Statistical Indicators
E-8
Breeding Value Estimation for Conformation Traits

▪ Introduction

In 1981 the herdbook CRV introduced the herd classification system. All lactating heifers of herds enrolled in this system are regularly scored for conformation. In 1991, 1996, 1999, 2000, 2004 and 2008 the standard traits for conformation were adapted. These traits are standard for the European Holstein Herdbooks. Heifers are evaluated according to three standards: the Black&White (Z), the Red&White (R) or the Local (Y) standard.
Koepon Genetics Europe used this herd classification system with the standard traits from February 2002 to July 2014. As of August 2002 data collected by Koepon Genetics Europe is used in the Dutch conformation evaluation.
The herdbook FHRS uses their own standard: the FHRS-standard (F). Heifers classified after June 15th 2002 in the FHRS system are used as of August 2002 in the Dutch conformation evaluation.
In Flanders the herd classification system was introduced in 1991 by Vlaamse Rundveeteelt Vereniging vzw. Heifers are evaluated according to the Black&White or Red&White standard. Starting in November 2002 the Flemish and Dutch data is used in a joint conformation evaluation.

The use of milking robots (AMS) in dairy farming made it possible to determine udder conformation traits based on teat coordinates recorded by the AMS. The AMS needs the teat coordinates to determine the position of the teat and then to connect the milk cup. These teat coordinates also allow it to determine the position of the teats relative to each other and to the floor. By using AMS systems, there are many more observations per animal and the observations are not just from heifers. Since April 2023, the animal model for conformation udder will use AMS data from 2014 onwards in addition to classification data. The AMS data will be split by lactations 1, 2 and 3.

The classification systems above have enabled the routine estimation of breeding values for conformation. In October 1991 the animal model for conformation was introduced: the NL-animal model for type.
The NL-animal model for type results in cow and bull conformation indexes. The working of this model is described in chapter E-7 (about milk production).
The selection of the classification data, selection of AMS data, the use of pedigree information, the statistical model and the calculation of the reliability will be discussed.

▪ Traits herd classification

The evaluations consist of the following linear traits and general characteristics:

Linear traits
- Stature
- Chest width
- Body depth
- Rib structure
- Body condition

	- Rump angle - Rump width - Rear leg rear view - Rear leg side view - Foot angle - Front feet orientation - Locomotion - Fore udder attachment - Front teat placement - Teat length - Udder depth - Rear udder height - Udder support - Rear teat placement
Overall traits	- Frame - Dairy strength - Udder - Feet and legs - Muscularity (only Y standard) - Overall conformation

▪ Traits AMS

Front udder attachment, teat length, rear udder height and udder support are only determined during the herd classification. Udder depth, front teat placement and rear teat placement are both determined from herd classification and AMS data. Front teat placement is in the AMS measured as the distance between the front teats, and rear teat placement is in the AMS measured as the distance between the rear teats. Udder balance is the only trait which fully relies on AMS data, and is not scored during the herd classification. A total of 12 traits is determined based on AMS data:

- Udder depth lactation 1;
- Front teat placement lactation 1;
- Rear teat placement lactation 1;
- Udder balance lactation 1;
- Udder depth lactation 2;
- Front teat placement lactation 2;
- Rear teat placement lactation 2;
- Udder balance lactation 2;
- Udder depth lactation 3;
- Front teat placement lactation 3;
- Rear teat placement lactation 3;
- Udder balance lactation 3.

The seven udder traits from the herd inspection, udder balance lactation 1 from the AMS and the composite udder will be published. The other udder traits derived from AMS data is only used as a correlated trait.

For the definition of the traits from the AMS systems, three teat coordinates per quarter are used: x, y and z. See Figure 1 for a graphic of the teat coordinates. Here, the x-coordinate indicates the distance in millimeters in relation to an imaginary line running straight through the box from front to back. The x-coordinate of the left quarters is therefore usually positive and the x-coordinate of the right quarters is therefore usually negative.

The y-coordinate indicates the distance in millimeters from the robot arm. The position of the robot arm varies from cow to cow, but this does not affect the distance in millimeters between the teat points based on the y-coordinate. The rear quarters will have a larger y-coordinate than the front quarters.
The z-coordinate indicates the distance in millimeters from the top of the teat to the floor.
Udder depth from AMS systems is derived as the average z-coordinate of the four quarters.
Distance front teats is the difference between the x-coordinate of the left front quarter and right front quarter.
Distance rear teats is the difference between the x-coordinate of the left-rear quarter and right-rear quarter.
Udder balance is the difference between the mean z-coordinate of the rear quarters and the mean z-coordinate of the front quarters.

