à la fertilité, le TB et le TP, sont chacune issues d'une seule publication donc leur fiabilité est limitée.

2.2.4.1.1.2 Criteria of genetic values associated with breed-dependent phenotypic traits

The phenotypic mean and genetic standard deviation specific values for dairy breeds are as follows:

Phenotypic trait name	Phenotypic mean reference			Genetic standard deviation ($\sigma_{A=\sqrt{0.7*variance}}$ (2))	
	Montbeliarde	Normande	Holstein	Montbeliarde and Normande	Holstein
Milk	7 786 kg (1)	7 126 kg (1)	9 657 kg (1)	553	599
FC	38.7 g/kg (1)	41.8 g/kg (1)	40.5 g/kg (1)	2.03	2.48
PC	33.1 g/kg (1)	34.4 g/kg (1)	32.2 g/kg (1)	1.16	1.24
Fer	1 (2)			0.059	0.059
MACL	1 (2)			0.037	0.034
BHBlait	1			0.048 (3)	0.046 (3)
RBi	1			0.1 (5)	0.1 (4)
RBni	1			0.06 (5)	0.06 (4)
RPTB	1			0.6474 (5)	0.6474 (3)

Table 113: Breed-dependent parameters of genetic values associated with phenotypic traits

(1) (Institut de l'élevage, 2024b), they concern the average lactation results «adult-level corrected – all lactations», they are the basis of simulation for two daily milking, (2) (ECOMAST), (3) Expert opinion, (4) Adapted from (Pérez-Cabal et Charfeddine, 2015) and (Croué *et al.*, 2017), (5) Data not available.

2.2.4.1.2 Individual genetic value

The genetic value of an individual depends on the average true genetic value of the herd A¯_two. The levels of these values are defined in *Table 113: Breed-dependent parameters of genetic values associated with phenotypic traits*.

2.2.4.1.2.1 True genetic value

For each individual *i*, the true genetic value A of each of its phenotypic traits is calculated according to the following formula:

$$A_{i,trait} = N(\bar{A}_{herd,trait}, \sigma_{A,trait})$$

Variability is applied considering the correlation between traits defined in *Table 112: Genetic correlation ρ between each phenotypic trait*.

2.2.4.1.2.2 Individual potential in adult stage

Individual potential is calculated differently if the unit linked to the index is to be a performance (quantitative index) or a standard deviation (qualitative index).

Individual potential based on a performance:

If the phenotypic trait is a performance (milk, FC and PC), the potential P of the individual "i" is calculated from the true genetic value as follows:

$$P_{i,trait} = \bar{P}_{herd,trait} + \frac{A_{i,trait} - \bar{A}_{herd,trait}}{h^2_{trait}}$$

It has the same unit measure as the performance (kg or g / kg).

Individual potential based on a standard deviation:

If the phenotypic trait is to be a standard deviation (Fer, MACL, BHBlait and RB), the potential P of the individual "i" will be centred on 1 and calculated from the true genetic value (centred on 0), with a X performance corresponding to a value of the genetic standard deviation defined to 3 for the increasing direction and -3 for the decreasing direction, according to the following equations:

Direction (*)	Equation for a true genetic value < 0	Equation for a true genetic value >= 0
Increasing	$P_{i,trait} = \frac{1}{\frac{(X-1)*A_{i,trait}}{-3}+1}$	$P_{i,trait} = \frac{(X-1)*A_{i,trait}}{3} + 1$
Decreasing	$P_{i,trait} = \frac{(X-1)*A_{i,trait}}{-3} + 1$	$P_{i,trait} = \frac{1}{\frac{(X-1)*A_{i,trait}}{3}+1}$

Table 114: Equations for calculating individual potentials P_i for indexes expressed as genetic deviation, where X is the performance for a value of genetic standard deviation defined as 3 for the increasing direction and -3 for the decreasing direction

(*) The direction is increasing if P_i increases when the true genetic value increases, decreasing otherwise.

The more heritable a trait is, the higher the value of X is, so heritability is intrinsically taken into account.

For Fer, BHBlait, MACL, RBi and RBni indexes, the individual performances are determined according to the following value table:

Phenotypic trait	Corrected performance used in simulation	X performance value (*)	Direction depending on the genetic value	Individual performance boundary
Fer	Coefficient applied to the probability of a successful insemination	2	Increasing	1/X for a -3 standard deviation X for a +3 standard deviation
BHBlait	Coefficient applied to the probability of occurrence of ketosis	1.5		
MACL	Coefficient applied to the probability of occurrence of mastitis	5	Decreasing	X for a -3 standard deviation 1/X for a +3 standard deviation
RBi	Coefficient applied to the probability of occurrence of infectious lameness	1.6		
RBni	Coefficient applied to the probability of occurrence of non-infectious lameness	1.6		

Table 115 : Individual performance values for the Fer, BHBlait, MACL, RBi and RBni indices, expressed as a standard deviation

(*) Data not available, estimated by experts.

Therefore, for Fer, MACL, BHBlait and RB (i and ni) indexes, represented as standard deviations, the coefficient used in the simulation to accentuate or reduce the effect will have the following values:

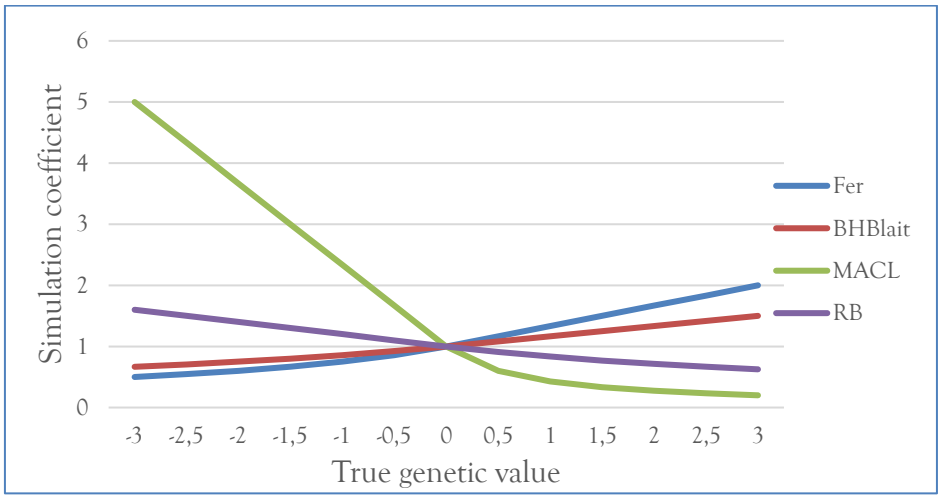


Figure 29: Coefficient to be applied to the performance of the Fer, BHBlait, MACL, RBi and RBni indices to take account of true genetic value

With specific regard to the RPTB index, the following equation is used (Sanchez *et al.*, 2022):

$$P_{i,trait} = \exp(-1.0313 * (A_{i,trait} + 0.1901))$$

2.2.4.1.3 Genetic value of bulls for insemination (including natural)

Bulls are not simulated as individuals; they are summarized to "bull" genetic values gathered in a catalogue. In the case of dairy breeds, these values benefit from annual genetic progress.

2.2.4.1.3.1 Catalogue of "bulls" genetic values

The catalogue of genetic values of dairy bulls (before genetic progress) is dimensioned according to the data loaded (see paragraph *2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue*).

For beef bulls used for the birth of calves for sale, and to ensure the biological consistency of the simulation, their true genetic value is 0 and their adult stage values are generically defined as:

- Milk: 2000 kg,
- FC: 50 g/kg,
- PC: 50 g/kg,
- Fer: 1 (centred coefficient),
- MACL: 1 (centred coefficient).
- BHBlait: 1 (centred coefficient).
- RBi: 1 (centred coefficient).
- RBni: 1 (centred coefficient).

No variability is applied in this case.

2.2.4.1.3.2 Annual genetic progress

An annual genetic progress of the dairy cattle herd is simulated. It involves increasing the performance of new individuals (births or purchases) in the following proportions:

Phenotypic trait	Montbeliarde	Normande	Holstein
MILK (kg) (1)	52	62	80
FC (g/kg) (1)	0.03	0.00	0.00
PC (g/kg) (1)	0.08	0.09	0.04
Fer (1)	0.05	0.02	0.05
MACL (1)	0.04	0.02	0.04
BHBlait (2)	0.00	0.00	0.00
RBi (2)	0.00	0.00	0.00
RBni (2)	0.00	0.00	0.00
RPTB (2)	0.00	0.00	0.00

Table 116: Annual population genetic progress according to dairy breeds for each phenotypic trait

(1) (Dezetter, 2015), (2) Data not available.

The genetic progress is applied each year in a general way on the state of the breed (annual modification of the phenotypic reference averages of *Table 113: Breed-dependent parameters of genetic values associated with phenotypic traits* with the phenotypic traits in the proportions of the genetic progress defined in *Table 116: Annual population genetic progress according to dairy breeds for each phenotypic trait* and in the same proportions for the genetic values "Bulls" of the catalogue.

No progress is simulated with regard to inseminations by bulls of beef breeds.

2.2.4.1.4 Genetic value of calves born from identified parents

The calculation principle implemented in the simulator to determine the true genetic value for each phenotypic trait of a calf born from identified parents involves additively heredity, a meiosis hazard and a heterosis effect (Dezetter, 2015):

$$VG_{calf,trait} = \overline{VG}_{parents,trait} + meiosis\ hazard_{trait} + heterosis_{trait}$$

2.2.4.1.4.1 Heredity

For each phenotypic trait, in expectation, the calf inherits half of the true genetic value of the dam and half that of the sire (Dezetter, 2015):

$$\overline{VG}_{parents,trait} = \frac{VG_{dam,trait} + VG_{sire,trait}}{2}$$

2.2.4.1.4.2 Meiosis hazard

The meiosis hazard $\emptyset$ is added to the genetic value of the calf previously calculated from its parentage. Correlated according to *Table 112: Genetic correlation ρ between each phenotypic trait*, it is calculated as follows (Dezetter, 2015):

$$\emptyset_{trait} = N(0, \frac{\sigma_{A,trait}}{\sqrt{2}})$$

The standard deviation σ_A is described in *Table 113: Breed-dependent parameters of genetic values associated with phenotypic traits.*

2.2.4.1.4.3 Heterosis

The heterosis effect is calculated as follows:

$$heterosis_{trait} = h \times H_{trait}$$

With *h* = 1 – percentage of the sire's breed in the dam's genetics (Dezetter, 2015), knowing that the calf will be 50% of the dam's breed (s) and 50% of the sire's breed.

The effect of heterosis H is defined in *Table 111: Common parameters of genetic values associated with phenotypic traits.*

The value of corrected P performance of the calf is then calculated in the same way as for a generated adult, described in paragraph *2.2.4.1.2 Individual genetic value*.

2.2.4.2 Parameters for genetic management

This paragraph describes the parameters to be considered for the application of genetic effects. This concerns the catalog of genetic character of bulls that will be used for insemination and natural mating, and the herd's performance level.

2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue

It is possible to compile a specific catalog of the genetic characteristics of bulls based on the following default values:

Genetic strategy (bull choice)	Breed *(Bull name)*	LGF	Phenotypic trait								
			Milk (kg)	FC (g/kg)	PC (g/kg)	Fer (standard deviation)	MACL (standard deviation)	BHBlait (standard deviation)	RBi (standard deviation)	RBni (standard deviation)	RPTB (standard deviation)
Balanced (best INEL index)	Montbéliarde *(Trekking)*	0.7	1249	2.0	2.7	0.3	0.6	0.0	0.0	0.0	0.0
	Normande *(Theix)*	0.8	1707	-1.8	1.6	-0.1	-0.2	0.0	0.0	0.0	0.0
	Prim'Holstein *(Topgun)*	2.0	1359	2.1	3.2	1.3	0.5	0.0	0.0	0.0	0.0
Priority to milk quantity (best Milk index)	Montbéliarde *(Sacha)*	1.6	1555	-0.9	-0.2	1.4	1.9	0.0	0.0	0.0	0.0
	Normande *(Theix)*	0.8	1707	-1.8	1.6	-0.1	-0.2	0.0	0.0	0.0	0.0
	Prim'Holstein *(Tjorpe RF)*	1.0	1514	1.1	0.5	2.0	0.6	0.0	0.0	0.0	0.0
Priority to functional longevity (best LGF index)	Montbéliarde *(Strass)*	3.1	1169	-2.8	-0.7	0.4	1.1	0.0	0.0	0.0	0.0
	Normande *(Talent)*	2.8	597	1.3	1.2	2.0	1.7	0.0	0.0	0.0	0.0
	Prim'Holstein *(Suribay P)*	3.1	746	4.0	3.0	3.1	2.3	0.0	0.0	0.0	0.0

Priority given to resistance to paratuberculosis (best RPTB index)	Montbéliarde [1]	2.9	1101	2.2	1.4	2.8	1.9	0.0	0.0	0.0	1.0
	Normande [1]	2.9	1101	2.2	1.4	2.8	1.9	0.0	0.0	0.0	1.0
	Prim'Holstein [2]	2.9	1101	2.2	1.4	2.8	1.9	0.0	0.0	0.0	1.0

Table 117: Default values for bulls' genetic indexes

[1] Data not available, [2] Expert opinion

The values for the first three strategies (best INEL index, best Milk index and best LGF index) are those for existing bulls (except for the BHBlait, RB and RPTB indices), taken from the genetic evaluation of artificial insemination in dairy cattle breeds (Institut de l'élevage, 2024a).

2.2.4.2.2 Genetic strategy

The simulator makes it possible to choose the genetic strategy for reproduction in the herd. They are of four types: balanced (INEL index), with priority to the quantity of milk produced (Milk index), with priority to functional longevity (LGF index) and paratuberculosis resistance (RPTB index). Depending on the strategy chosen by the experimenter, the reproduction bull used for insemination or natural reproduction will be drawn from among those of the expected breed present in the catalog and meeting this criterion. By default, the balance strategy is selected.

With regard to the reform aimed at regulating population size (see paragraph *2.2.5.1.1.2.2.2 Culling for population regulation*), the score assigned to each individual depends on the genetic strategy in force and will correspond to the relevant index.

In order to better observe its effects, the PTB genetic strategy is only implemented after 5 years of simulation. Until that point, the equilibrium strategy is applied. Once the PTB genetic strategy is active, genotyping is systematically carried out on females at birth (not on any heifers that may have been purchased, on the assumption that this will have been done beforehand). This genotyping is generally carried out by the farmer themselves in a transparent manner (when fitting the ear tag) without the presence of a vet. It is therefore not necessary to record a specific action for the farmer in this case, nor for the vet.

2.2.4.3 Data produced

This data is generated automatically, regardless of the version of the simulator.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Production type: annual.

Information level: Herd.

This table represents the annual technical genetic balance.

The available fields are:

Field name	Format	Value
Mean_index_lgf Mean_index_lait Mean_index_tb Mean_index_tp Mean_index_fer Mean_index_macl Mean_index_bhb Mean_index_rbi Mean_index_rnbi Mean_index_rptb	real	The average of the corresponding index values for all animals present at the end of the financial year.

Table 118: Structure of data relating to genetic results

2.2.5 Population and batch management

The management of the herd population, including renewal and culling, and the distribution of animals in batches are proposed to the user.

2.2.5.1 Constant biological and technical values

The paragraph "Population and batch management" defines the population management method (number, culling, renewal, mortality), as well as the batch distribution.

2.2.5.1.1 Herd population

Throughout the simulation, the herd size is regulated by sales and purchases.

2.2.5.1.1.1 Gradual herd increase

Before the simulation starts on the set dates, a pre-simulation is carried out starting from a situation where there are no cows in the herd yet, dedicated to ramping up the herd, by purchasing heifers in stages. If the option of grouping calvings is opted, the heifers are purchased in such a way that they only calve during the planned periods.

2.2.5.1.1.2 Herd population management

For a herd composed of a nominal size, the renewal will be applied under the conditions defined by the user. The aim being that at the end of a campaign, the herd has been renewed at the level of what has been planned (see paragraph *2.2.5.2.1.3 Annual herd renewal rate*). This renewal, taking into account possible exits due to mortality or health or fertility problems, is organized every day. It makes possible to determine the animals for sale because if the purchase of new pregnant heifers. If there are not enough cows in the herd and no pregnant heifers from the "Bred heifers" batch to join the "Dried cows and pregnant heifers" batch within one month weighted by the target numbers divided by 100, the purchase of pregnant heifers will be made.

Only the observation is taken into account by the simulator when comparing performances in order to determine the best candidates for sale (female calves and pregnant heifers). Genotyping of breeding stock is not implemented.

2.2.5.1.1.2.1 Sale of female calves

Several strategies are planned for the sale of female calves, they are described in the paragraph *2.2.5.2.1.4 Female calves management strategy*.

2.2.5.1.1.2.2 Heifer sales and adult cow culling

Except in cases where a health problem requires immediate culling, culling of cows is generally done in two steps: the decision to no longer inseminate and the culling at the end of lactation. Moreover, if this principle is not sufficient for the regulation of the number of cows, or depending on the renewal strategy adopted, the sale of pregnant heifers can be carried out.

2.2.5.1.1.2.2.1 Decision to no longer inseminate

Cows or heifers that have been designated for culling (due to clinical cases of disease, a positive paratuberculosis test result, etc.) are never inseminated. There may be other reasons why a farmer decides to stop inseminating their animals; these include:

- fertility problems, i.e. those described in paragraph *2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility*. This also applies to females that have lost their embryos or have aborted (without lactation) after the end of the insemination period,
- when the maximum number of lactations is reached, this parameter is defined in paragraph *2.2.5.2.1.5 Maximum lactation number*,
- an observed production in early lactation (from the calving day to the day of the insemination decision) that is lower than the herd average calculated on the basis of the last 12 months of observed production.

This does not apply to cross-bred dairy cows. The setting of the applicable ratio is described in paragraph *2.2.5.2.1.6 Production performance of the cow regarding the one of the herd*,

- when the cow does not recover from her last mastitis, determined by a SCC level exceeded during the last two milk controls of the previous lactation and the first milk control for the new lactation (see paragraph *2.2.5.2.1.7 SCC level*),
- in case of long lameness (see paragraph *2.2.3.3.1.1.3.5 Lameness-related culling and mortality*),
- in the case of group calving, where the cow or heifer has not been fertilised within the planned period.

2.2.5.1.1.2.2.2 Culling for population regulation

Decision:

Some cows are culled immediately or at a later date. This applies to those suffering from a health problem so serious that recovery is not considered likely, or where paratuberculosis tests are positive (see paragraph *2.2.3.5.1.1.2.5 Mortality and culling risk*).