Figure 1. Graphical representation of teat coordinates from AMS

Selection of Classification Data

The NL-animal model for type uses all classifications of animals scored as heifer since 1981. Requirements for a classification to be included in the animal model are:

1. the cow must have a pedigree (S) registration;
2. the cow must have a known calving date and was a heifer at the time of classification. Only heifer classifications are selected for breeding value estimation because little or no selection has occurred in young cows. One inspection is included. When there are multiple inspections, the first inspection of the animal is chosen;
3. the cow must have calved after the age of 610 days and before 1095 days;
4. the cow must have a known herd at the time of classification;
5. the cow must be classified according to the Z, R, Y or F standard;
6. the classification must have been performed as part of herd classification or in an additional classification system. These systems are described in this E-chapter;
7. the linear traits must have scores between 1 and 9, with the exception of height, which is measured in centimeters;
8. index traits must have scores between 71 and 89 points. Animals with an index trait with a valid score below 71 points will be placed at 71 points. Animals with an index trait with a score above 89 points will be placed at 89 points;
9. if an animal has been classified multiple times as a heifer by the same or different organizations, the first inspection of an animal will be used in the breeding value estimation.

Selection of AMS Data

All available data coming from AMS systems is included in the breeding value estimation for udder conformation traits. The requirements for an observation to be included in the animal model are:

1. an animal is female, pedigree registered and the sire of the cow is known;
2. an animal has a known herd on the day of milking;
3. an animal is less than 50% Belgian White-Blue;
4. an animal has at least 1 observation in lactation 1;
5. animal is in lactation 1, 2 or 3;
6. age at first calving is between 610 days and 1095 days;
7. observation is between day 15 and day 350 in lactation;
8. the observation is from an AMS herd, where the day prior to milking was also milked with an AMS;
9. the milking must not have failed or been refused;
10. milk yield must be greater than 0.0 kg and all four quarters produce milk;
11. teat coordinates are known;
12. the distance from teat to floor must be greater than 0 millimeters but shorter than 1,000 millimeters;
13. the distance between left front and left rear teats as well as the distance between right front and right rear teats must be greater than 0 millimeters;
14. the distance between left and right rear teats must be greater than -30 millimeters but shorter than 300 millimeters;
15. the distance between left and right front teats must be greater than 0 millimeters but shorter than 400 millimeters;
16. the difference in height between front and rear udder is not larger than 125 millimeters;
17. observations that deviate more than 4 standard deviations from the expected curve of the same animal are considered highly deviant and will be removed;
18. Measurements of milkings with an inter-milking time of less than 5 hours between two consecutive milkings will be removed.

The repeatability of the traits is high, and thus is it not necessary to include all measurements, as well as not making the calculation time too long. Therefore, only the first observation of each animal and then every twentieth observation are included in the breeding value estimation. Due to the large amount of data, this does not affect the estimated breeding values.

▪ Use of pedigree information

The use of pedigree information in the animal model for type, is similar to that in the breeding value estimation for milk production traits. See also chapter E-7.

▪ Statistical Model

Classification

The statistical model used in the NL-animal model for udder conformation udder based on classification data is:

$$Y_{ijklmnopqrs} = RB_i + IK_j + AGE_k + LACT_l + AGE\_M_m + CAT\_S_n + HET_o + REC_p + INB_q + A_r + Rest_s$$

In which:

$Y_{ijklmnopqrs}$	: heifer classification date * herd combination *i*, classifier * half-year * classification standard combination *j*, at age *k* of animal *r* in stage of lactation *l*, with age of mother *m* at birth of animal *r*, and bull category * age of sire *n* at time of inspection of animal *r*;
RB_i	: date * herd combination *i*;
IK_j	: classifier * half-year * classification standard combination *j*;
AGE_k	: age class *k* of animal *r* at time of classification * 3 year;
$LACT_l$	: stage of lactation class *l* of animal *r* at the time of classification * 3 year;
AGE_M_m	: age class *m* of dam at the time of birth of animal *r* * 6 year;
CAT_S_n	: sire category * age class *n* of sire at the time of classification of animal *r* * 6 year;
HET_o	: heterosis *o* of animal *r*;
REC_p	: recombination *p* of animal *r*;
INB_q	: inbreeding *q* of animal *r*;
A_r	: additive genetic effect or breeding value of animal *r*;
$Rest_s$	: residual-term *s* of $Y_{ijklmnopqr}$, which is not explained by the model.

Effects A and Rest are random effects, heterosis, recombination and inbreeding are covariables, and the remaining effects are fixed effects.

If dairy strength is not scored, then dairy strength is derived from the linear traits: chest width, body depth, body condition and rump width. Dairy strength has a direct relationship with longevity. The mentioned linear traits are so-called optimum traits regarding the relationship with the percentage cows culled at the beginning of the third lactation. Every trait has an optimum for the weight in dairy strength that is a bit higher than the average score of 5 (on a scale of 1 to 9). This choice was made because of the wishes of the Dutch dairy farmers to breed a bit heavier cows with a bit more body condition than the current cows. The score for dairy strength is derived for all cows that have a score for chest width, body depth, body condition and rump width.
Over time, changes in trait definitions occurred for several traits. When a trait definition changed, this has to be considered in the breeding values estimation, because we want to publish according to the latest definition.

In order to be able to use the scores of the trait according to old definitions, the genetic correlation between old and present definition in the breeding value estimation is used.
There are also differences in trait definition between Flanders and the Netherlands. Three traits have a difference in trait definition: chest width, Frame. and Feet & Legs. The data scored by Flemish classifiers before September 1st 2002 are treated as a different trait in the evaluation. After September 1 2002 Flemish and Dutch classifiers score according to the same definition.
Besides trait definition changes, introduction of new traits in the classification system occurs as well. Animals which have been scored prior to introduction of the new trait do not have a score for this trait. The consequence will be that cows without a score and sires with few or no daughters scored, will get a breeding value with a low reliability for this trait. To avoid this, a multiple trait evaluation is used. The new trait will have a reasonable genetic correlation with traits already present in the classification system. In that case these genetic correlations will be used in the breeding value estimation. Therefore animals without a score for this new trait will still get a reliable breeding value for this trait.

A multiple trait genetic evaluation is used to accommodate both of the above situations (change in trait definition and new trait). There are 3 trait groups: frame traits, udder traits and feet & leg traits. Correlations are used within trait groups. Table 1 shows the correlations for the trait group frame, table 2 for the udder traits, and table 3 for the feet & legs traits.

Table 1. Genetic correlations between body traits.

	STA	CWI	BDE	RS	BCS	RAN	RWI	MU	MUL	CW2	BD2	BD3	RS2	RW2
Stature	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Chest width	0.08	1.00	-	-	-	-	-	-	-	-	-	-	-	-
Body depth	0.52	0.47	1.00	-	-	-	-	-	-	-	-	-	-	-
Rib structure	0.44	0.03	0.65	1.00	-	-	-	-	-	-	-	-	-	-
Body Condition	-0.14	0.70	-0.04	-0.44	1.00	-	-	-	-	-	-	-	-	-
Rump angle	0.12	-0.11	-0.07	0.09	-0.03	1.00	-	-	-	-	-	-	-	-
Rump width	0.26	0.30	0.31	0.19	-0.01	-0.06	1.00	-	-	-	-	-	-	-
Muscularity	0.10	0.66	0.20	-0.30	0.82	0.07	0.23	1.00	-	-	-	-	-	-
Muscularity linear	0.05	0.67	0.17	-0.35	0.84	0.05	0.18	0.91	1.00	-	-	-	-	-
Chest width 2	-0.25	-0.82	-0.51	-0.01	-0.72	0.02	-0.32	-0.83	-0.82	1.00	-	-	-	-
Body depth 2	0.34	0.61	0.84	0.55	0.15	-0.02	0.40	0.34	0.31	-0.62	1.00	-	-	-
Body depth 3	0.25	0.56	0.77	0.50	0.19	-0.04	0.32	0.37	0.35	-0.61	0.87	1.00	-	-
Rib structure 2	0.37	-0.25	0.48	0.70	-0.75	-0.06	0.12	-0.62	-0.64	0.34	0.31	0.27	1.00	-
Rump width 2	0.38	0.45	0.50	0.27	0.18	0.09	0.72	0.45	0.39	-0.54	0.55	0.52	0.08	1.00
VRV chest width	0.59	0.75	0.67	0.33	0.39	0.05	0.50	0.52	0.49	-0.75	0.66	0.53	0.05	0.63