The other culls are carried out with a view to regulating the number of cows. In this context, the decision not to inseminate a cow with a view to culling her is taken according to her genetic value in relation to the others in the light of the breeder's genetic strategy (see § *2.2.4.2.2 Genetic strategy*) or because of infertility.

Culling:

The culling of a cow scheduled to be culled is actually carried out at the end of her lactation, in priority according to an individual score determined by the following equation:

$$Score = \frac{\overline{SCC}_{7\ last\ days}}{\overline{Milk\ quantity}_{7\ last\ days}}$$

Whatever, the principle for considering that a cow to be culled has completed her lactation (after a plateau of 250 days of lactation) is based on the threshold of the quantity of milk produced (smoothed over the last 7 days), weighted by a ratio which, depending on the objective of the herd, makes it possible to define the break-even point. The break-even point calculated for two levels of production is as follows:

Production level of the herd (kg/cow)	Break-even point (kg)
6000	10
9500	16

Table 119: Break-even point of production according to the level of the herd

This threshold can be adjusted by a configurable factor (see paragraph *2.2.5.2.1.8 Break-even point for milk production*).

2.2.5.1.1.2.2.3 Pregnant heifer sale

Where there is an excess of heifers relative to the desired replacement rate (as observed over a four-month period), the herd size is regulated by the sale of heifers due to be mated, selected on the basis of their individual scores in line with the current genetic strategy (see paragraph *2.2.4.2.2 Genetic strategy*).

2.2.5.1.1.2.3 Purchase of heifers

When the herd size is insufficient, the simulator carries out the purchase of pregnant heifers, inseminated according to the conditions of the first insemination provided in the mating plan, and for an estimated date of calving a two weeks later. The genetic value of bought pregnant heifers takes into account the progress made at the relevant stage of simulation since its beginning. The heifers purchased did not suffer from any GENNI-related diseases early in their lives.

Once the herd has been established (pre-simulation period), this option to purchase heifers is no longer utilised when the strategy for managing female calves is to retain them all for sale as breeding heifers.

2.2.5.1.1.3 Mortality

Calves and cows are exposed daily to a natural risk of mortality. This risk is determined on the basis of the average mortality observed in dairy herds, and in suckling herds for crossbred calves (Perrin *et al.*, 2011), as follows:

Age group	Average annual risk (%)	
	dairy	beef
< 7 days (*)	F : 6.0 M : 7.9	4.36
7 days to 1 month	2.96	1.63
1 to 2 months	1.26	0.88
2 to 6 months	2.31	1.69
6 months to 1 year	1.52	1.35
1to 2 years	1.53	1.56
2 to 3,5 years	2.6	1.5
3,5 to 5 years	3.01	1.67
5 to 10 years	4.42	1.84
> 10 years	7.54	4.28

Table 120: Mortality risk among the herd

(*) according to the "Reproscope" observatory of the "Institut de l'Elevage" (IDELE), out of 65381 French dairy herds observed for the 2013-2014 campaign, the risk of stillbirths (between birth and two days) is quite the same as the one of the first week of life, so it is not treated specifically.

These data represent basic mortality, integrating the lethalities due to the various simulated health disorders.

For crossbred dairy-beef calves, the mortality risk is the average mortality risk of both breeds.

The veterinary care contract option provides a de facto improvement in mortality due to managed diseases. For unmanaged diseases, the simulator applies a 10% reduction in mortality after one year's contract.

2.2.5.1.2 Batch management

All animals are assigned to a lot which, depending on the current location (housing, Outdoor), constitutes the environment of the animal.

2.2.5.1.2.1 Assignment

The assignment dynamics in batches is as follows:

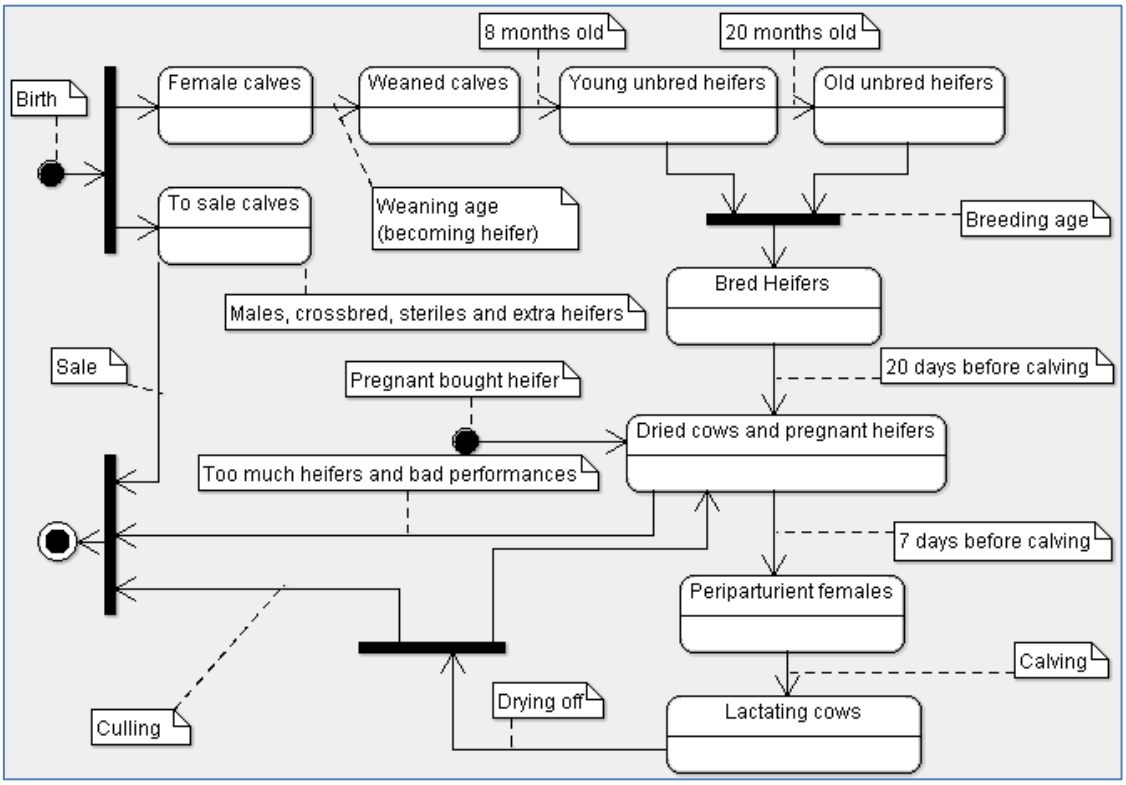


Figure 30: Assignment dynamic in batches within the farm

From birth, male calves, crossbred beef calves and sterile females are put in a batch that will be sold weekly, when they have reached the minimum age of 20 days, as are the extra female calves. Females destined to be raised are affected in the batch of female calves. Once weaned, they join the weaned calve batch, and at the age of 8 months the young unbred heifer batch. If the breeding age exceeds 20 months, they are grouped together once they reach this age in the batch of old unbred heifers, until they reach the breeding age that leads them into the bred heifer batch. At 20 days from the calving date, if they can contribute to an excess number of cows renewed with respect to the parameterized rate, their theoretical production performance is evaluated based on that of their dam. In case of a lower performance than the other heifers in the dried cows and pregnant heifer batch, they will be sold. Otherwise, they will be included in the batch to replace others with lower estimated performance that will be sold. Furthermore, at this stage and in case of understaffing, the necessary number of heifers will be bought and integrated into the same lot. At 7 days from calving, heifers and dry cows are integrated into the periparturient female batch until calving, which will lead them into the lactating cow batch.

Therefore, the different batches managed within the farm are the following:

- calves meant for sales (males, beef crossbreed, sterile and extra females,
- female calves (unweaned),
- weaned calves (under 8 months old),
- young unbred heifers (under 20 months old),
- old unbred heifers (if breed age is over 20 months),
- bred heifers,
- dried cows and pregnant heifers (at less than 1 month for calving),
- periparturient females (at less than 7 days for calving).
- lactating cows (inseminated or not).

2.2.5.1.2.2 Indoor/outdoor housing

The 3 batches are never outdoor. Heifer and cow batches are outdoor according to the planning set (see paragraph *2.2.5.2.2.1 **Stabling and grazing***), it will define the diets (see paragraph *2.2.6.2.1 Balanced diet*) and may influence health risks.

2.2.5.2 Parameters for population and batch management

This module makes it possible to better the population management and outdoor schedule.

2.2.5.2.1 Population

Different parameters enable different strategies to manage the population.

2.2.5.2.1.1 Initial cow breed

The initial cow breed can be chosen. The default breed is Holstein.

2.2.5.2.1.2 Average number of adult cows

The average number of adult cows is configurable. Its default value is 50.

2.2.5.2.1.3 Annual herd renewal rate

It is possible for the user to define the annual herd renewal rate. This parameter is expressed as a decimal value between 0.25 (renewal of a quarter per year) and 0.5 (renewal of half per year). The default value is 0.33 (renewal of one third per year).
In addition, a parameter allows the renewal rate initially set to be increased annually. This parameter defines the differential to be added each year to the current rate, starting from the year following the first year in which the results are produced. The default value is 0.

2.2.5.2.1.4 Female calves management strategy

Three strategies for managing unweaned female calves are proposed to the user:
a) Retention of all calves

The surplus will be sold as heifers for breeding when the time comes, under the same selection conditions as for the following option.

b) Mandatory sale of selected calves

This is the default option.

Priority will be given to calves born to cows with low dairy potential, namely: females born to the 10% of cows with the lowest recorded milk production potential[1] in the herd must be sold. Conversely, female calves born to cows recorded as the most productive (the top 20% of the herd) must be excluded from this sale, even if they have contracted GENNI. Surplus female calves whose milk production performance cannot be compared to that of their ancestors will be sold systematically. The remaining calves are classified in order of estimated milk production performance (taking into account the effect of a potential GENNI during their first lactation as adults, see paragraph *2.2.3.4.1.1.3.2 Decrease in average growth*).

The herd size is adjusted to the renewal requirement, calculated on the basis of the number of female calves under one year of age in the herd, which must not exceed the target adult population multiplied by the expected annual renewal rate, plus a 5% safety margin.

c) Sale of all calves

All female calves are systematically sold, and heifers are purchased according to the desired herd size.

2.2.5.2.1.5 Maximum lactation number

The maximum number of lactations, determining the end of inseminations, is configurable. The default value is 7.

[1] Only dairy potential is currently taken into account. Depending on requirements and in a future version of the simulator, other genetic indexes such as disease susceptibility could optionally be considered at the time of selection.

2.2.5.2.1.6 Production performance of the cow regarding the one of the herd

Inseminations are stopped for cows producing less than the herd average. The applicable ratio is configurable, it is 0.86 by default.

2.2.5.2.1.7 SCC level

The SCC level leading to stop the inseminations is configurable, the default value is 1000.

2.2.5.2.1.8 Break-even point for milk production

A modulation factor for the break-even point for milk production at the end of long lactation can be set. The default value is 1.

2.2.5.2.2 Batch management

The levers of control for the management of the batches concern the timing of grazing and the use of a straw bed.

2.2.5.2.2.1 Stabling and grazing

Calves are never outdoor. For other animals, outdoor periods are configurable, default values are

Calves are never outdoor. For the other animals, the pasture periods can be set according to two modalities: in one hand heifers and dry cows, and in a second hand lactating cows.

For heifers, dry cows and peri-partum cows, the default grazing values are as follows:

Under 20 months unbred heifers	**Other heifers and dry and peri-partum cows**
April 15 to november 10	March 15 to november 10

Table 121: Default grazing schedule for heifers under 20 months, other heifers, dry cows and peri-partum

If no grazing period is to be set, the value "0" must be applied for the days and months of the corresponding parameter. The rest of the year, the animals are in stalls.

For lactating cows, the default values for grazing and stabling are as follows:

Usage	**Lactating cows**
100% pasture	March 20 to june 30
100% stabulation	November 11 to march 10

Table 122: Default grazing and housing schedule for the lactating cow batch

If no grazing and/or stabling period is to be set, the value "0" must be applied for the days and months of the corresponding parameter. The rest of the year, lactating cows are on pasture during the day and in stalls at night.

Note: This two calendars are also used for feeding (see paragraph *2.2.6.2.1 Balanced diet*).

2.2.5.2.2.2 Straw bed

By default, the beds are straw-covered in indoor, as follows:

Calves	**Indoor heifers**	**Indoor adult cows** (*)
2	3.5	7

Table 123: Default straw consumption for straw beds (kg/d)

(*) this consumption is halved when the adult cows are indoor at night and outdoor during the day.

2.2.5.3 Data produced relating to population management

Data produced concern only technical assessment related to population management. They are generated automatically, regardless of the version of the simulator.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Production type: annual.

Information level: Herd.

This result allows for the recording of movements and the population situation in the herd (births, sales, purchases, mortality, culling, renewal rate) for the campaign.

The available fields are:

Field name	Format	Value
Present_adult_cow_count	integer	Number of adult cows in the herd at the end of the campaign
Present_not_adult_animal_count	integer	Number of non-adult animals in the herd at the end of the campaign
Present_over_24_months_animal_count	integer	Number of animals aged 24 months and over in the herd at the end of the campaign
Herd_cow_average	integer	Average number of adult cows in the herd
Births_count	integer	Number of births
Male_sales_count	integer	Number of male calves sold
Beef_crossed_bred_sales_count	integer	Number of beef crossed calves sold
Sterile_female_sales_count	integer	Number of sterile female calves sold
Extra_female_sales_count	integer	Number of extra female calves sold
Extra_pregnant_heifer_sales_count	integer	Number of extra pregnant heifer sold
Heifer_bought_count	integer	Number of pregnant heifers bought
Primipare_count	integer	Number of heifers having calved
Dead_calves_count	integer	Number of dead calves (calves awaiting sale and unweaned females)
Dead_calve_per_100_calves	integer	Number of dead calves (calves awaiting sale and unweaned females) for 100 births
Dead_heifers_count	integer	Number of dead heifers
Dead_adults_count	integer	Number of dead near calving heifers and adults
Dead_adults_per_100_cows	integer	Number of dead near calving heifers and adults for 100 cows
Infertility_not_bred_decisions_count	integer	Number of not bred decisions for infertility
Lactation_rank_not_bred_decisions_count	integer	Number of not bred decisions because of lactation rank
Low_milk_product_not_bred_decisions_count	integer	Number of not bred decisions for low milk production level
Culling_percent	real	Culling percentage (number of cows culled / average number of cows)
Health_culling_count	integer	Number of animals culled for health reason
Infertility_culling_count	integer	Number of animals culled for infertility
Lactation_rank_culling_count	integer	Number of animals culled because of lactation rank
Low_milk_product_culling_count	integer	Number of cows culled for low milk production level
PTB_culling_count	integer	Number of cows culled due to their clinical status (PTB)
Longevity	real	Percentage of milk controls with cows of 4 or more lactations among milk controls
Mean_herd_life	integer	Average age of animals when they leave the herd, having remained there for at least 27 days since birth
Mean_lenght_of_productive_life	integer	Average number of days between first calving and cow exit date
Survivability_48m	real	Number of cows born in the herd and reaching 48 months of age during the year / number of calves reaching 27 days of age four years earlier
Mean_lifetime_milk_production	real	Average cumulative gross milk production during the cows' career when they leave the herd
Time_between_decision_and_culling_average	integer	Average time between decision and culling (*)
Lactation_stage_at_culling_average	integer	Average lactation stage at culling (*)
Day_milk_quantity_at_culling_average	real	Average day milk quantity at culling (*)
Max_milk_quantity_at_culling	real	Max milk quantity at culling day (*)
Min_lactation_stage_at_culling	integer	Min lactation stage at culling day (*)

Table 124: Data structure on annual results of herd management

(*) Except health reason.

2.2.6 Feeding

The simulator doesn't aim to compare dairy cow feeding plans but to integrate the economic impact of food consumption which varies according to the number and production of animals. Therefore, it is essential to determine the quantities of food consumed in the herd.

2.2.6.1 Constant biological and technical values

2.2.6.1.1 Rations

On the first day of their lives, calves are fed on the dam's colostrum. Then they receive a daily quantity of milk until weaning or sale. The type and quantity of used milk is configurable (see paragraph *2.2.6.2.1.1 Unweaned calf* feeding). Female calves that are to be weaned receive a ration of concentrate, its composition can be configured.

For the rest, the diets implemented depend mainly on two criteria:

- the current batch of belonging (see paragraph *2.2.5.1.2.1 Assignment*),
- the local situation (see paragraph *2.2.5.1.2.2 Indoor/outdoor housing*) if the batch is concerned.

In the special case of the milk production period, two diets may be used:

- the Basic Balanced Diet (BBD) which is systematically granted, it is sized for a milk production determined by the farmer and can be parameterised (see paragraph *2.2.6.2.1.4 Lactating cow feeding*),
- the relative and complementary diet of production concentrate, allocated when the day's production exceeds the threshold corresponding to the parameterised BBD (see paragraph *2.2.6.2.2 Production concentrate diets*)

A primiparous cow consumes only 95% of the multiparous cow diet throughout her first lactation.

For the diets of the animals in the dry cows and pregnant heifers batch, the values used, not configurable, are 1/3 of the BBD given to multiparous lactating cows (see paragraph *2.2.6.2.1.4 Lactating cow feeding*), plus 1 kg Dry Matter (kgDM) of hay for indoor situation. For peripartum cows, their diet (not configurable) is the one defined above for dry cows and pregnant heifers, with the addition of 0.5 kg of Crude Matter (kgCM) of rapeseed and 0.5 kgCM of barley, all specifically reduced by 10% for heifer (Jarrige, 1988).

2.2.6.1.2 Faeces produced

As regards the amount of faeces produced per day per animal, this depends on the animal's circumstances (Nennich *et al.*, 2005):

Situation	Amount of faeces produced (kg/day)
Calf	Entre 5 et 28
Heifer	24.5
Adult cow	35

Table 125: Amount of faeces produced per day per animal, depending on its circumstances

2.2.6.2 Parameters for feeding management

Various parameters allow the user to define the management rules related to feeding. The principle is to define, for a given ration, its quantity in kg and its composition in the form of a ratio, namely hay, grass, corn silage, and grass silage for the forage ration, and rapeseed and soybean meal and barley for the concentrate ration. The total ratio of a ration must be 1.

This setting deals with balanced diets and production supplements.

2.2.6.2.1 Balanced diet

The following configuration is used to define diets in order to have balanced feeding and nominal production as defined in paragraph *2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination*.

The biological impact of diet consumption is not simulated. It is solely used for its accounting aspect. The experimenter's choices must therefore be consistent with balanced diets.

2.2.6.2.1.1 Unweaned calf feeding

The calves concerned in this paragraph are unweaned female calves kept for breeding and calves intended for sale (male, crossbred meat, sterile and extra females).

Milk:

For simplicity, the quantity of milk consumed by the calves is constant every day until weaning age. This quantity can be parameterised and is defined by default at 6kg/day. The simulator proposes also the use of 3 kinds of milk that can be defined as following:

- produced milk, taken from the bulk and therefore not sold (default value),
- discarded milk, deducted from discarded milk, then milk produced if the quantity of discarded milk of the day is not insufficient,
- discarded milk, deducted from discarded milk, then reconstituted milk from milk powder purchased by the farmer if the quantity of discarded milk of the day is not insufficient,
- reconstituted milk based on dehydrated milk bought by the farmer.

Preparing for weaning:

The weaning age of female calves (kept for breeding) can be set, its default value is 70 days. For their preparation for weaning, the given diet, which can be adjusted, is based on a concentrate mixture distributed daily and at constant level. By default, this concentrate mixture is 0.35 kgCM constituted of 80% barley and 20% soya meal.

2.2.6.2.1.2 Weaned calf feeding

Weaned calves are fed with forage, concentrate and minerals and vitamins intake (MVI). The balance values are configurable, defined by default as follows:

	Maize silage	**Hay**	**Barley**	**Soybean meal**	**MVI**
Quantity	2 kgDM	1 kgDM	1 kgCM	1 kgCM	0.02 kgCM

Table 126: Default values for daily feeding of weaned female calves.

These values are distributed daily at a constant level and correspond to a median age of 5 months.

2.2.6.2.1.3 Heifer feeding

The heifers are fed differently in indoor and outdoor, with a forage mixture and a possible supplement of concentrate and MVI. The default values for the forage and balance concentrate mixtures, and for MVI, distributed per day, are as follows:

Diet type		**Heifers under 20 months (median age to 13 months)**		**Not bred heifers from 20 months**		**Bred heifers**	
		Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Forage (kgDM/day)	Maize silage	5.5	0	6.5	0	8	0
	Grass	0	6	0	6.5	0	9
	Hay	0	0	0	0	1	0
	Grass silage	0	0	0	0	0	0
Concentrate (kgCM/ day)	Rapeseed meal	0	0	0	0	0	0
	Soybean meal	0,5	0	0.75	0	1	0
	Barley	0	0	0	0	0	0
MVI (kgCM/day)		0.06	0	0.06	0	0.08	0

Table 127: Default values for feeding heifers according to age and location.

2.2.6.2.1.4 Lactating cow feeding

The BDD distributed to lactating cows is sized for a dairy production determined by the farmer defined by default at 26 kg/day. Forage and balanced concentrate diets distributed during this period depend on the schedule. The default values are:

Period (*)	Forage					Concentrate				MVI (kgCM)
	Quantity (kgDM)	Maize silage (%)	Grass (%)	Hay (%)	Grass silage (%)	**Quantity (kg**CM)	Rapeseed (%)	Soybean (%)	Barley (%)	
Indoor	16	95	0	5	0	3.1	20	0	80	0.25
Outdoor	20	0	100	0	0	0	0	0	0	0
Outdoor the day and indoor at night	16	38	62	0	0	1.5	20	0	80	0.1

Table 128: Default values for feeding lactating cows according to indoor/outdoor periods.

(*) see calendar paragraph *2.2.5.2.2.1 Stabling and grazing.*

Feeding of lactating cows may be reduced as a result of production losses due to the occurrence of certain diseases. This cumulative impact is described for each disease concerned in their "*Impact on feeding*" paragraph. This only concerns the consumption of forage and concentrate.

2.2.6.2.1.5 Dry cow feeding

Dry cows are put in the same batch as the heifers, so they receive the same diet.

2.2.6.2.2 Production concentrate diets

When the milk production level of a cow (primiparous or multiparous) exceeds the threshold corresponding to the defined BBD (see paragraph *2.2.6.2.1.4 Lactating cow feeding*), a daily ration of production concentrate is distributed in addition to them. This ration, in kgCM, corresponds to a parameterized production gain equivalent defined by default to 2.5kg of milk per 1 kgCM of concentrate, the type of which is modifiable. By default, it is 70% barley and 30% soybean meal.

2.2.6.3 Data produced

The data produced make it possible to report forage, concentrate and minerals and vitamins consumption, they are generated automatically, regardless of the version of the simulator. The difference is made between calves, heifers and cows. The calculation method used is to divide the total annual consumption by the daily average of the animals present in the herd.

2.2.6.3.1 Milk, concentrate and minerals and vitamins consumed by calves

Result name: « CalfFeedingResults »

Production type: annual.

Level information: Herd.

This data is produced on the last day of the campaign. It concerns the consumption of calves for sale (male, crossbred, sterile and extra females), unweaned female calves and weaned female calves before they join the young heifers batch.

The available fields are:

Field name	Format	Value
Date	Date (*)	Milk consumption assessment date
Liter_discarded_milk	real	Quantity of discarded milk given to calves
Liter_bulk_milk	real	Quantity of milk from the bulk given to calves
Dehydrated_milk	real	Quantity of milk powder given to calves
Maize_silage	real	Quantity of maize silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 129: Data structure on milk consumption by calves

(*) See *Table 2: Type data formats* page *15.*

Milk power quantity is calculated by applying a constant rate of dilution of 125 g of powder per kilo of milk.

2.2.6.3.2 Forage, concentrate and minerals and vitamins consumed by heifers

Result name: « HeiferFeedingResults »

Production type: annual.

Information level: Herd.

This data is produced on the last day of the campaign. It is calculated taking into account forage, concentrate and minerals and vitamins consumption by the heifers until one month before their first calving.

The available fields are:

Field name	Format	Value
Date	Date (*)	Consumption assessment date
Maize_silage	real	Quantity of corn silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 130: Data structure on forage and concentrate consumption by calves prepared at weaning and heifers

(*) See *Table 2: Type data formats page 15.*

2.2.6.3.3 Forage, concentrate and minerals and vitamins consumed by cows

Result name: « CowFeedingResults »

Production type: annual.

Information level: Herd.

This data is produced on the last day of the campaign. It is calculated taking into account forage, concentrate and minerals and vitamins consumption by cows.

The available fields are:

Field name	Format	Value
Date	Date (*)	Consumption assessment date
Maize_silage	real	Quantity of corn silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 164: Structure of the fields defining the simulation framework*	

Table 131: Data structure on forage and concentrate consumption by cows

(*) See *Table 2: Type data formats page 15.*

2.2.7 Accounting

2.2.7.1 Accounting parameters

The accounting model integrates the price of each operation for which accounting is desired. Thus, during the simulation, for each operation carried out for which a price is foreseen, this price is added to the accounting year of the farm.

For all accounting data, negative amounts are expenses for the holding, and positive amounts are income. When what is described as a product is purchased (e.g. heifers), the system uses the value as a product and reverses the sign to make it an expense.

By default, prices do not change during a simulation. However, it is possible to set a trend concerning the annual evolution (decrease or increase) of one or more of these prices, which is taken into account monthly during the simulation. This setting is described in paragraph *3.1.2 Accounting model creating*.

The initial prices (at the start of the simulation) can be amended; the default values are the observed average values. For each module, these are set out below.

2.2.7.1.1 Reproduction

Accounting operation	Accounting class [1]	Charge (€)
Assisted calving by a vet	Reproduction_costs	-3.00
Insemination by service	Reproduction_costs	0.00
Conventional artificial insemination	Reproduction_costs	-40.00
Male sexed artificial insemination	Reproduction_costs	-60.00
Female sexed artificial insemination	Reproduction_costs	-60.00
Cost per cow present and per year of the veterinary breeding contract	Reproduction_costs	-30.00
Cost of veterinary treatment for calved cow not seen in heat	Reproduction_costs	-9.00
Cost of veterinary treatment for successive non-fertilising artificial inseminations	Reproduction_costs	-30.00
Cost of veterinary treatment for negative pregnancy diagnosis	Reproduction_costs	-9.00

Table 132: Default rates for reproduction-related accounting transactions

2.2.7.1.2 Production

Accounting operation	Accounting class [1]	Charge (€)
Sale of a ton of milk (without penalty neither quality criteria)	Milk_sales	330.00
Cell penalty 1st threshold (for 1 ton)	Milk_sales	-3.049
Cell penalty 2nd threshold (for 1 ton)	Milk_sales	-9.147
Cell penalty 3rd threshold (for 1 ton)	Milk_sales	-15.245
TB quality bonus (for 1 ton and 38g/l based)	Milk_sales	2.60
TP quality bonus (for 1 ton and 32g/l based)	Milk_sales	6.60

Table 133: Default rates for production-related accounting transactions

The price of the milk delivered is calculated annually (no seasonal or monthly variation, unless a trend is set, see previous paragraph), it is a function of quality: if it has a cell rate higher than various levels (see paragraph *2.2.2.1.1.5 Milk destination*), a penalty will be applied, by tranche, according to the defined parameterization and whose default values are shown in *Table 133: Default rates for production-related accounting transactions*. With regard to the valuation of TB and TP, if the rate exceeds the reference rate (see *Table 133: Default rates for production-related accounting transactions*), the parameterised bonus is added per tonne according to the difference observed. On the other hand, if the quality is lower than that of the reference, a malus is applied under the same conditions.

[1] See the name of the field in the economic balance sheet published under the *Table 140: Structure of the economic balance sheet data expressed in euros*

2.2.7.1.3 Health

Accounting operation	Accounting class [1]	Charge (€)
Cost per cow present and per year of the veterinary care contract	Other_health_costs	-30.00
Cost per calving and per year of the veterinary care contract	Other_health_costs	-31.50
Cost per kiloliter per year of the veterinary care contract	Other_health_costs	-3.52
Cost out of contract for a basic treatment for lactating G1 mastitis	Mastitis_health_costs	-20.00
Cost under contract for a basic treatment for lactating G1 mastitis	Mastitis_health_costs	-20.00
Cost out of contract for a basic treatment for lactating G2 mastitis	Mastitis_health_costs	-20.00
Cost under contract for a basic treatment for lactating G2 mastitis	Mastitis_health_costs	-18.00
Cost out of contract for a basic treatment for lactating G3 mastitis	Mastitis_health_costs	-250.00
Cost under contract for a basic treatment for lactating G3 mastitis	Mastitis_health_costs	-50.00
Cost out of contract for a basic treatment for mastitis in dry cows	Mastitis_health_costs	-9.00
Cost under contract for a basic treatment for mastitis in dry cows	Mastitis_health_costs	-9.00
Additional cost of mastitis prevention with veterinary care contract / cow / year	Mastitis_health_costs	-9.00
Monensin bolus cost	Ketosis_health_costs	-40.00
Cost out of contract for basic treatment for G1 severity ketosis	Ketosis_health_costs	-6.00
Cost under contract for basic treatment for G1 severity ketosis	Ketosis_health_costs	-5.00
Cost out of contract for basic treatment for G2 severity ketosis	Ketosis_health_costs	-100.00
Cost under contract for basic treatment for G2 severity ketosis	Ketosis_health_costs	-60.00
Additional cost of ketosis prevention with veterinary care contract / cow / year	Ketosis_health_costs	-5.00
Annual cost of a foot bath	Foot_bath_lameness_costs	-67.00
Minimum cost of operating a foot bath (up to 75 cows)	Foot_bath_lameness_costs	-324.00
Maximum cost of operating a foot bath (from 76 cows)	Foot_bath_lameness_costs	-648.00
Cost of installing the trimming facility (curative or preventive)	Curative_trimming_lameness_costs or Preventive_trimming_lameness_costs	-75.00
Cost of collective preventive or individual curative trimming of a healthy or lame cow	Curative_trimming_lameness_costs or Preventive_trimming_lameness_costs	-20.00
Cost of treating a cow found to be lame or detected as non-infectious (all severities)	Curative_collective_non_infectious_lameness_costs or Curative_individual_non_infectious_lameness_costs	-17.00
Cost of treating a cow found or detected to be lame and infectious (all severities)	Curative_collective_infectious_lameness_costs or Curative_individual_infectious_lameness_costs	-5.00
Non-targeted treatment outside of veterinary care contracts for GENNI severity G1 up to 7 days of age	GENNI_health_costs	-29.60
Non-targeted treatment outside the veterinary care contract for a GENNI with severity G1 from 8 days of age	GENNI_health_costs	-24.33
Non-targeted treatment under veterinary care contract for a GENNI of severity G1 up to 7 days of age	GENNI_health_costs	-25.00
Non-targeted treatment under veterinary care contract for a GENNI of severity G1 from 8 days of age	GENNI_health_costs	-20.00
Non-targeted treatment outside of veterinary care contracts for GENNI severity G2 up to 7 days of age	GENNI_health_costs	-131.06
Non-targeted treatment outside the veterinary care contract for a GENNI with severity G2 from 8 days of age	GENNI_health_costs	-125.79
Non-targeted treatment under veterinary care contract for a GENNI of severity G2 up to 7 days of age	GENNI_health_costs	-100.00
Non-targeted treatment under veterinary care contract for a GENNI of severity G2 from 8 days of age	GENNI_health_costs	-95.00
Targeted ETEC treatment outside of veterinary care contracts for a GENNI with severity G1	GENNI_health_costs	-29.60
Targeted ETEC treatment under veterinary care contract for a GENNI of severity G1	GENNI_health_costs	-25.00
Targeted ETEC treatment outside of veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-131.06
Targeted ETEC treatment under veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-100.00
Targeted Crypto treatment outside of veterinary care contract for a GENNI with severity G1	GENNI_health_costs	-47.49
Targeted Crypto treatment under veterinary care contract for a GENNI with severity G1	GENNI_health_costs	-40.00
Targeted Crypto treatment outside of veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-149.05
Targeted Crypto treatment under veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-110.00

Targeted treatment for Rota outside the veterinary care contract for a GENNI of severity G1	GENNI_health_costs	-24.33
Targeted treatment Rota under veterinary care contract for a GENNI of severity G1	GENNI_health_costs	-20.00
Targeted treatment for Rota outside the veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-125.79
Targeted treatment Rota under veterinary care contract for a GENNI of severity G2	GENNI_health_costs	-95.00
Targeted treatment for coronavirus outside of veterinary care contracts for a GENNI with severity level G1	GENNI_health_costs	-24.33
Targeted treatment for coronavirus under veterinary care contract for a GENNI with severity G1	GENNI_health_costs	-20.00
Targeted treatment for coronavirus outside of veterinary care contracts for a GENNI with severity level G2	GENNI_health_costs	-125.79
Targeted treatment for coronavirus under veterinary care contract for a GENNI with severity level G2	GENNI_health_costs	-95.00
Additional veterinary examination not covered by veterinary care contract for a GENNI with severity level G1	GENNI_health_costs	-38.67
Additional veterinary examination under veterinary care contract for a GENNI with severity G1	GENNI_health_costs	-30.00
Additional veterinary examination not covered by veterinary care contract for a GENNI with severity level G2	GENNI_health_costs	-64.76
Additional veterinary examination under veterinary care contract for a GENNI with severity G2	GENNI_health_costs	-50.00
ETEC + Rota + Corona vaccination not covered by veterinary care contract	GENNI_health_costs	-14.67
ETEC + Rota + Corona vaccination under veterinary care contract	GENNI_health_costs	-12.00
Crypto vaccination not covered by veterinary care contract	GENNI_health_costs	-13.58
Crypto vaccination under veterinary care contract	GENNI_health_costs	-11.00
Additional maintenance costs for hygiene scores of 3 and 4	GENNI_health_costs	-0.54
Additional maintenance cost for a hygiene score of 5	GENNI_health_costs	-1.91
Annual cost of maintenance equipment for a hygiene score of 3 or 4	GENNI_health_costs	-33.60
Cost of maintenance equipment for a hygiene score of 5	GENNI_health_costs	-57.40
Cost of an individual serum ELISA test, with 50 per cent of the cost covered by the GDS	PTB_health_costs	-6.25
Cost of the quantitative PCR test, with 50 per cent of the cost covered by the GDS	PTB_health_costs	-18.25

Table 134: Default rates for health-related accounting transactions

2.2.7.1.4 Genetics

Accounting operation	Accounting class [1]	Charge (€)
Cost of RPTB genotyping, with 50 per cent covered by the GDS	Genetic_costs	-41.00

Table 135: Default rates for genetic-related accounting transactions

2.2.7.1.5 Population

Accounting operation	Accounting class [1]	Charge (€)
Sale of a female dairy calf	Calf_sales	60.00
Sale of a male dairy calf	Calf_sales	80.00
Sale of a beef crossbreed female calf	Calf_sales	300.00
Sale of a beef crossbreed male calf	Calf_sales	320.00
Sale of a live heifer of less than one year old	Heifer_sales	250.00
Sale of a live heifer of more than one year old	Heifer_sales	600.00
Sale/purchase of a pregnant heifer	Heifer_sales/Population_costs	800.00
Sale of a culled cow	Cull_sales	700.00

Table 136: Default rates for population-related accounting transactions

2.2.7.1.6 Feeding

Accounting operation	Accounting class [1]	Charge (€)
Purchase of one ton of a dehydrated milk powder	Feed_costs	-2000.00
Product cost of one ton of maize plant (dry matter)	Feed_costs	-200.00
Product cost of one ton of grass (crude matter)	Feed_costs	-45.00
Product cost of one ton of hay (dry matter)	Feed_costs	-140.00
Product cost of one ton of grass silage (crude matter)	Feed_costs	-130.00
Purchase of one ton of rapeseed (crude matter)	Feed_costs	-300.00
Purchase of one ton of soybean (crude matter)	Feed_costs	-330.00
Purchase of one ton of barley (crude matter)	Feed_costs	-160.00
Purchase of one ton of minerals and vitamins (crude matter)	Feed_costs	-660.00

Table 137: Default rates for feeding-related accounting transactions

2.2.7.1.7 Other accounting items

By default, the various accounting elements modelled have the following values:

Accounting operation	Accounting class [1]	Charge (€)
Rendering of a dead heifer aged up to 1 year	Other_costs	-20.00
Rendering of a dead heifer aged between 1 and 2 years	Other_costs	-30.00
Rendering of a dead cow	Other_costs	-40.00
Monthly test-day (per cow and per year)	Other_costs	-45.00
Cetodetect ® milk control test (per cow per year)	Other_costs	-3.76
Cost Herd Navigator ® (per cow per year)	Other_costs	-35.00
Product cost of one ton of straw (dry matter)	Other_costs	-20.00

Table 138: Default rates for miscellaneous accounting transactions

In order to take into account breeding costs which are not explicitly described but which nevertheless exist, the following flat rates are applied including tariffs and frequency. The modifiable tariff values have the following default values:

Package	Accounting class (*)	Price (€)	Frequency
Purchase of bedding for a calf	Other_costs	-20.00	One time (2 month old calves)
Veterinary costs per heifer in the herd	Other_health_costs	-50.00	
Other costs of raising a calf	Other_costs	-10.00	
Purchase of bedding per cow present average	Other_costs	-20.00	Annual
Average veterinary costs per cow present (excluding managed diseases)	Other_health_costs	-40.00	
Other livestock costs per average cow present (maintenance of milking infrastructure and udder hygiene)	Other_costs	-80.00	

Table 139: Default rate and frequency of not described costs

2.2.7.2 Data produced

The data produced is about the details of the technical assessment related to economical assessment, is generated automatically, regardless of the version of the simulator.