The upper left most corner of the table within the black lines are the traits that are published. The other traits are correlated traits. The traits with their time frame are:

Current traits	**Historical traits**
Stature (1980)	Muscularity linear (scored from 1980 to 1996 for all animals, for Red and White to 2004)
Chest width (1996)	Chest width 2 (scored from 1986 to 1988)
Body depth (1996)	Body depth 2 (scored from 1991 to 1996)
Rib structure (2008)	Body depth 3 (scored from 1980 to 1991)
Body condition (1998)	Rib structure 2 (scored from 1996 to 2008)
Rump angle (1980)	Rump width 2 (scored from 1980 to 1991)
Rump width (1991)	VRV Chest width = Chest width scored in Flanders (scored from 1991 to 2002)
Muscularity (only MRIJ, 1980)	Dairy strength (2007)
	Dairy strength derived (1998)

Table 2. Genetic correlations between udder traits from herd classification.

	FUA	FTP	FTL	UDE	RUH	USU	RTP
Fore udder attachment	1.00	-	-	-	-	-	-
Front teat placement	0.31	1.00	-	-	-	-	-
Teat length	0.03	-0.19	1.00	-	-	-	-
Udder depth	0.79	0.26	-0.07	1.00	-	-	-
Rear udder height	0.47	0.24	0.08	0.41	1.00	-	-
Udder support	0.02	0.38	-0.03	0.10	0.33	1.00	-
Rear teat placement	0.06	0.62	-0.21	0.11	0.25	0.78	1.00

Current traits
Fore udder attachment (1996)
Front teat placement (1980)
Teat length (1980)
Udder depth (1980)
Rear udder height (1996)
Median suspensory (1980)
Rear teat placement (2000)

Table 3. Genetic correlations between feet & legs traits.

	RLR	RLS	FAN	FFO	LOC	F&L	FA2
Rear leg rear view	1.00	-	-	-	-	-	-
Rear leg side view	-0.06	1.00	-	-	-	-	-
Foot angle	0.13	-0.82	1.00	-	-	-	-
Front feet orientation	0.41	-0.07	0.18	1.00	-	-	-
Locomotion	0.87	0.01	0.03	0.51	1.00	-	-
Feet & legs	0.87	-0.07	0.12	0.50	0.95	1.00	-
Foot angle 2	0.53	-0.66	0.83	0.45	0.51	0.59	1.00
VRV Feet & Legs	0.72	-0.63	0.65	0.43	0.70	0.76	0.90

The upper left corner of the table within the black lines are the traits that are published. The other traits are correlated traits. The traits with their time frame are:

Current traits
Rear leg rear view (1998)
Rear leg side view (1980)
Foot angle (1997)
Front feet orientation (2017)
Locomotion (2002)
Feet & Legs (1980)

Historical traits
Foot angle 2 (1991-1997)
Feet & legs in Flanders (1991-2002)

In total, breeding values for 25 traits are estimated. For the estimation of the breeding values for conformation, the classification data are corrected in two ways: by means of an adjustment for variation of classifications per classifier, and by means of a model.

Adjustment for Variation per Classifier
Before classifications are used in the model, an adjustment is made for the variation of these classifications with respect to the classifiers. This adjustment is made per classification, standard for all the classifications that a classifier has made in a six month period. The goal is to standardise the variation of the classifications, because some classifiers have more variation in their classification of cows than others, and this variation may change during time. The formula for standardisation of variation is:

$S^* = (S - M_{in})*(STD_{tot}/STD_{in})+M_{in}$

In which:

S^* = adjusted score
S = score for trait given by classifier
STD_{tot} = variation of all classifications per trait per six months per classification-standard
STD_{in} = variation of all classifications of one classifier per six months per classification standard
M_{in} = mean score for trait given by the classifier

The effects in the Model

The effects in the model are:
1. date * herd
2. classifier * half a year * classification standard
3. age at classification * 3 years
4. lactation stage at classification * 3 years
5. age of dam * 6 years
6. sire category * age of sire * 6 years
7. heterosis
8. recombination
9. inbreeding
10. additive genetic effect or breeding value

*Date * herd*

Each date * herd combination represents a new level in the model. This means that all the classifications on one day in one herd are compared with each other. Animals that are classified on the same day but by different classifiers or on different classification standards, will be compared with each other in the same date * herd class in the genetic evaluation.