Result name: these results are included in the structure of technical results described in paragraph *3.3 Result structure*.

Production type: annual.

Information level: Herd.

These data, all expressed in euros, are produced at the end of the campaign.

The available fields are:

Field name	Method of calculation
Gross_margin	Gross margin: Total revenue - total expenses
Total_products	Sale of milk + sale of cull cows + sale of heifers + sale of calves
Milk_sales	Proceeds from the sale of milk (including bonuses and penalties)
Cull_sales	Proceeds from the sale of cull cows
Heifer_sales	Proceeds from the sale of heifers
Calf_sales	Proceeds from the sale of calves
Total_expenses	Cost of feed + health + reproduction + other
Feed_costs	Expenses related to the purchase and production of feed
Health_costs	Expenses related to the health management
Mastitis_health_costs	Cost of mastitis treatments
Ketosis_health_costs	Cost of G1 and G2 ketosis treatments + Monensin treatment
Curative_individual_infectious_lameness_costs	Cost of individual treatments for infectious lameness (trimming + treatment)
Curative_individual_non_infectious_lameness_costs	Cost of individual treatments for non-infectious lameness (trimming + treatment)
Curative_collective_infectious_lameness_costs	Cost of collective treatment of infectious lameness (treatment only)
Curative_collective_non_infectious_lameness_costs	Cost of collective treatment of non-infectious lameness (treatment only)
Curative_trimming_lameness_costs	Cost of individual curative trimming (workshop assembly only)
Overall_curative_lameness_costs	Global cost of curative trimming
Preventive_trimming_lameness_costs	Cost of preventive trimming (workshop assembly + trimming)
Foot_bath_lameness_costs	Operating costs of the foot bath
Genni_health_costs	Cost of preventive measures and treatment for GENNI G1 and G2
PTB_health_costs	Cost of preventive measures against paratuberculosis
Other_health_costs	Cost of other health expenses
Reproduction_costs	Insemination-related expenses
Population_costs	Expenses related to population management
Genetic_costs	Expenses related to genetics
Other_costs	Residual costs: rendering, milk control

Table 140: Structure of the economic balance sheet data expressed in euros

3 Technical modalities to use the simulator

3.1 General principle governing the operation of the simulator

The general procedure for using the simulator involves creating livestock farms, linking them to an accounting model, adjusting parameter values according to the scenarios to be simulated, creating simulation protocols associated with the previously configured farms, and running the simulation for the desired protocols. The results are then generated.

3.1.1 Farm creating

Creating a farm involves setting up an instance that will include all the default values as described in the previous chapters. The user must then modify the farm's settings so that it corresponds to the scenario they wish to test. Appendix I: List of the keys and formats of the husbandry parameters provides details of the quantity and quality of all the parameters available for configuring a farm. The user can create as many farms as they wish. This will enable them to simulate a variety of scenarios and analyse the results based on the differences between them.

Depending on the variations, it may also be necessary to create an accounting model that assigns an accounting dimension to certain actions.

3.1.2 Accounting model creating

Creating an accounting model involves creating an instance that will contain all the default values as described in the previous section *2.2.7.1 Accounting parameters*. This is necessary for the implementation defined in section *3.2.4 R package*; it is not necessary for the implementation defined in section *3.2.1 Application Programming Interface (API)*, as in that case the accounting model instance is included within the breeding process itself.

The user must then modify the accounting model's parameters so that it corresponds to the scenario they wish to test. *Appendix II: List of accounting model parameter keys* provides details of the quantity and nature of all the parameters available for configuring an accounting model. The user may create as many accounting models as they wish. This will enable them to simulate a variety of accounting scenarios and analyse the results based on their differences.

3.1.3 Protocol creating

The protocols are used to define the criteria relating to the simulation. These include:

- The duration of the simulation, in whole years,
- The duration of the 'warm-up' period, which is a period during which the rearing process continues without producing any results,
- The month and year on which the simulation begins
- The number of repetitions: the simulator is a stochastic model, which means that each repetition will produce its own results, which will differ statistically from the others. To ensure the results are statistically significant, it is recommended that several hundred repetitions be carried out.
- The breeding programme created beforehand and associated with these simulation guidelines.
- Depending on the variant, the associated accounting model (in the case of the R package, see section *3.2.4 R package*).

In the case of the API variant (see section *3.2.1 Application Programming Interface (API)*), two types of protocols are available: simple protocols and cross-protocols.

3.1.3.1 Simple protocols

Simple protocols allow a protocol to be associated with a breeding programme with fixed settings. This is the simplest way of defining a protocol. It is optional for the API version but mandatory for the R package version (see section *3.2.4 R package*).

The results will be categorised by the value of discriminant 1, which takes the name of the corresponding herd (see section *3.3 Result structure*).

3.1.3.2 Crossed protocols

The crossed protocol differs from the simple protocol in that, for the same simulation context, it allows combinations of parameter crossovers from a reference herd. Thus, starting from a pre-configured herd scenario, the protocol, when run, can modify certain parameters according to the crossovers requested by the user. For example, the protocol will be able to simulate the reference herd by varying the mastitis prevention value to 0.8, then to 1 and finally to 1.2. In the simulation results, the discriminants will enable the results for each prevention level to be identified. Up to four levels of parameter combinations can be programmed; these will be distinguished by a variable specifically termed 'discriminant' (see section *3.3 Result structure*).

This feature has been proposed for the API version (see section *3.2.1 Application Programming Interface (API)*) to prevent users from having to create as many herds as there are combinatorial variants to test. It is not proposed for the R package version (see section *3.2.4 R package*) as this drawback does not arise; writing the code as a script technically allows the desired crosses to be carried out within programming loops.

3.1.4 Running the simulation and obtaining the results

Once the cultures have been created and the simulation protocols are in place, the simulation can be run. Depending on the number of repetitions requested, the simulation may take anywhere from a few seconds to several hours.

The results are provided in the form of a CSV file, the structure of which is described in section *3.3 Result structure* with regard to the simulation context, and in each of the 'Data produced' sections of the various modules with regard to the technical data.

The R package (see section *3.2.4 R package*) also allows the data to be retrieved in the form of a `"dataframe"`.

3.2 Variants of the simulator

3.2.1 Application Programming Interface (API)

The API is the technical interface that enables a client application to communicate with the simulation server. It is implemented during the development of the web interface for a third-party software solution, and is also used for the web application version of DHM (see section *3.2.2 Web application*).

Technically, communications must adhere to the JSON format, both in the syntax of commands and in the retrieval of their results.

The basic structure of a command is as follows:

```
{
    "user":"<user id>",
    ,"isPublic":<public>
    ,"cmd":"<command key>"
    <,"<arg n key>":"<arg n>">
}
```

With:

- <user id> = user identification (integer)
- <public> = the user is public (boolean value to true ou false)
- <command key> = command key (string)
- <arg n key> = specific argument key (string)
- <arg n> = specific argument value (format depending on the argument).

The basic structure of the standard return message is as follows:

```
{
    "user":"<user id>"
    ,"cmd":"<command key>"
    <,"<field n key>":<field n value>>
    ,"result":"<result code>"
}
```

With:

- <field n key> = returned key name (optional, string)
- <field n value> = associated value (format depending on the field),
- <result code> = returned message code (string, see section *3.2.1.8 Message codes*)

3.2.1.1 Command relating to farms

3.2.1.1.1 Farm creation

This command creates a farm with default values, associated with a default accounting model. The arguments are as follows:

Key	Value
"cmd"	"createFarm"
"farmName"	New farm name
"comment"	Farm description

Table 141: Keys and values for the command to create a farm

This command does not return any specific field.

3.2.1.1.2 Farm rename

This command allows you to rename an existing farm. The arguments are as follows:

Key	Value
"cmd"	"renameFarm"
"farmName"	Concerned farm name
"newName"	New farm name

Table 142: Keys and values for the command to rename a farm

This command does not return any specific field.

3.2.1.1.3 Obtaining the list of farms

This command displays a list of existing farms. The arguments are as follows:

Key	Value
"cmd"	"getFarmList"

Table 143: Key and value for the command to get farm list

The specific returned fields and associated values (<field n key> et <field n value>) are « ,"farms":["<farm name 1>",…,"<farm name n>"] ».

3.2.1.1.4 Obtaining farm parameters

This command allows you to obtain the parameters of an existing farm as well as those of the accounting model relating to it. The arguments are as follows:

Key	Value
"cmd"	"getFarmParameters"
"farmName"	Concerned farm name

Table 144: Keys and values to obtain farm parameters

The keys for specific return fields, along with the associated values and fidelity to default values, are grouped according to whether they are farming parameters or parameters from the associated accounting model, namely:

```
"farmParameters":[["<key 1>", <content 1>, <1 is default>]
                  ,["<key n>", <content n>, <n is default>]],
"accountingModelParameters":
               [["<key 1>", <content 1>, <tendency 1>, <1 is default>]
               ,["<key n>", <content n>, <tendency n>, <n is default>]]
```

The keys returned correspond to those described *in Appendix I: List of the keys and formats of the husbandry parameters* and *Appendix II: List of accounting model parameter keys*. The value `<is default>` Boolean. The text contains are surrounded by "".

3.2.1.1.5 Modifying the parameters of a farm

This command allows you to modify the parameters of an existing farm as well as the accounting model associated with it. The arguments are as follows:

Key	Value	Reference
"cmd"	"setFarmParameters"	*Table 164: Structure of the fields defining the simulation framework* or *Table 164: Structure of the fields defining the simulation framework*
"farmName"	Concerned farm name	
"farmParameters"	Farm parameter list	
"accountingModelParameters"	Accounting model parameter list	

Table 145: Keys and values for the command to modify a farm parameter

The keys and associated values to be provided are grouped according to whether they are breeding parameters or parameters of the associated accounting model, namely:

```
"farmParameters":[["<key 1>", "<content 1>"]
                  ,["<key n>", "<content n>"]],
"accountingModelParameters":
               [["<key 1>", "<content 1>", "<tendency 1>"]
               ,["<key n>", "<content n>", "<tendency n>"]]
```

The keys to be provided and the data formats are described in *Appendix I: List of the keys and formats of the husbandry parameters* and *Appendix II: List of accounting model parameter keys*.

This command does not return any specific field.

3.2.1.1.6 Farm duplication

This command allows you to create a copy of an existing farm and its associated accounting model. The arguments are as follows:

Key	Value
"cmd"	"duplicateFarm"
"farmName"	Concerned farm name

Table 146: Keys and values for the command to duplicate a farm

The name of the new farm is generated automatically from the name of the original farm name, to which an "_n" is added, where "n" is the version number.

This command does not return any specific field.

3.2.1.1.7 Farm deleting

This command allows you to delete an existing farm. The arguments are as follows:

Key	Value
"cmd"	"deleteFarm"
"farmName"	Concerned farm name

Table 147: Keys and values for the command to delete a farm

If the concerned farm was associated with a protocol, the latter would also be deleted.

This command does not return any specific field.

3.2.1.2 Commands related to simulation protocols

Simple protocols are those associated with a farm that have not been enriched with cross-management. They are therefore executed by simply applying the parameters that define them. Cross protocols allow different values to be defined for different parameters (breeding only, not accounting model), so that all possible combinations can be simulated. Cross parameter management is covered in section *3.2.1.2.7 Management of cross-protocol parameters*.

3.2.1.2.1 Creation of a protocol

This command allows you to create a protocol based on an existing farm. The arguments to be emphasized are as follows:

Key	Value	Technical format
"cmd"	"createProtocol"	string
"simple"	true or false	boolean
"protocolName"	Protocol name	string
"farmName"	Associate farm name	string
"comment"	Protocol description	string
"simulationDuration"	Simulation duration	interger
"runNumber"	Run number	interger
"warmupDuration"	Heating period duration	interger
"simMonth"	Simulation begin month	interger
"simYear"	Simulation begin year	interger

Table 148: Keys and values for the command to create a protocol

String-type content must be enclosed in “"“.

This command does not return a specific field.

3.2.1.2.2 Renaming a protocol

This command allows you to rename a protocol. The arguments are as follows:

Key	Value
"cmd"	"renameProtocol"
"protocolName"	Concerned protocol name
"newName"	New protocol name

Table 149: Keys and values for the command to rename a protocol

This command does not return a specific field.

3.2.1.2.3 Obtaining protocol list

This command allows you to obtain protocol list. The arguments are as follows:

Key	Value
"cmd"	"getProtocolList"
"simple"	true or false

Table 150: Keys and values for the command to obtain the protocol list

The "simple" argument specifies whether simple or cross protocols are required for the list.

The specific return field keys and associated values (<field n key> et <field n value>) are:

,"simple":true or false

,"protocols":["< *protocol 1 name*>",…,"< *protocol n name*>"]

3.2.1.2.4 Obtaining protocol parameters

This command allows you to obtain the parameters of an existing protocol . The arguments are as follows:

Key	Value
"cmd"	"getProtocolParameters"
"protocolName"	Concerned protocol name

Table 151: Keys and values for the command to protocol parameters

The keys for specific return fields and their associated values are provided as follows:

"protocolParameters":[["*<key 1>*",*<content 1>*],
["*<key n>*",*<content n>*]]

The specific return field keys and associated values are identical to those defining the parameters described in section ***Erreur ! Source du renvoi introuvable. Erreur ! Source du renvoi introuvable.***. Character string content is enclosed in “”“. Simple protocols do not return discriminant values, as these are automatically assigned based on the name of the protocol itself. However, for cross protocols, the cross values for each discriminant position are returned as follows:

```
"protocolDiscriminants":[
                    {"discriminantPos":0,
                     "<parameter 1 key>":[val 1, val n],
                     "<parameter n key>":[val 1, val n]},
                    {"discriminantPos":n,
                    {"<parameter 1 key>":[val 1, val n],
                     "<parameter n key>":[val 1, val n]}]
```

3.2.1.2.5 Modifying protocol settings

This command allows you to modify protocol parameters. The arguments are as follows:

Key	Value	Reference
"cmd"	"setProtocolParameters"	See section ***Erreur ! Source du renvoi introuvable. Erreur ! Source du renvoi introuvable.***
"protocolName"	Concerned protocol name	
"protocolParameters"	Protocol parameter list	

Table 152: Keys and values for the command to modify protocol parameters

The keys and associated values to be provided are grouped as follows:

"protocolParameters": [["*<key 1>*", *<content 1>*]
,["*<key n>*", *<content n>*]]

The parameter keys *<key>* are the same as those described in section *3.2.1.2.1 Creation of a protocol* above. Character string content must be enclosed in "".

This command does not return any specific fields.

3.2.1.2.6 Protocol deleting

This command allows you to delete an existing protocol. The arguments are as follows:

Key	Value
"cmd"	"deleteProtocol"
"protocolName"	Concerned protocol name

Table 153: Keys and values for the command to delete a protocol

This command does not return any specific fields.

3.2.1.2.7 Management of cross-protocol parameters

Cross-management of parameters can only be added to a protocol created as cross-management (see section *3.2.1.2.1 Creation of a protocol* above). To do this, one command allows you to add a list of values for a given breeding parameter, and another to delete it.

3.2.1.2.7.1 Adding a list of breeding parameter values to be crossed

The command to add (or replace) a list of values to be crossed for a given farm parameter is as follows:

Key	Value	Reference
"cmd"	"appendProtocolCrossedValues"	*Table 164: Structure of the fields defining the simulation framework*
"protocolmName"	Concerned protocol name	
"discriminantPos"	Position of the discriminant concerned (integer, 0 based)	
"key"	Concerned parameter key	
"values"	[*<val 1>*, *<val 2>*, *<val n>*]	

Table 154: Keys and values for the command to add (or replace) a list of parameter values to be cross-referenced

This command does not return any specific fields.

3.2.1.2.7.2 *Delete a list of breeding parameter values having been crossed*

The command to delete a list of values having been crossed for a given farm parameter is as follows:

Key	Value	Reference
"cmd"	"removeProtocolCrossedValues"	*Table 164: Structure of the fields defining the simulation framework*
"protocolmName"	Concerned protocol name	
"discriminantPos"	Position of the discriminant concerned (integer, 0 based)	
"key"	Concerned parameter key	

Table 155: Keys and values for the command to delete a list of parameter values having been cross-referenced

This command does not return any specific fields.

3.2.1.2.7.3 *Changing the header name of the discriminants*

The command to change the header name of each discriminant is as follows:

Key	Value
"cmd"	"setDiscriminantHeaderName"
"protocolName"	Concerned protocol name
"0"	Name to be assigned to discriminant 1
"1"	Name to be assigned to discriminant 2
"2"	Name to be assigned to discriminant 3
"3"	Name to be assigned to discriminant 4

Table 156: Keys and values for the command to change the header name of a discriminant

This command does not return any specific fields. If the same name to be assigned appears more than once, error 408 is returned.