*Classifier * half year * classification standard*

This effect makes it possible to compare animals in one herd that are classified on a different standard. The differences between these animals are adjusted for the differences made by the classifier between two classification standards in half a year. This effect also accounts for the differences made by two classifiers that classify cows in one herd at one day.
The minimum number of observations per class is 100. If there are less than 100 observations per classification standard, the records are successively merged within classifier and year of classification, across classifiers and within half a year of classification, across classifiers and within year of classification, and possibly across classifiers and across years of classification. A year of classification runs from September to August because adaptations to the classification sheet are mainly made in September.

*Age at Classification * 3 years*

Research shows that the age at classification has an effect on the classification. This has to be included in the model. A total of 21 age categories are distinguished, from which category 1 is adjusting classifications to the age of 21 month and younger. Category 2 to 20 adjusts to the age of 22 to 40 months at classification. In category 21 all the cows are included that are 41 months old or older. The age classes are divided in periods of 3 years. This is to take into account the changing of how classifiers judge the type depending on age of the cow.

*Lactation Stage at Classification * 3 years*

Research shows that, besides age, also the lactation stage at classification has an effect on the classification and is therefore included in the model. In total, 13 lactation categories are distinguished, one category for each month in lactation. In category 13 all the cows are included that have been in lactation for 13 months or more at the moment of classification. The lactation stage classes are divided in periods of 3 years. This is to take in account the changing of how classifiers judge the type depending on the lactation stage of the cow.

*Age of dam * 6 years*
Age of dam at birth of classified cow, divided in whole years. Cows of 7 years and older are grouped together. Dams with an unknown birthdate are grouped in a separate class. With this division, a distinction is made between cows born from heifers, which are not fully matured and give lighter calves, and older cows, which are mature and give heavier calves. Calves born from heifers can be less developed when they are classified. The age of dam classes are divided in periods of 6 years. This is to take in account the changes of how classifiers judge the type depending on the age of the dam at the moment of birth of the classified cow.

*Sire category * age of sire * 6 years*
Sire category * age class *n* of sire of animal *q* at the time of classification. There are four sire categories: a) first crop daughters of A-category bulls (nationally tested AI sires), b) second crop daughters of A-category bulls, c) second crop daughters of B-category bulls (internationally tested AI sires), and d) daughters of C-category bulls (not AI tested sires) + rest. Age of sire is divided in 14 classes (2, 3, 4, …, 14, ≥15 year). With this division per sire category, a distinction is made between different types of sires and how these sires are used. For example, first crop bulls are used more randomly and second crop bulls are used more selective. The sire category * age of sire classes are divided in periods of 6 years. This is to take in account the changes of how classifiers judge the type depending on the sire category * age of the sire at the moment of classification of the classified cow.

Heterosis and recombination
Heterosis and recombination effects play a role in the combining of breeds. These are genetic effects that are not transmitted to the offspring. Research has shown that a correction must be made for these effects. The amount of the heterosis is defined as the difference in level or the trait in the crossing with the average of the parent breeds. Recombination is the loss of the usually positive effect of heterosis and occurs when the earlier achieved crossing product is crossed back with one of the parent breeds.

Inbreeding
Inbreeding is the making of a mating between two animals whose DNA is more related to each other than the average relatedness in the population. Therefore, inbreeding leads to an increase in homozygosity. By comparing inbred animals with non-inbred animals on a trait, the negative effect of inbreeding can be estimated. Inbreeding is not heritable.

Additive Genetic Effect or Breeding Value
Each trait has its own heritability in the NL-animal model for type. These heritabilities are shown in table 4. Principles of breeding value estimation are explained in E-7.

Table 4. Heritabilities (h^2) used in the NL-animal model for type.