3.2.1.2.7.4 *Obtaining the header discriminant names of a protocol*

The command for retrieving the header name for each of the discriminants is as follows:

Key	Value
"cmd"	"getDiscriminantHeaderNames"
"protocolName"	Concerned protocol name

Table 157: Keys and values for the command to change the header name of a discriminant

The keys for specific return fields and their associated values (<field n key> and <field n value> are:

,"0":"*<header discriminant 1 name>*"

,"1":"*<header discriminant 2 name>*"

,"2":"*<header discriminant 3 name>*"

,"3":"*<header discriminant 4 name>*"

3.2.1.3 Reference values

It is possible to find out the reference values for the parameters. The command is as follows:

Key	Value
"cmd"	"getRefParameterValues"

Table 158: Key and value for the command to get the parameter reference values

The specific return field keys and associated values are grouped according to whether they relate to breeding parameters, associated accounting models, or protocols, namely:

```
"farmParameters":
[["<key 1>", <default 1>, <min 1>, <max 1>, <format 1>, <1 qualitative>],
 ["<key n>", <default n>, <min n>, <max n>, <format n>, <n qualitative>]],
"accountingModelParameters":
[["<key 1>", <default 1>, <min 1>, <max 1>, <format 1>, <1 qualitative>],
 ["<key n>", <default n>, <min n>, <max n>, <format n>, <n qualitative>]],
"protocolParameters":
[["<key 1>", <default 1>, <min 1>, <max 1>, <format 1>, <1 qualitative>],
 ["<key n>", <default n>, <min n>, <max n>, <format n>, <n qualitative>]]
```

The keys returned correspond to those described in *Appendix I: List of the keys and formats of the husbandry parameters,* in *Appendix II: List of accounting model parameter keys* and in section ***Erreur ! Source du renvoi introuvable. Erreur ! Source du renvoi introuvable.***. The information line for each parameter consists of several fields:

- the default value,
- the minimum value,
- the maximum value,
- The data format:
  - `"boolean"` for Boolean values,
  - `"text"` for text values,
  - `"integer"` for integers,
  - `"double"` for decimals.
- Data qualification (qualitative vs. quantitative):
  - Qualitative data: `"true"`,
  - Quantitative data: `"false"`.

Text data has minimum and maximum values set to `"null"`.

This command also allows you to provide the default names of discriminants that can be used for cross protocols, with `<key n>` being the rank of the discriminant concerned, whose value will range from `"0"` to `"3"`, since a maximum of 4 discriminants can be implemented, and `<default n>` will be the default value of type character string enclosed in "".

3.2.1.4 Restoring previous values

It is possible to retrieve farm values, accounting models and protocols that were saved during the last simulation. This data is stored in XML format in the results directory; it allows the data to be retrieved in a readable format so that it can be corrected if necessary, should an update to the simulator prevent the use of older parameter values. The command is as follows:

Key	Value
`"cmd"`	`"restorePreviousDataCommand"`

Table 159: Key to the command for restoring previous values

There are no specific input or output fields for this command.

3.2.1.5 Simulation launch command

This command launches the simulation of the specified protocols:

Key	Value
`"cmd"`	`"run"`
`"protocols"`	Protocol name list to be simulated

Table 160: Keys and values for the command to launch simulations

The list of protocol names must be provided as follows:

"protocols": ["*<name 1>*", "*< name n>*"]

The results are provided in the form of the following specific fields:

"simple":true *or* false,

"protocolName":"*<crossed protocol name>*",

"timestamp":"*<yyyy>*-*<mm>*-*<dd>*T*<hh>*:*<mm>*:*<ss.sssssssss>*Z",

"results":

```
 {"<every key>":
        {"<every discriminant pos>":
              {"<every variation>":
                    {"<every year>":
                          {
                                "min":<min value>,
                                "D1":<D1 value>,
                                "Q1":<Q1 value>,
                                "moy":<mean value>,
                                "med":<median value>,
                                "Q3":<Q3 value>,
                                "D9":<D9 value>,
                                "max":<max value>
                          },{<...>}
                    },{<...>}
              },{<...>}
        },{<...>}
}
```

The "protocolName" field is set in the case of a simulation based on a cross-protocol approach. For single protocols, this field is set to "null". The <every key> keys are described in the "results" section for each of the modules presented in paragraph *2.2 Modules*2.2 in the "Field name" column. If, following a connection failure, a simulation is requested whilst one is already in progress for the user, error 503 is returned.

3.2.1.6 Command to obtain the latest summarised simulation results

This command allows you to obtain the latest summarised simulation results:

Key	Value
"cmd"	"getLastResults"

Table 161: Key and value for the command to obtain last summarised simulation results

These results are provided with the same structure as described in section *3.2.1.5 Simulation launch command* above. The result "**"results":{}**" is returned is no simulation has been launched before by the current user.

3.2.1.7 Command to retrieve the latest gross simulation results

This command allows you to obtain the latest gross simulation results:

Key	Value
`"cmd"`	`"getLastGrossResults"`

Table 162: Key and value for the command to obtain last gross simulation results

These results are provided in raw form as a list of rows, the first of which is the header row and the subsequent rows contain the annual results, as described in paragraph *3.3 Result structure*.

3.2.1.8 Message codes

All requests to the simulation server return a `<result code>` (see section *3.2.1 Application Programming Interface* above). The codes have the following meanings:

Code number	Meaning
General	
200	Operation performed without error
201	Unknown command
Farms	
300	Unknown farm name
301	Farm already exists
302	Unknown farm parameter key
303	Incorrect farm parameter value
304	Unknown accounting model key
305	Incorrect accounting model parameter value
Protocols	
400	Unknown protocol name
401	Protocol already exists
402	Unknown protocol parameter key
403	Incorrect protocol parameter value
404	Maximum number of cross-values already reached
405	Maximum number of discriminants already reached
406	The number of values for each parameter to be cross-referenced for a discriminant is not the same
407	The simulation duration must be longer than the warm-up period
408	A discriminant name is already in use by another discriminant
409	There is no discriminant at the specified position
410	The number of values for each parameter to be cross-referenced for a discriminant is not the same.
Simulation	
500	Simulation requested without active protocol
501	The cross-protocol simulation cannot be launched because no cross-protocol is programmed.
502	The simulation must be requested for one or more simple protocols, or a single cross-protocol.
503	A simulation is already running for the standard user.

Table 163: API Return Code Table

3.2.2 Web application

The web application is accessible to the public via the following link: www.dairyhealthmanager.fr. It allows any visitor, once registered, to create breeding scenarios using a number of adjustable parameters, to create simple protocols with a limited number of repetitions, and to run simulations. Public users have access to all

the results of their simulations. The application's 'administrator' profile allows the granting of configuration rights for each of the DHM modules, which are not accessible to public visitors by default.

3.2.2.1 Creating and configuring a farm

Once registered and logged in, the user can create one or more herds by clicking on '+ I create my first breeding':

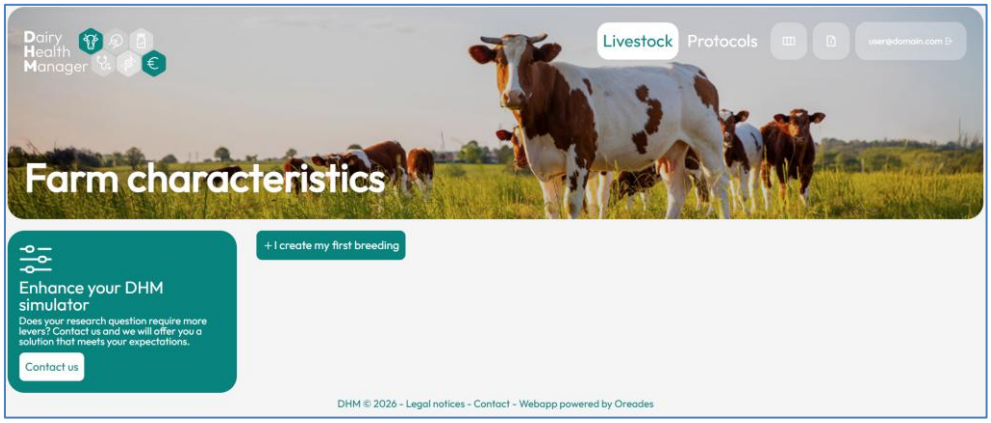


Figure 31: Creating a farm with the web application

You then need to enter a name and a description:

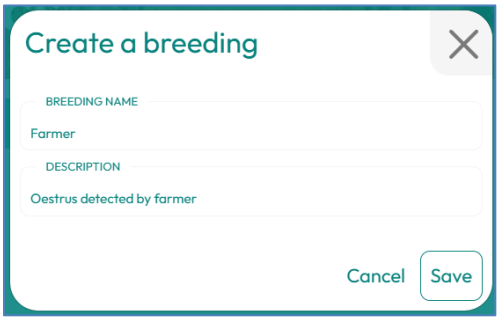


Figure 32: Name and description of a farm with the web application

It is then possible to amend one or more parameters (technical or accounting) which will enable the rearing scenario to be defined in practical terms:

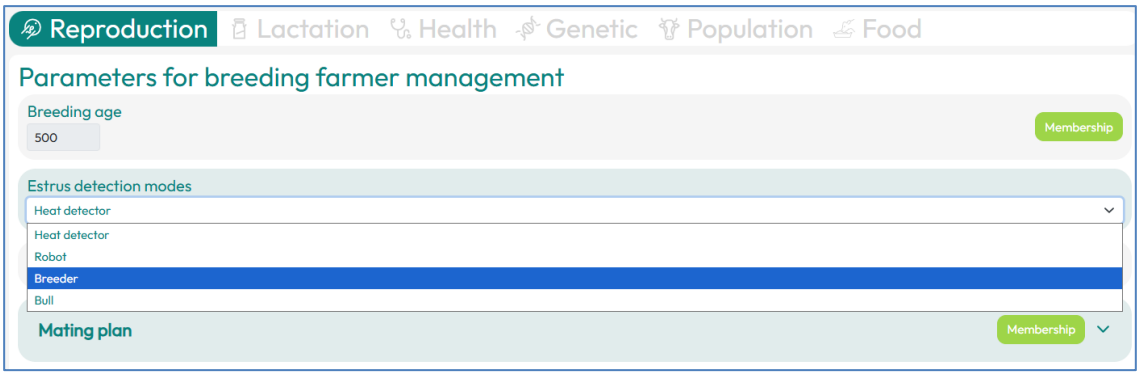


Figure 33: Changing a farming parameter with the web application

Please note that in the public version, only certain settings can be changed. To access further settings, we recommend contacting UMR BIOEPAR (an online form is available). It should also be noted that, in the web application, the accounting model to be linked is configured in the settings section for the farm itself.

3.2.2.2 Creating and configuring a simulation protocol

The user can create one or more protocols by clicking on 'Add simple protocol':



Figure 34: Creating a simple protocol with the web application

On the protocol settings page, you must give the protocol a name and, where applicable, set the relevant parameters. It is at this stage that the protocol must be linked to a farm:

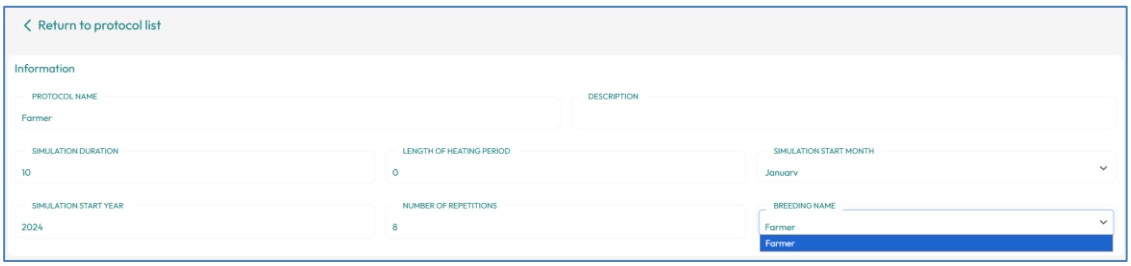


Figure 35: Configuring a simple protocol with the web application

The configuration of a cross-protocol is identical. Users who have subscribed to paid options will be able to cross-reference certain parameters by creating the necessary criteria to organise the simulation of this cross-protocol:

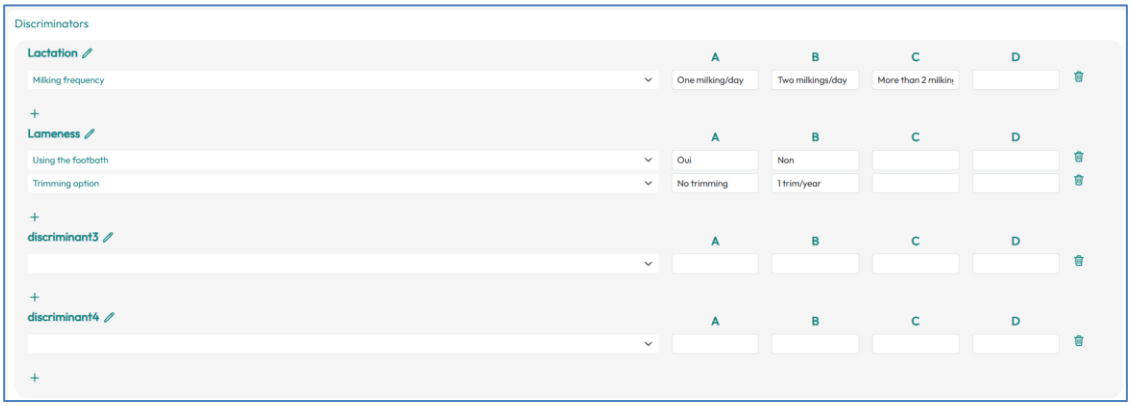


Figure 36: Discriminants of a cross-protocol approach with the web application

In the example above, the user has defined two levels of classification:

- The level named 'lactation', which considers three milking methods,
- The classification named 'lameness', which considers two methods of using the footbath and trimming.

In practical terms, when this protocol is launched, the underlying herds will be created on a temporary basis and simulated individually, namely:

- Herd AA: 'one milking per day', footbath used and no hoof trimming,
- Herd AB: 'one milking per day', footbath not used and one hoof trimming per year,

- Farm BA: 'two milkings per day', footbath used and no hoof trimming,
- Farm BB: 'two milkings per day', footbath not used and one hoof trimming per year,
- Farm CA: 'more than two milkings per day', footbath used and no hoof trimming,
- Farm CB: 'more than two milkings a day', footbath not used and one hoof trim per year,

Please note: for a discriminant, the number of categories for each parameter must be the same (in this case, two for the 'Lameness' discriminant).

3.2.2.3 Running the simulation

To start the simulation, the user selects the relevant protocol(s) and clicks the 'Start the simulation of selected simple protocols' button for simple protocols, and the 'Start the simulation of the selected cross protocol' button:

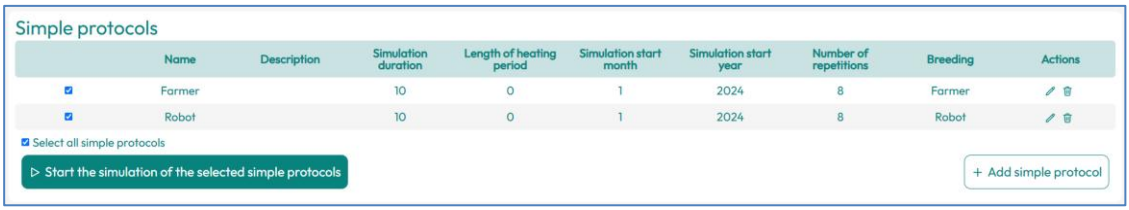


Figure 37: Launching the simulation with the web application

It is not possible to run simulations for several cross-protocols simultaneously.

Once the simulation has finished, an initial summary of the results is displayed. This covers both technical and health-related results:



Figure 38: Technical and health-related simulation results with the web application

This also applies to the financial results:



Figure 39: Simulated accounting results with the web application

The protocol management page allows you to download the raw data (in CSV format) from the most recent simulation, so that you can process it using a third-party data analysis tool if required:



Figure 40: Downloading the raw data from the latest simulation with the web application

3.2.2.4 User management

In addition to providing access to all simulation tools, the administrator profile allows you to manage registered users and create new ones:

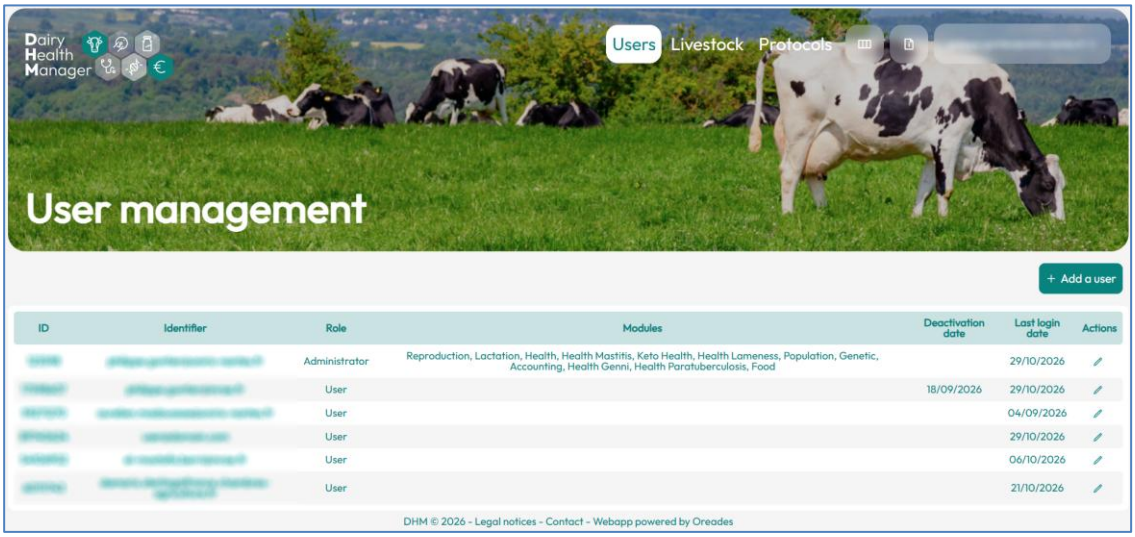


Figure 41: User management interface with the web application

This is the interface used to grant the agreed modules to a specific user:

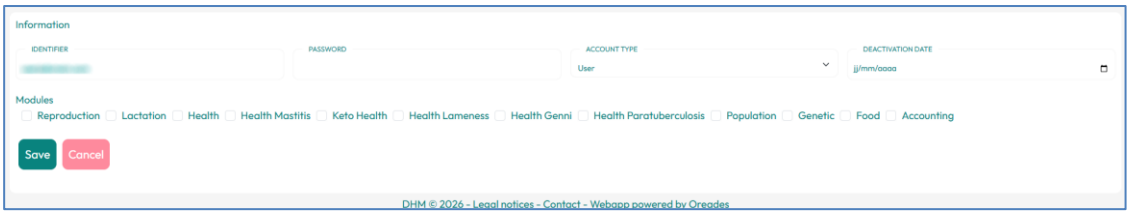


Figure 42: Assigning modules to users with the web application

3.2.3 Standalone application

The installable version allows you to deploy the web application described above locally, with all features enabled. This enables you to run the desired simulations independently, with results generated locally. The validity period of this installation is set by the installer in accordance with the agreed licence terms. Once the validity period has expired, the application will only offer the public configuration, under the same conditions as those set out in the previous paragraph.