	Linear traits	h^2		Linear traits	h^2
STA	Stature	0.51	FFO	Front feet orientation	0.14
CWI	Chest width	0.21	LOC	Locomotion	0.13
BDE	Body depth	0.29	FUA	Fore udder attachment	0.25
RS	Rib structure	0.10	FTP	Front teat placement	0.31
BCS	Body condition score	0.27	FTL	Teat length	0.38
RAN	Rump angle	0.33	UDE	Udder depth	0.39
RWI	Rump width	0.37	RUH	Rear udder height	0.26
RLR	Rear leg rear view	0.16	USU	Udder support	0.22
RLS	Rear leg side view	0.18	RTP	Rear teat placement	0.29
FAN	Foot angle	0.13			

AMS

The statistical model used in the NL-animal model for udder conformation based on AMS data is split for the first three lactations. For lactation 1, the model is:

$Y1_{ijklmnopqrs} = HYS_i + DIL_j + AFC_k + HY_l + HET_m + REC_n + INB_o + HGT_p + TLE_t + A_q + PME_r + Rest_s$

For lactation two, the model is:

$Y2_{ijklmnopqrs} = HYS_i + DIL_j + AFC_k + HY_l + HET_m + REC_n + INB_o + HGT_p + TLE_t + A_q + PME_r + Rest_s$

And the model for lactation three is:

$Y3_{ijlmnopqrs} = HYS_i + DIL_j + HY_l + HET_m + REC_n + INB_o + HGT_p + TLE_t + A_q + PME_r + Rest_s$

In which:

$Y1_{ijklmnopqrst}$	: observation on herd*year*season*box *i*, with lactation stage *j*, age of calving *k*, herd*year of first calving *l*, heterosis effect *m*, recombination effect *n*, inbreeding effect *o*, height effect *p*, teat length effect *t* and permanent environment effect *r* of animal *q* in lactation 1;
$Y2_{ijklmnopqrst}$	: observation on herd*year*season*box *i*, with lactation stage *j*, age of calving *k*, herd*year of first calving *l*, heterosis effect *m*, recombination effect *n*, inbreeding effect *o*, height effect *p*, teat length effect *t* and permanent environmental effect *r* of animal *q* in lactation 2;
$Y3_{ijlmnopqrst}$	: observation on herd *year* season*box *i*, with lactation stage *j*, herd *year of first calving *l*, heterosis effect *m*, recombination effect *n*, inbreeding effect *o*, height effect *p*, teat length effect *t* and permanent environmental effect *r* of animal *q* in lactation 3;
HYS_i	: farm * year * season * box number *i*;
DIL_j	: days in lactation *j*;
AFC_k	: age of first calving *k*;
HY_l	: herd * year of first calving *l*;
HET_m	: heterosis effect *m*;
REC_n	: recombination effect *n*;
INB_o	: inbreeding effect *o*;
HGT_p	: height effect *p*;
TLE_t	: teat length effect *t*;
A_q	: additive genetic effect of animal *q*;
PME_r	: permanent environmental effect *r*;
$Rest_s$	: residual term *s* of that which is not explained by the model of $Y_{ijklmnopqrt}$.

The effects A, PME and Rest are random, the effects HET, REC, INB, HGT and TLE are covariables, the other effects are fixed. The covariables HGT and TLE are only added to the model for udder depth.

The effects in the model

The eleven effects in the model are:

1. herd * year * season * box number;
2. days in lactation * 3 year;

3. age of calving * 3 year;
4. herd * year of first calving;
5. heterosis;
6. recombination;
7. inbreeding;
8. height;
9. teat length;
10. additive genetic effect or breeding value;
11. permanent environmental effect.

*Herd * year * season * box number*
During the year and across seasons, there is variation in udder traits. In addition, there may be variation between herds and individual farms over time. There may also be variation between boxes on one herd if multiple AMS systems are present. This variation is corrected for through this effect. Each unique herd*year*season*box number will be a new level in the model.

*Days in lactation * 3 year*
During different phases of lactation, udder characteristics may vary. For example, an animal may have oedema in the udder at the beginning of lactation and, for that reason, a somewhat different udder conformation can be observed than at a later point in lactation. In total, 33 lactation stage classes of 10 days are distinguished, from day 15 to day 350 so that sufficient data is available for each class. This means that class 33 consists of 16 days. The classes for days in lactation are grouped per three years in order to correct for time effects as well.

The udder balance of a cow is increasing at the beginning of lactation. This is because the front udder becomes 'deep' faster; the distance to the ground decreases faster for the front udder, increasing the difference in depth with the rear udder. Between day 100 and day 250 in lactation, the udder balance remains relatively constant because both the rear and front udder do not decrease or increase in depth. At the end of lactation, after day 250, the rear udder begins to deepen faster relative to the front udder; the udder balance decreases. This trend is also shown in Figure 2 and Figure 3. It should be noted that, on average, the variation in udder depth over the lactation is small; it is only fifteen millimeters difference in udder depth for the front udder and rear udder and five millimeters difference in udder balance. However, this is an average; the differences between individual cows are large.