This package is not available for download; you must use the web application's contact form to request it.

3.2.4 R package

This package enables simulation using R scripts to be developed by the user; it is supplied as a binary XML archive. As with the standalone installer, this package is not available for download and does not appear in the CRAN library of public R packages. It is made available in the `"pkg"` directory within the installation folder of the standalone version of DHM (see paragraph *3.2.3 Standalone application*).

3.2.4.1 Installing the R package

The prerequisite for installing the R package is as follows:

- Install R: https://cran.r-project.org/
- Install R Studio: https://posit.co/download/rstudio-desktop/#download
- Install RTools: https://cran.r-project.org/bin/windows/Rtools/rtools45/rtools.html
- Install Rcpp library: https://cran.r-project.org/web/packages/Rcpp/index.html

In R studio, click on `"Packages" -> "Install" -> "Package Archive File"` and choose archive file (named `"dhm_<version>.zip"`).

3.2.4.2 Using R package

The first step is to create the simulation instance:

```
dhm_init_instance()
```

3.2.4.2.1 Creating farms using the R package

To create a farm, you need to load the default values into a data set and then, if necessary, amend the relevant parameter(s):

```
# Farm 1 : Default : Without vet care contract
farm1_name = "Without vet care contract"
Farm1 = dhm_get_defaut_farm_parameters()
errorMessage <- dhm_create_dairy_farm(Farm1, farm1_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")


# Farm 2 : specific : With vet care contract
farm2_name = "With vet care contract"
```

```
Farm2 = dhm_get_defaut_farm_parameters()
Farm2$vetCareContract = "1"
errorMessage <- dhm_create_dairy_farm(Farm2, farm2_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")
```

The name of the parameters to set in the farm data (here `"Farm1"` et `"Farm2"`) is defined depending on the key described in *Appendix I: List of the keys and formats of the husbandry parameters*.

3.2.4.2.2 Creating accounting models using the R package

In the same way, to create an accounting model, you need to load the default values into a data set and then, if necessary, amend the relevant parameter(s):

```
# Get a default accounting parameter
accounting_model_name = "Default accounting model"
default_amp <- dhm_get_defaut_accounting_model_parameters()
errorMessage <- dhm_create_accounting_model(default_amp, accounting_model_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")
```

The name of the parameters to set in the accounting model data (here `"default_amp"`) is defined depending on the key described in *Appendix II: List of accounting model parameter keys*.

3.2.4.2.3 Creating protocols using the R package

In the same way, to create protocol, you need to load the default values into a data set and then, if necessary, amend the relevant parameter(s):

```
# Protocol creating (one by farm)
protocol_list <- c("Protocol farm 1", "Protocol farm 2")
farm_list <- c(farm1_name, farm2_name)
discriminant_list <- c("Default", "Specific")
for (i_protocol in 1:length(protocol_list))
{
  if (errorMessage == "")
  {
    # Get a default protocol parameter list
    pp <- dhm_get_defaut_protocol_parameters()
    pp$simulationDuration = "15"
    pp$warmupDuration = "5"
    pp$runNumber = "64"
    pp$farmName = farm_list[i_protocol]
    pp$accountingModelName = accounting_model_name
    pp$discriminant1 = discriminant_list[i_protocol]

    # Create the protocol based on this parameters
    errorMessage <- dhm_create_protocol(pp, protocol_list[i_protocol])
  }
}
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")
```

The R package does not provide cross-protocol setting, as it is easy to write the necessary loops in an R script to cross the desired variables.

3.2.4.2.4 Running the simulation using the R package

Once the farms, accounting models and protocols have been created, the simulation can be run:

```
#resultPath = "C:/your/result/folder/" # if you want to create result csv files
resultPath = "" # -> no csv result files, but dataframe
results <- dhm_execute_protocols(resultPath)
```

3.2.4.2.5 Retrieving results using the R package

Depending on the chosen output mode, the results will be output to a dataframe (`"results"` in our example) and, optionally, in the form of a CSV file stored in the specified directory (`"resultPath"` in our example) if it has not been initialised to `""`.

A complete example of how to use the R package is provided in *Appendix III: R package use example*. This example produces the following results:

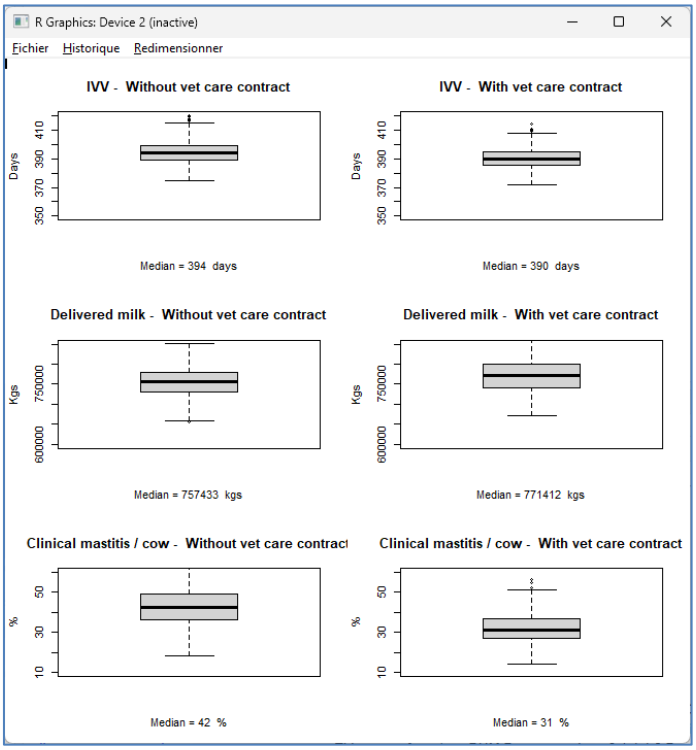


Figure 43: Technical comparison of two scenarios using R packages

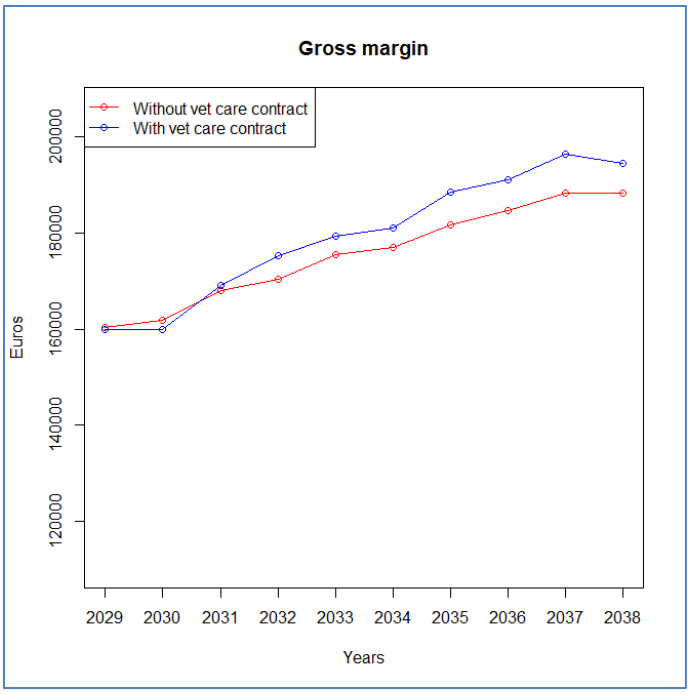


Figure 44: Economical comparison of two scenarios using R packages

The final step to follow to exit the simulator is as follows:

```
dhm_leave_instance()
```

3.3 Result structure

For the standalone application, the results files are stored in the directory specified during software installation. When used with R, they are provided in the specified directory and/or in the form of a `"dataframe"`. The results returned by the API comply with the structure defined in section *3.2.1.5 Simulation launch command*.

Most of the results are described in each of the relevant chapters. Specific fields include those defining the simulation framework, namely:

Field name	Description
Campaign (*)	Campaign involved
Run_number	Run number (0 based)
Discriminant1 (**)	Discriminant values (see paragraph *3.1.3 Protocol creating*)
Discriminant2 (**)	
Discriminant3 (**)	
Discriminant4 (**)	

Table 164: Structure of the fields defining the simulation framework

(*) See *Table 2: Type data formats* page *15*.

(**) *Default name.*

For each result, the following fields are as described in the corresponding chapters.

However, to facilitate their analysis, some specific results have been merged into a single structure `"TechnicalAndEconomicalResults"`. This is the case for the technical results relating to reproduction, production, diseases managed, population management and the economic balance sheet. This structure is organised as follows:

Field class	Reference
Simulation framework	*Table 164: Structure of the fields defining the simulation framework*
Reproduction data	*See paragraph 2.2.1.3.3*
Production data	*See paragraph 2.2.2.3.4*
Managed diseases data	*See paragraph 2.2.3.6*
Population data	*See paragraph 2.2.5.3*
Economical data	*See paragraph 2.2.7.2*

Table 165: Technical data structure

3.4 Sensitivity analysis

The sensitivity analysis of the model was carried out in 2025 as part of the COMAD-DHM project and was the subject of a report (Caillat *et al.*, 2025).

3.5 Technical data

The characteristics necessary for the simulator use are as follows:

Standalone desk:

The minimum characteristics expected are as follows:

- Memory: 16 GB

- CPU: 4GHz clock, 8 cores

- Disk space: 1 GB (depending on the simulation protocols).

The duration and number of repetitions for the simulations performed with “full results” version from the default farm according to the default protocol are as follows

- 8 years of pre-simulation + 1 year of actual simulation, no warmup, 8 repetitions

- 8 years of pre-simulation + 10 years of actual simulation, no warmup, 8 replicates

- 8 years of pre-simulation + 15 years of actual simulation, no warmup, 16 replicates

This protocol leads to 32 repetitions for a total machine time of about 8 seconds, which represents about 0.25 second per repetition. For the standalone application, the results spend 4.57 MB of disk space for the standalone version.

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6 Tables

Table 1: Breeds involved 14
Table 2: Type data formats 15
Table 3: Days between ovulations 17
Table 4: Estrus detecting sensitivity for first insemination 18
Table 5: Estrus detection sensitivity for following inseminations 18
Table 6: Multiplicative value increasing sensitivity in the case of concomitant estrus 19
Table 7: Probability of a lack of specificity for heifers 20
Table 8: Probability of a lack of specificity for cows after calving 20
Table 9: Basic fertility rate (not taking into account the adverse effects of certain factors) according to fertilization modes 21
Table 10: Calculation of the value of the fertility factor related to milk production at peak 21
Table 11: Breed-specific probability of late embryonic mortality 23
Table 12: Late abortion probability 23
Table 13: Breed and parity-specific average Pregnancy duration 23
Table 14: Twin pregnancy probability 24
Table 15: Post-partum cyclicity resumption by breed and parity 25
Table 16: Default values for mating plans 26
Table 17: Veterinary treatment plan under the breeding contract 27
Table 18: Structure of calving-based reproductive performance data for primiparous cows 28
Table 19: Structure of calving-based reproductive performance data for multiparous cows 29
Table 20: Structure of insemination-based reproductive performance data for nulliparous cows 29
Table 21: Structure of insemination-based reproductive performance data for primiparous and multiparous cows 30
Table 22: Structure of the data on technical results related to reproduction 30
Table 23: Basis levels of somatic milk cell count in mammary infection absence depending on the parity 32
Table 24: Divisor value of the milk quantity produced during adulthood according to parity 34
Table 25: Gain in FC and PC due to the omission of the drying up of the previous lactation 35
Table 26: Minored value of milk production of a cow that is pregnant according to its lactation stage 35
Table 27: Performance-specific seasonal multiplier factor 36
Table 28: Parameters specific to each parity for the equation of milk quantity reduction related to milk SCC 37
Table 29: Daily hazard on milk performance 37
Table 30: Data structure of monthly results of delivered milk 38
Table 31: Data structure of monthly results of discarded milk 39
Table 32: Data structure of monthly test-day results 40
Table 33: Structure of data on technical production results 41
Table 34: Bacterium responsible for IMI 42
Table 35: IMI severity levels 42
Table 36: Modulation in IMI severity by lactation stage and rank 43

Table 37: Risk levels according to IMI type and severity 43
Table 38: IMI occurrence impact on quarter SCC 43
Table 39: Consequences of IMI clinical cases on quarter milk production 44
Table 40: Probability of quarter loss in G3 mastitis 44
Table 41: Mortality and culling risk related to G3 severity 45
Table 42: Distribution of each IMI type occurrence according to pregnancy and lactation stage over a year 46
Table 43: Risk factor values for mastitis incidence according to udder milk production and bacterium presence .. 48
Table 44: IMI risk depending on lactation rank 48
Table 45: IMI risk related to potential milk 48
Table 46: Risk factor values for mastitis incidence according to the pre-existing level of SCC 49
Table 47: IMI risk related to quarter interdependence 49
Table 48: Relative risk of mastitis occurrence due to competition with other disease episodes 49
Table 49: IMI contagion effect in the batch 50
Table 50: Baseline rate of spontaneous cure of a G1 seriousness IMI not detected according to the pathogen 51
Table 51: Probability of pre-existing mastitis during the cure of a previous mastitis 51
Table 52: Clinical recurrence of persistent subclinical infection depending on bacterium type 51
Table 53: Pathogen-related relapse probability 52
Table 54: Defaults values for IMI incident change factors by seasons 53
Table 55: Share of bacterial types in mastitis incidence 53
Table 56: Default values of mastitis treatment plan according to the period and the bacterium 53
Table 57: Clinical incidence of mastitis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract 54
Table 58: Structure of annual outcome data for clinical mastitis 55
Table 59: Ketosis Severity Levels 56
Table 60: Impacts of ketosis on fertility 56
Table 61: Effect on milk production as a function of ketosis severity level compared to healthy cows (G0) 57
Table 62: Percentage lethality for an episode of ketosis based on severity and lactation rank of the affected cow .. 58
Table 63: Baseline incidence of subclinical ketosis by breed 59
Table 64: Relative risk of ketosis according to lactation rank 60
Table 65: Modulation of the incidence of ketosis related to competition from other disease episodes 60
Table 66: Risk of ketosis depending on the calving to calving interval 61
Table 67: Sensitivity and specificity of the Cetodetect ®test 61
Table 68: Sensitivity and specificity of the blood test for ketosis 62
Table 69: Clinical incidence of ketosis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract 64
Table 70: Default values for ketosis treatment plan 65
Table 71: Data structure for annual results of subclinical and clinical ketosis 66
Table 72: Lameness Severity Levels 66
Table 73: Effect of lameness on heat detection sensitivity (Gaude *et al.*, 2017) 67

Table 74: Effect on milk production as a function of severity of lameness compared to healthy cows (G0) 68
Table 75: Culling and lameness-related mortality 68
Table 76: Baseline incidence of infectious and non-infectious lameness according to risk periods 69
Table 77: Risk of lameness according to lactation rank 70
Table 78: Relative risk of occurrence of lameness due to competition from other diseases 70
Table 79: Risk of incidence of non-infectious lameness in trimmed cows 72
Table 80: Risk of incidence of infectious lameness in trimmed cows 72
Table 81: Risk of incidence of infectious lameness of cows in a foot bath 72
Table 82: Risk of recovery from infectious lameness of cows in a foot bath 73
Table 83: Sensitivity of detection of lame cows 73
Table 84: Spontaneous healing from G1 severity lameness 74
Table 85: Valeurs par défaut du plan de traitement de la boiterie 76
Table 86: Structure of the data on annual lameness results 76
Table 87: Pathogens responsible of GENNI 77
Table 88: GENNI severity levels 77
Table 89: Distribution of the risk of severity of the first GENNI 77
Table 90: Delay in first calving caused by GENNI 78
Table 91: Effect of GENNI on animal mortality related to unmanaged diseases 79
Table 92: Modulation of GENNI incidence linked to maternal parity 79
Table 93: Effect on the incidence of colostrum intake failure on the incidence of GENNI 80
Table 94: Risk factors for immunity failure induced by the type and quality of colostrum management 80
Table 95: Risk factors for immunity failure induced by the time elapsed before colostrum intake and the amount received 80
Table 96: GENNI risk factors related to dam vaccination 80
Table 97: Modulation of GENNI incidence related to calf thermal comfort 81
Table 98: Modulation of GENNI incidence related to environmental hygiene 81
Table 99: Probability of flare up of undetected GENNI G1 to G2 81
Table 100: Setting the proportion of pathogens in incidence 82
Table 101: Breakdown of the breeder's activities relating to GENNI vaccination of future dams and associated costs 82
Table 102: Default values for the GENNI processing plan, general case 82
Table 103: Effectiveness of treatment provided by the breeder to males in cases of severity G2 82
Table 104: Structure of data relating to the daily status of GENNI calves 83
Table 105: Definition of the stages of paratuberculosis infection 84
Table 106: Decrease in milk production according to the stage of paratuberculosis infection 85
Table 107: MAP excretion levels depend on the stage of the disease 87
Table 108: Classification of individuals according to their level of excretion 87
Table 109: Characteristics of the ELISA test 90
Table 110: Structure of data on technical heath results 95

Table 111: Common parameters of genetic values associated with phenotypic traits 96
Table 112: Genetic correlation ρ between each phenotypic trait 96
Table 113: Breed-dependent parameters of genetic values associated with phenotypic traits 97
Table 114: Equations for calculating individual potentials P_i for indexes expressed as genetic deviation, where X is the performance for a value of genetic standard deviation defined as 3 for the increasing direction and -3 for the decreasing direction 98
Table 115 : Individual performance values for the Fer, BHBlait, MACL, RBi and RBni indices, expressed as a standard deviation 98
Table 116: Annual population genetic progress according to dairy breeds for each phenotypic trait 99
Table 117: Default values for bulls' genetic indexes 101
Table 118: Structure of data relating to genetic results 101
Table 119: Break-even point of production according to the level of the herd 103
Table 120: Mortality risk among the herd 104
Table 121: Default grazing schedule for heifers under 20 months, other heifers, dry cows and peri-partum 107
Table 122: Default grazing and housing schedule for the lactating cow batch 107
Table 123: Default straw consumption for straw beds (kg/d) 107
Table 124: Data structure on annual results of herd management 108
Table 125: Amount of faeces produced per day per animal, depending on its circumstances 109
Table 126: Default values for daily feeding of weaned female calves. 110
Table 127: Default values for feeding heifers according to age and location. 110
Table 128: Default values for feeding lactating cows according to indoor/outdoor periods. 111
Table 129: Data structure on milk consumption by calves 112
Table 130: Data structure on forage and concentrate consumption by calves prepared at weaning and heifers ... 112
Table 131: Data structure on forage and concentrate consumption by cows 113
Table 132: Default rates for reproduction-related accounting transactions 114
Table 133: Default rates for production-related accounting transactions 114
Table 134: Default rates for health-related accounting transactions 117
Table 135: Default rates for genetic-related accounting transactions 117
Table 136: Default rates for population-related accounting transactions 117
Table 137: Default rates for feeding-related accounting transactions 118
Table 138: Default rates for miscellaneous accounting transactions 118
Table 139: Default rate and frequency of not described costs 118
Table 140: Structure of the economic balance sheet data expressed in euros 119
Table 141: Keys and values for the command to create a farm 122
Table 142: Keys and values for the command to rename a farm 122
Table 143: Key and value for the command to get farm list 122
Table 144: Keys and values to obtain farm parameters 123
Table 145: Keys and values for the command to modify a farm parameter 123
Table 146: Keys and values for the command to duplicate a farm 124
Table 147: Keys and values for the command to delete a farm 124

Table 148: Keys and values for the command to create a protocol 124
Table 149: Keys and values for the command to rename a protocol 125
Table 150: Keys and values for the command to obtain the protocol list 125
Table 151: Keys and values for the command to protocol parameters 125
Table 152: Keys and values for the command to modify protocol parameters 126
Table 153: Keys and values for the command to delete a protocol 126
Table 154: Keys and values for the command to add (or replace) a list of parameter values to be cross-referenced 126
Table 155: Keys and values for the command to delete a list of parameter values having been cross-referenced .. 127
Table 156: Keys and values for the command to change the header name of a discriminant 127
Table 157: Keys and values for the command to change the header name of a discriminant 127
Table 158: Key and value for the command to get the parameter reference values 127
Table 159: Key to the command for restoring previous values 128
Table 160: Keys and values for the command to launch simulations 128
Table 161: Key and value for the command to obtain last summarised simulation results 129
Table 162: Key and value for the command to obtain last gross simulation results 130
Table 163: API Return Code Table 130
Table 164: Structure of the fields defining the simulation framework 138
Table 165: Technical data structure 139
Table 166: Keys and formats for farm management parameters 161
Table 167: Keys to the parameters of the accounting model 164

7 Figures

Figure 1 : Biological processes and farmer decisions used in the simulator 13
Figure 2: Diagram of the organization in modules and interaction representation 16
Figure 3: Reproduction stages 17
Figure 4: Periods at risk of pregnancy loss 23
Figure 5: Delay of cyclicity resumption time after embryo or fetal mortality 24
Figure 6: Lactation initiation and end steps 31
Figure 7: Daily dairy production curve for the Montbeliarde breed 32
Figure 8: Daily dairy production curve for the Normande breed 32
Figure 9: Daily dairy production curve for the Holstein breed 32
Figure 10: SCC wood curves of the udder in mammary infection absence 33
Figure 11: Effect of the decreased milk production due to reduced dry period at the next lactation 34
Figure 12: Specific effect of the month on the dairy production of the cow 36
Figure 13: IMI epidemiological model 45
Figure 14: Sequence and duration of (re)productive periods at IMI risks 46
Figure 15: Distribution of each IMI type occurrence according to pregnancy-lactation stage over a year 47
Figure 16: Risk factor for mastitis incidence according to milk production 47
Figure 17: IMI evolution dynamics 50
Figure 18: Distribution of the loss of milk quantity (Kg) over 55 days for a cow producing 10000 kg of milk during a lactation period of 305 days 58
Figure 19: Incidence curve of subclinical ketosis as depending on lactation stage 59
Figure 20: Dynamics of ketosis evolution 62
Figure 21: Basic daily risk curve for the incidence of lameness, starting from calving and for a 305-day lactation .. 69
Figure 22: Risk of becoming lame from an infectious disease as a function of batch prevalence 71
Figure 23: Risk of becoming lame from an infectious disease by staying in a building for a certain period of time 71
Figure 24: Dynamics of lameness evolution 74
Figure 25: GENNI epidemiological model 79
Figure 26: GENNI risk periods 79
Figure 27: Beta distribution of GENNI durations 81
Figure 28: States and transitions in the epidemiological model of paratuberculosis 91
Figure 29: Coefficient to be applied to the performance of the Fer, BHBlait, MACL, RBi and RBni indices to take account of true genetic value 98
Figure 30: Assignment dynamic in batches within the farm 105
Figure 31: Creating a farm with the web application 131
Figure 32: Name and description of a farm with the web application 131
Figure 33: Changing a farming parameter with the web application 131
Figure 34: Creating a simple protocol with the web application 132
Figure 35: Configuring a simple protocol with the web application 132
Figure 36: Discriminants of a cross-protocol approach with the web application 132

Figure 37: Launching the simulation with the web application 133
Figure 38: Technical and health-related simulation results with the web application 133
Figure 39: Simulated accounting results with the web application 134
Figure 40: Downloading the raw data from the latest simulation with the web application 134
Figure 41: User management interface with the web application 134
Figure 42: Assigning modules to users with the web application 135
Figure 43: Technical comparison of two scenarios using R packages 137
Figure 44: Economical comparison of two scenarios using R packages 138

Appendix I: List of the keys and formats of the husbandry parameters

The keys used in the husbandry parameter file must be among those shown in the following table:

Module	Parameter key	Format of the associated value	Description
General	"comment"	Char string	Free comment to describe the paramatred farm
Reproduction (see paragraph 2.2.1.2)	"ageToBreedingDecision"	Integer value	See paragraph *2.2.1.2.1 Breeding age*
	"detectionMode"	0 = embedded sensor 1 = robot 2 = farmer 3 = bull, when mating	See paragraph *2.2.1.2.2 Estrus detection modes*
	"slipperyFloor"	True (1) or false (0)	See paragraph *2.2.1.2.3 Slippery floor*
	"matingPlan_TypeInseminationSemen_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Insemination type (*)	See paragraph *2.2.1.2.4 Mating plans*
	"matingPlan_TypeInseminationRatio_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Decimal value, 0 to 1	
	"matingPlan_BreedInseminationSemen_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Breed (*)	
	"matingPlan_BreedInseminationRatio_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Decimal value, 0 to 1	
	"matingPlan_<*f/l*>ExcludedMonthForHeiferCalving" <*f/l*> = "First" et "Last" (2 values in total)	Included month Integer value (0 = no grouping)	See paragraph *2.2.1.2.5 Grouped calvings*
	"fertilityFactor"	Decimal value, centred on 1	See paragraph *2.2.1.2.6 Herd-specific fertility factor*
	"breedingDelayAfterCalvingDecision"	Integer value	See paragraph *2.2.1.2.7 Minimum post-partum delay before breeding (waiting period)*
	"numberOfDaysAfterHeiferBreedingDecisionForStopFirstInseminationDecision"	Integer value	See paragraph *2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility*
	"numberOfDaysAfterHeiferBreedingDecisionForStopInseminationDecision"	Integer value	
	"numberOfDaysAfterAdultBreedingDecisionForStopFirstInseminationDecision"	Integer value	
	"numberOfDaysAfterAdultBreedingDecisionForStopInseminationDecision"	Integer value	
	"vetReproductionContract"	True (1) or false (0)	See paragraph *2.2.1.2.9 Breeding contract*
	"reproductionTreatmentPlan_<No/Too/Negative>_name" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Char string	
	"reproductionTreatmentPlan_<No/Too/Negative>_effectDelay" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Integer value	
	"reproductionTreatmentPlan_<No/Too/Negative>_successProbability" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Decimal value, 0 to 1	
	"reproductionTreatmentPlan_Too_much_unsuccessful_inseminations_fertilityDelta"	Decimal value, 0 to 1	
Lactation (see paragraph 2.2.2.2)	"driedPeriodDuration"	Integer value	See paragraph *2.2.2.2.1 Drying-off*
	"milkingFrequency"	0 = once a day, 1 = twice a day, 2 = above twice a day	See paragraph *2.2.2.2.2 Milking frequency*
	"dayBeforeDeliverMilk"	Integer value	See paragraph *2.2.2.2.3 Minimum lactation stage for delivered milk*
	herdProductionDelta_<*char*>	Decimal value, centred on 0	See paragraph *2.2.2.2.4 Herd production level*

Module	Parameter key	Format of the associated value	Description
	<*char*> = "Lait", "TB" and "TP" (3 values in total)		
Health: Intramammary infection (IMI) (see paragraph 2.2.3.1.2)	"G1MastitisDetectionSensibility"	Decimal value, 0 to 1	See paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis*
	"mastitisSaisonalityProbabilityFactor_<*bacterium*>_<*month*>" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" and "CB" <*month*> = "jan", "feb", "mar", "apr", "may", "jun", "jul", "aug", "sep", "oct", "nov" and "dec" (60 values in total)	Decimal value, centred on 1	See paragraph *2.2.3.1.2.2 Seasonal impact on IMI incidence*
	"mastitisBacteriumIncidencePart<*bacterium*>" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (5 values in total)	Decimal value, 0 to 1	See paragraph *2.2.3.1.2.3 Share of bacterial type in incidence*
	"mastitisTreatmentPlan_<*stage*>_name" <*stage*> = "Lactation" and "Dry" (2 values in total)	Char string	See paragraph *2.2.3.1.2.4 Treatment plans*
	"mastitisTreatmentPlan_<*stage*>_effectDelay" <*stage*> = "Lactation" and "Dry" (2 values in total)	Integer value	
	"mastitisTreatmentPlan_<*stage*>_milkWaitTime" <*stage*> = "Lactation" and "Dry" (2 values in total)	Integer value	
	"mastitisTreatmentPlan_<*stage*>_healingProbability_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (10 values in total)	Decimal value, 0 to 1	
	"mastitisTreatmentPlan_<*stage*>_protectProbability_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (10 values in total)	Decimal value, 0 to 1	
	"mastitisTreatmentPlan_<*stage*>_protectDuration_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" and "CB" (10 values in total)	Integer value	
	"individualMastitisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.1.2.5 Prevention factor for mastitis at the individual level*
	"herdMastitisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.1.2.6 Prevention factor for mastitis at herd level*
	"vetCareContract"	0 = no veterinary care contract 1 = contract based on cow count 2 = contract based on calving count 3 = contract based on milk quantity	See paragraph *2.2.3.1.2.7 Veterinary care contract option*
Health: Ketosis (or acetonaemia) (see paragraph 2.2.3.2.2)	"ketosisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.2.2.1 Prevention factor*
	"monensinBolusUsage"	True (1) or false (0)	See paragraph *2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®)*
	"cetoDetectUsage"	True (1) or false (0)	See paragraph *2.2.3.2.2.2.1 Cetodetect ® option during milk control*
	"herdNavigatorOption"	True (1) or false (0)	See paragraph *2.2.3.2.2.2.2 Herd Navigator ® option of the milking robot*
	" ketosisTreatmentPlan_<*severity*>_name" <*severity*> = "G1" and "G2" (2 values in total)	Char string	See paragraph *2.2.3.2.2.3 Treatment plan*
	" ketosisTreatmentPlan_<*severity*>_effectDelay" <*severity*> = "G1" and "G2" (2 values in total)	Integer value	
	" ketosisTreatmentPlan_<*severity*>_milkWaitTime" <*severity*> = "G1" and "G2" (2 values in total)	Integer value	
	"ketosisTreatmentPlan_<*severity*>_healingProbability" <*severity*> = "G1 and "G2" (2 values in total)	Decimal value, 0 to 1	
	"ketosisTreatmentPlan_<*severity*>_flareupRisk" <*severity*> = "G1" and "G2" (2 values in total)	Decimal value, 0 to 1	
	"ketosisTreatmentPlan_<*severity*>_firstIASuccessRisk" <*severity*> = "G1" and "G2" (2 values in total)	Decimal value, 0 to 1	

Module	Parameter key	Format of the associated value	Description
Health: Lameness (see paragraph 2.2.3.3)	"lamenessNonInfectiousIncidencePreventionFactor" "lamenessInfectiousIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.3.2.1.1 Global prevention factors*
	"footBathOption"	True (1) or false (0)	See paragraph *2.2.3.3.2.1.2 Option to prevent infectious lameness by using a foot bath*
	"footBathEffectDuration	Integer value	
	"footBathStabulationFrequency" "footBathFullPastureFrequency" "footBathHalfStabulationPastureFrequency"	Integer value	See paragraph *2.2.3.3.2.1.3 Foot bath frequency option*
	"preventiveTrimmingOption"	0 = no trimming 1 = trimming once a year 2 = trimming twice a year 3 = trimming by small groups	See paragraph *2.2.3.3.2.1.4 Option to prevent infectious and non-infectious lameness through trimming*
	"lamenessDetectionMode"	0 = sensor 1 = low sensitive farmer 2 = sensitive farmer	See paragraph *2.2.3.3.2.2 Detection options*
	"cowNumberForSmallTrimmingOrCareGroup"	Integer value	See paragraph 2.2.3.3.2.3 *Trimming grouping and individual lameness cases for treatment*
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_name" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" (4 values in total)	Char string	See paragraph *2.2.3.3.2.4 Treatment plan*
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_*<limit>*_effectDelay" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" *<limit>* = "min" and "max" (8 values in total)	Integer value	
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_milkWaitTime" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" (4 values in total)	Integer value	
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_healingProbability_*<number>*" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" *<number>* = "1" and "2" (8 values in total)	Decimal value, 0 to 1	
Health: Neonatal infectious gastroenteritis (GENNI) (see 2.2.3.4)	"genniDetectionSensitivity"	Integer value	See paragraph *2.2.3.4.2.1 Sensitivity of detection of minor GENNI*
	"genniIncidencePathogenPart"	0 = mean profile 1 = ETEC profile 2 = Crypto profile 3 = Rota profile	See paragraph *2.2.3.4.2.2 Proportion of each type of pathogen in the incidence*
	"colostrumAndManagementQualityControl"	0 = no quality control 1 = bad weigh colostrum management 2 = good weigh colostrum management 3 = bad refractometer management 4 = good refractometer management	See paragraph *2.2.3.4.2.3 Quality control of colostrum and colostrum bank management*
	"colostrumTimeSpentQuantityReceived"	0 = with dam 2 = less than 4 hours, less than 4 l 3 = less than 4 hours, over 4 l 4 = over 4 hours, less than 4 l 5 = over 4 hours, over 4 l	See paragraph *2.2.3.4.2.4 Time spent for colostrum and quantity received*
	"calveReceivingColostrumProportion"	Integer value 0 to 100	See paragraph *2.2.3.4.2.5 Proportion of calves receiving colostrum*
	"damGenniVaccinationModality"	0 = no vaccine 1 = vaccine on complementary exam 2 = systemic vaccine	See paragraph *2.2.3.4.2.6 Vaccination of pregnant cows*
	"damGenniPathogenTargetVaccination"	0 = ETEC + Rota + Coron 1 = Crypto 2 = all pathogens	
	"calveCagePosition"	0 = indoor 1 = outdoor	See paragraph *2.2.3.4.2.7 Position of the calf pen*
	"genniHygieneScore"	0 = level 1 very low 1 = level 2 low 2 = level 3 mean	See paragraph *2.2.3.4.2.8 Hygiene score*

Module	Parameter key	Format of the associated value	Description
		3 = level 4 good 4 = level 5 very good	
	"genniFurtherVetExamination"	0 = systemic exam 1 = exam on lot of cases 2 = no exam	See paragraph *2.2.3.4.2.9 Treatment plan*
	"genniCaseNumberForFurtherVetExamination"	Integer value	
	"genniG2MaleTreatmentByFarmer"	True (1) or false (0)	
	"genni<*target*>TreatmentPlan_<*severity*>_<*pathogen*>_name" <*target*> = "Targeted" and "NonTargeted" <*severity*> = "G1" and "G2" <*pathogen*> = "Etec", "Crypto", "Rota" *and* "Corona" (16 values)	Char string	
	"genni<*target*>TreatmentPlan_<*severity*>_<*pathogen*>_effectDelay" <*target*> = "Targeted" and "NonTargeted" <*severity*> = "G1" and "G2" <*pathogen*> = "Etec", "Crypto", "Rota" *and* "Corona" (16 values)	Integer value	
	"genni<*target*>TreatmentPlan_<*severity*>_<*pathogen*>_healingProbability" <*target*> = "Targeted" and "NonTargeted" <*severity*> = "G1" and "G2" <*pathogen*> = "Etec", "Crypto", "Rota" and "Corona" (16 values)	Decimal value, 0 to 1	
	"genniTreatmentPlanG2MaleFarmer_<*pathogen*>_name" <*pathogen*> = "Etec", "Crypto", "Rota" *and* "Corona" (4 values)	Char string	
	"genniTreatmentPlanG2MaleFarmer_<*pathogen*>_effectDelay " <*pathogen*> = "Etec", "Crypto", "Rota" *and* "Corona" (4 values)	Integer value	
	"genniTreatmentPlanG2MaleFarmer_<*pathogen*>_healingProbability" <*pathogen*> = "Etec", "Crypto", "Rota" *and* "Corona" (4 values)	Decimal value, 0 to 1	
	"genniIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.4.2.10 Overall GENNI prevention factor*
Health: Paratuberculosis (see paragraph 2.2.3.5)	"caseNumberOfParatuberculosis"	Integer value	See paragraph *2.2.3.5.2.1 Occurrence of cases of paratuberculosis*
	"PTBtestStrategy"	0 = tests on cows with clinical signs 1 = regular tests 2 = regular, spaced-out tests	See paragraph 2.2.3.5.2.4 Test strategy
Genetics (see paragraph 2.2.4.2)	"male_genetic_catalog_<strategy>_<breed>_<index>" <strategy> = "well_balanced", "milk_priority", "longevity_priority" *and* "PTB" <breed> = "montbeliarde", "normande" *and* "holstein" <index> = "lait", "tb", "tp", "fer", "macl", "bhb", "rbi", "rnbi" *and* "rptb" (120 values)	Decimal value	See paragraph *2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue*
	"geneticMaleStrategy"	0 = balanced, 1 = priority to the milk quantity produced, 2 = priority to functional longevity, 3 = PTB priority	See paragraph *2.2.4.2.2 Genetic strategy*
Population and batch management (see paragraph 2.2.5.2)	"initialBreed"	Breed (*)	See paragraph *2.2.5.2.1.1 Initial cow breed* (used too for the default breed for inseminations, see paragraph 2.2.1.2.4)
	"meanAdultNumberTarget"	Integer value	See paragraph *2.2.5.2.1.2 Average number of adult cows*
	"annualHerdRenewablePart"	Decimal value	See paragraph *2.2.5.2.1.3 Annual herd renewal rate*
	"annualHerdRenewableDelta"	Decimal value	
	"femaleCalveManagement"	0 = conservation of all female calves, 1 = sale of females from cows with low milk potential, 2 = sale of all female calves	See paragraph *2.2.5.2.1.4 Female calves management strategy*
	"maxLactationRankForEndInseminationDecision"	Integer value	See paragraph *2.2.5.2.1.5 Maximum lactation number*
	"minMilkProductionHerdRatioForEndInseminationDecision"	Decimal value	See paragraph *2.2.5.2.1.6 Production performance of the cow regarding the one of the herd*
	"maxSCCLevelForEndInseminationDecision"	Integer value	See paragraph *2.2.5.2.1.7 SCC level*
	"minimumMilkQuantityFactorForRentability"	Decimal value	See paragraph *2.2.5.2.1.8 Break-even point for milk production*

Module	Parameter key	Format of the associated value	Description
	"youngHeifer<b/e>PastureDate_<d/m>" <b/e> = "Begin" and "End" <d/m> = "day" and "month" (4 values in total)	Integer value	See paragraph *2.2.5.2.2.1 Stabling and grazing*
	"otherHeiferAndDriedCow<b/e>PastureDate_<d/m>" <b/e> = "Begin" and "End" <d/m> = "day" and "month" (4 values in total)	Integer value	
	"lactatingCow<b/e><p/s>Date_<d/m>" <b/e> = "begin" and "end" <d/m> = "day" and "month" (4 values in total)	Integer value	
	"<c/h/a>StrawConsumption" <c/h/a> = "calf", "heifer" and "adult" (3 values in total)	Decimal value	See paragraph *2.2.5.2.2.2 Straw bed*
Feeding (see paragraph 2.2.6.2)	"calfMilkQuantity"	Decimal value	See paragraph *2.2.6.2.1.1Unweaned calf feeding*
	"calfMilkType"	0 = produced milk, 1 = discarded milk and produced, 2 = discarded milk and reconstituted 3 = reconstituted milk	
	"weaningAge"	Integer value	
	"unweanedFemaleCalfConcentrateMixture_<q/t>" <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (4 values in total)	Decimal value	
	"weanedFemaleCalf<f/c>Mixture_<q/t>" <f/c> = "Forage" and "Concentrate" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay"and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (9 values in total)	Decimal value	See paragraph *2.2.6.2.1.2 Weaned calf feeding*
	"youngUnbredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (18 values in total)	Decimal value	See paragraph *2.2.6.2.1.3 Heifer feeding*
	"youngUnbredHeiferMineralVitamins_<s/p>" <s/p>= "stabulation" and "pasture" (25 values in total)	Decimal value	
	"oldUnbredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (18 values in total)	Decimal value	
	"oldUnbredHeiferMineralVitamins_<s/p>" <s/p>= "stabulation" and "pasture" (2 values in total)	Decimal value	
	"bredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley"	Decimal value	

Module	Parameter key	Format of the associated value	Description
	(18 values in total)		
	"bredHeiferMineralVitamins_<*season*>" <*season*> = "winter", "spring" and "summerAndAutumn" (3 values in total)	Decimal value	
	"RBE_MilkProduction"	Decimal value	See paragraph *2.2.6.2.1.4 Lactating cow feeding*
	"lactation<*f/c*>Mixture_<*season*>_<*q/t*> " <*f/c*> = "Forage" and "Concentrate" <*s/p/h*> = "stabulation", "pasture" and "halfStabulationPasture" If <*f/c*> = "Forage": <*q/t*> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <*f/c*> = "Concentrate": <*q/t*> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (27 values in total)	Decimal value	
	"lactationPeriodMineralVitamins_<*season*>" <*s/p/h*> = "stabulation", "pasture" and "halfStabulationPasture" (3 values in total)	Decimal value	
	"gainForOneConcentrateKilo"	Decimal value	See paragraph *2.2.6.2.2 Production concentrate diets*
	"productConcentrateMixture_type_<*type*>" <*type*> = "rapeseed", "soja" and "barley" (3 values in total)	Decimal value	

Table 166: Keys and formats for farm management parameters

(*) See *Table 2: Type data formats* page *15*.

Parameters that are not defined in the file will be applied with the default value indicated in the "Farm management parameters" section of each of the modules described in the chapter *2.2 Modules*.

Appendix II: List of accounting model parameter keys

Parameter key	Description
"femaleDairyCalfPrice"	Sale of a female dairy calf
"maleDairyCalfPrice"	Sale of a male dairy calf
"femaleBeefBredCalfPrice"	Sale of a beef crossbreed female calf
"maleBeefBredCalfPrice"	Sale of a beef crossbreed male calf
"underOneYearCalfPrice"	Sale of a live heifer of less than one year old
"underTwoYearCalfPrice"	Sale of a live heifer of more than one year old
"pregnantHeiferPrice"	Sale of a pregnant heifer
"culledCowPrice"	Sale of a culled cow
"underOneYearDeathCalfPrice"	Rendering of a dead heifer aged up to 1 year
"underTwoYearDeathCalfPrice"	Rendering of a dead heifer aged between 1 and 2 years
"deathCowPrice"	Rendering of a dead cow
"calfBirthPrice"	Assisted calving by a vet
"naturalInseminationPrice"	Insemination by service
"conventionalArtificialInseminationPrice"	Conventional artificial insemination
"maleSexedArtificialInseminationPrice"	Male sexed artificial insemination
"femaleSexedArtificialInseminationPrice"	Female sexed artificial insemination
"vetReproductionContractPrice"	Annual price per adult cow of the veterinary breeding contract
"vetNoOestrusSeenTreatmentPrice"	Treatment for recurrence of heat
"vetUnsuccessfulIATreatmentPrice"	Treatment against succession of non-fertile inseminations
"vetNegativePregnancyTreatmentPrice"	Treatment following a negative pregnancy diagnosis
"milkTonPrice"	Sale of a ton of milk (without quality criteria and without penalty)
"milkControlPrice"	Monthly test-day (per cow and per year)
"level1SCCPenaltyPrice"	Penalty 1st threshold (for 1 ton)
"level2SCCPenaltyPrice"	Penalty 2nd threshold (for 1 ton)
"level3SCCPenaltyPrice"	Penalty 3rd threshold (for 1 ton)
"TBQualityBonusPrice"	TB quality bonus (for 1 ton)
"TPQualityBonusPrice"	TP quality bonus (for 1 ton)
"vetCareContractBasedOnCowPrice"	Annual price per adult cow of the veterinary health contract
"vetCareContractBasedOnCavingPrice"	Annual price per calving of the veterinary health contract
"vetCareContractBasedOnKiloliterPrice"	Annual price per kiloliter of the veterinary health contract
"G1mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G1 mastitis without vet contract
"G1mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G1 mastitis with vet contract
"G2mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G2 mastitis without vet contract
"G2mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G2 mastitis with vet contract
"G3mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G3 mastitis without vet contract
"G3mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G3 mastitis with vet contract
"mastitisDryWithoutContractTreatmentPrice"	Cost of a basic treatment for clinical mastitis in dry cows without vet contract
"mastitisDryWithContractTreatmentPrice"	Cost of a basic treatment for clinical mastitis in dry cows with vet contract
"mastitisPreventiveActionsPrice"	Annual cost of mastitis prevention per cow
"monensinBolusPrice"	Cost of a monensin bolus
"cetoDetectPrice"	Cetodetect ® milk control test (per cow per year)
"herdNavigatorPrice"	Herd navigator option (per cow and per year)
"G1ketosisWithoutContractTreatmentPrice"	Cost of basic treatment for G1 ketosis without vet contract
"G1ketosisWithContractTreatmentPrice"	Cost of basic treatment for G1 ketosis with vet contract
"G2ketosisWithoutContractTreatmentPrice"	Cost of basic treatment for G2 ketosis without vet contract
"G2ketosisWithContractTreatmentPrice"	Cost of basic treatment for G2 ketosis with vet contract
"ketosisPreventiveActionsPrice"	Annual cost of ketosis prevention per cow
"lamenessAnnualFootBathPrice"	Annual cost of a foot bath
"lamenessMinFootBathUsagePrice"	Minimum cost of using a foot bath
"lamenessMaxFootBathUsagePrice"	Maximum cost of using a foot bath
"lamenessFootTrimmingWorkshopPrice"	Cost of setting up the trimming workshop
"lamenessCowFootTrimmingPrice"	Cost of trimming a cow
"nonInfectiousLamenessCowFootTreatmentPrice"	
"infectiousLamenessCowFootTreatmentPrice"	
"genni*<severity>*<*vet*>VetContractNonTargeted*<age>*TreatmentPrice" *<severity>* = "G1" et "G2" *<vet>* = "With" et "Without" *<age>* = "7" et "8" (8 values)	

"genni<*severity*><*Pathogen*><*vet*>VetContractTargetedTreatmentPrice" <*severity*> = "G1" et "G2" <*Pathogen*> = "Etec", "Crypto", "Rota" et "Corona" <*vet*> = "With" et "Without" (16 values)	
"genniEtecRotaCorona<*vet*>VetContractVaccinePrice" <*vet*> = "With" et "Without" (2 values)	
"genniCrypto<*vet*>VetContractVaccinePrice" <*vet*> = "With" et "Without" (2 values)	
"genni<*severity*><*vet*>VetContractComplementaryExaminationPrice" <*severity*> = "G1" et "G2" <*vet*> = "With" et "Without" (4 values)	
hygiene<*level*>ScorePreventionActionPrice <*level*> = "3And4" et "5" (2 values)	
hygiene<*level*>ScorePreventionEquipmentPrice <*level*> = "3And4" et "5" (2 values)	
"elisaTestPrice"	Cost of an ELISA test, with 50 per cent of the cost covered by the GDS
"PCRTestPrice"	Cost of a PCR test, with 50 per cent of the cost covered by the GDS
"genotypagePrice"	Cost of genotyping, with 50 per cent of the cost covered by the GDS
"dehydratedMilkTonPrice"	Price of one ton of a dehydrated milk powder
"strawTonPrice"	Price of one ton of a straw (dry matter)
"maizePlantTonPrice"	Price of one ton of corn plant (dry matter)
"grassTonPrice"	Price of one ton of grass (crude matter)
"hayTonPrice"	Price of one ton of hay (dry matter)
"grassSilageTonPrice"	Price of one ton of grass silage (crude matter)
"rapeseedTonPrice"	Price of one ton of rapeseed (crude matter)
"sojaTonPrice"	Price of one ton of soybean (crude matter)
"barleyTonPrice"	Price of one ton of barley (crude matter)
"mineralVitaminTonPrice"	Price of one ton of minerals and vitamins (crude matter)
"calfBeddingPrice"	Bedding costs for a calf
"heiferMiscellaneousVetCost"	Veterinary costs per heifer in the herd
"otherCalfBreedingCost"	Other costs of raising a calf
"annualCowBeddingPrice"	Purchase of bedding per cow present average
"annualCowMiscellaneousVetCost"	Average veterinary costs per cow present
"otherAnnualCowBreedingCost"	Other livestock costs per average cow present

Table 167: Keys to the parameters of the accounting model

Parameters that are not defined in the file will be applied with the default value (see paragraph ***Erreur ! Source du renvoi introuvable. Erreur ! Source du renvoi introuvable.***).

Appendix III: R package use example

```
#    _____ _       _ __  __   _____           _
#   |  __ \| |   | |  \/  | |  __ \         | |
#   | |  | | |__| | \  / | | |__) |_ _  ___| | ____ _  __ _  ___
#   | |  | |  __  | |\/| | |  ___/ _` |/ __| |/ / _` |/ _` |/ _ \
#   | |__| | |  | | |  | | | |  | (_| | (__|   < (_| | (_| |  __/
#   |_____/|_|  |_|_|  |_| |_|   \__,_|\___|_|\_\__,_|\__, |\___|
#                                                       __/ |
#     _   _                                            |___/
#    | |  | |                                          | |
#    | |  | |___  ___    _____ ____ _ _ __ ___  ___ _ __| | ___
#    | |  | / __|/ _ \  / _ \ \/ / _` | '_ ` _ \| '_ \| |/ _ \
#    | |__| \__ \  __/ |  __/>  < (_| | | | | | | |_) | |  __/
#     \____/|___/\___|  \___/_/\_\__,_|_| |_| |_| .__/|_|\___|
#                                               | |
#                                               |_|

# Info : Pour lancer ce script en mode ligne de commandes :
# - ouvrir le terminal
# - taper : Rscript "C:/Your/Working/Folder/Example.R"

# Load library
library(dhm)

# ----------
# Simulation
# ----------

# DHM instance (mandatory)
# ------------------------
dhm_init_instance()

# -------------------
show("Farm creating")
# -------------------
# Farm 1 : Default : Without vet care contract
farm1_name = "Without vet care contract"
Farm1 = dhm_get_defaut_farm_parameters()
errorMessage <- dhm_create_dairy_farm(Farm1, farm1_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")

# Farm 2 : specific : With vet care contract
farm2_name = "With vet care contract"
Farm2 = dhm_get_defaut_farm_parameters()
Farm2$vetCareContract = "1"
#Farm2$geneticStrategy = "3"
errorMessage <- dhm_create_dairy_farm(Farm2, farm2_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")

# -------------------------------
show("Accounting model to apply")
# -------------------------------
# Get a default accounting parameter
default_amp <- dhm_get_defaut_accounting_model_parameters()

# Create the accounting model based on this parameters (same for both farms)
accounting_model_name = "Default accounting model"
errorMessage <- dhm_create_accounting_model(default_amp, accounting_model_name)
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")

# --------------------------
show("Simulation protocols")
# --------------------------
# Protocol creating (one by farm)
protocol_list <- c("Protocol farm 1", "Protocol farm 2")
farm_list <- c(farm1_name, farm2_name)
discriminant_list <- c("Default", "Specific")
for (i_protocol in 1:length(protocol_list))
{
  if (errorMessage == "")
  {
    # Get a default protocol parameter list
    pp <- dhm_get_defaut_protocol_parameters()
    pp$simulationDuration = "15"
    pp$warmupDuration = "5"
    pp$runNumber = "64"
    pp$farmName = farm_list[i_protocol]
    pp$accountingModelName = accounting_model_name
    pp$discriminant1 = discriminant_list[i_protocol]
```

```
    # Create the protocol based on this parameters
    errorMessage <- dhm_create_protocol(pp, protocol_list[i_protocol])
  }
}
if (errorMessage != "") cat("\033[31m", errorMessage, "\033[0m\n", sep = "")

# ----------------------------------
show("Simulation and result storage")
# ----------------------------------
#resultPath = "C:/your/result/folder/" # if you want to create result csv files
resultPath = "" # -> no csv result files, but dataframe
results <- dhm_execute_protocols(resultPath)

# DHM release (recommended to free memory)
# ----------------------------------------
dhm_leave_instance()

# ---------------------
show("Result analysis")
# ---------------------
if (resultPath == "")
{
  View(results)

  windows()
  par(mfrow=c(3,2))

  # Result stats
  # ------------
  # IVV :
  for (i in 1:length(discriminant_list))
  {
    discriminant = discriminant_list[i]
    farm_name = farm_list[i]
    title = paste("IVV - ",farm_name)
    subReproResults           <-           subset(results$TechnicalAndEconomicalResults$IVV,
results$TechnicalAndEconomicalResults$Discriminant1 == discriminant)
    boxplot(as.numeric(subReproResults), main=title, ylim=c(350,420), ylab="Days", xlab =
paste("Median =",round(median(as.numeric(subReproResults)),0), " days"))
  }

  # Production :
  for (i in 1:length(discriminant_list))
  {
    discriminant = discriminant_list[i]
    farm_name = farm_list[i]
    title = paste("Delivered milk - ",farm_name)
    subProductionResults                                                                    <-
subset(results$TechnicalAndEconomicalResults$Delivered_milk_liter_quantity,
results$TechnicalAndEconomicalResults$Discriminant1 == discriminant)
    boxplot(as.numeric(subProductionResults),main=title, ylim=c(600000,850000), ylab="Kgs",
xlab = paste("Median =",round(median(as.numeric(subProductionResults)),0), " kgs"))
  }

  # Mastitis :
  for (i in 1:length(discriminant_list))
  {
    discriminant = discriminant_list[i]
    farm_name = farm_list[i]
    title = paste("Clinical mastitis / cow - ",farm_name)
    subEconomicalResults                                                                    <-
subset(results$TechnicalAndEconomicalResults$Clinical_mastitis_occurency_by_cow,
results$TechnicalAndEconomicalResults$Discriminant1 == discriminant)
    boxplot(as.numeric(subEconomicalResults),main=title, ylim=c(10,60), ylab="%", xlab =
paste("Median =",round(median(as.numeric(subEconomicalResults)),0), " %"))
  }

  # Gross margin by year :
  windows()
  par(mar=c(5, 4, 4, 2) + 0.1)

  # Data
  campaigns <-unique(results$TechnicalAndEconomicalResults$Campaign)
  bilanWithout <- integer(0)
  bilanWith <- integer(0)
  for (i in 1:length(campaigns))
  {
    # Filter by campaign
    subCampaign               <-              subset(results$TechnicalAndEconomicalResults,
results$TechnicalAndEconomicalResults$Campaign == campaigns[i])
    # Filter by discriminant
```

```
    subWithout <- subset(subCampaign, subCampaign$Discriminant1 == discriminant_list[1])
    bilanWithout[i] = mean(as.numeric(subWithout$Gross_margin))
    subWith <- subset(subCampaign, subCampaign$Discriminant1 == discriminant_list[2])
    bilanWith[i] = mean(as.numeric(subWith$Gross_margin))
  }

  # Plot creation
  plot(campaigns, bilanWithout, type="o", col="red", xlab="Years", ylab="Euros", main="Gross
margin",
       ylim=c(100000, max(bilanWithout, bilanWith))+10000, xaxt='n')
  axis(1, at=campaigns)
  lines(campaigns, bilanWith, type="o", col="blue")
  legend("topleft", legend=c(farm1_name, farm2_name), col=c("red", "blue"), lty=1, pch=1)
}
```