Figure 2. Depth of front- and rear-udder over the lactation..

Figure 3. Udder balance during the lactation.

*Age of calving * 3 year*

Animals that calve for the first time at a very young age may have a different udder conformation compared to animals that calve at a slightly older age for the first time. Similarly, animals that calve at an older age for the first time compared to the average, may have a different udder conformation compared to animals that calve earlier.

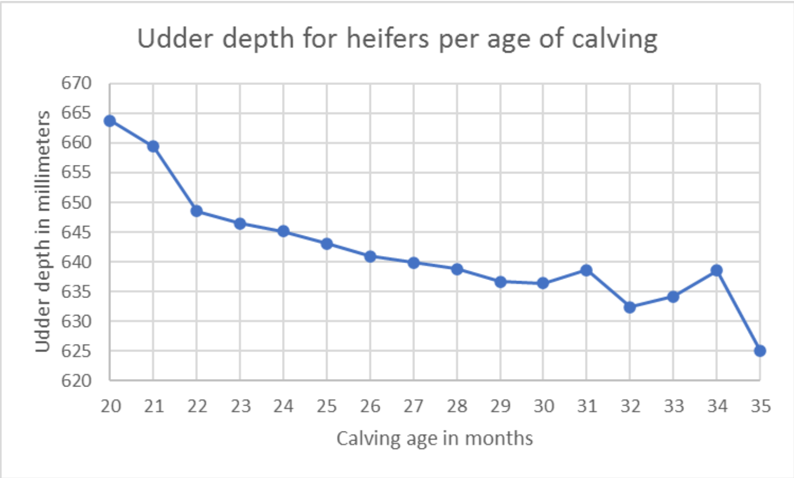

Figure 4. Udder depth of heifers per calving age..

Figure 4 shows the effect of calving age in months for udder depth in heifers. This variation is corrected by including calving age as heifer and calving age as second parity cow in the model. Sixteen calving ages are distinguished into categories of one month (20 - 35 months). To correct for time effects, the classes of calving ages will be grouped into 3-year groups. This effect is only included in the model for lactation 1 and lactation 2.

*Herd * year of first calving*

To correct for selection within a herd, animals are compared to herd mates that calved in the same year for the first time. Each unique herd *year will be a level in the model.

Heterosis and recombination

Heterosis and recombination effects play a role in the combining of breeds. These are genetic effects that are not transmitted to the offspring. Research has shown that a correction must be made to these effects. The amount of the heterosis is defined as the difference in level or the trait in the crossing with the average of the parent breeds.

Recombination is the loss of the usually positive effect of heterosis and occurs when the earlier achieved crossing product is crossed back with one of the parent breeds.

Heterosis has a negative effect on all udder conformation breeding values based on AMS data, recombination has a positive effect on all udder conformation breeding values based on AMS data, except udder depth lactation 1 and udder depth lactation 2. However, the effects on breeding values are small. The largest effect of one percentage increase in heterosis is for udder depth lactation 1 with 0.01 on the relative breeding value, and the largest effect of one percentage increase in recombination is for distance front teats with 0.01 on the relative breeding value.

Inbreeding
Inbreeding is the making of a mating between two animals whose DNA is more related to each other than the average relatedness in the population. Therefore, inbreeding leads to an increase in homozygosity. By comparing inbred animals with non-inbred animals on a trait, the negative effect of inbreeding can be estimated. Inbreeding is not heritable. Inbreeding has the largest effect on udder balance lactation 1. One percentage increase in inbreeding leads to an increase of the breeding value of 0.07.

Height
The effect of height is only included in the model for udder depth, the average distance from the floor to the top of the teat. Thus, a taller cow will have a larger distance from floor to teat top than a small cow. It is the absolute udder depth. But this does not necessarily say anything about the relative udder depth. This is why height is corrected based on the estimated breeding value for height that the animal has.

Teat length
Udder depth is measured as distance from the teat top to the floor. Therefore, cows with long teats have on average a smaller distance from the teat top to the floor. However, the required distance is the distance from the bottom of the udder to the floor. Therefore, it is necessary to correct for teat length. This is done by including the cow breeding value for teat length as a covariable in the model.

Additive genetic effect or breeding value
The additive genetic effect (or animal effect) is the breeding value. This effect contains an animal's genetic contribution to the observation and determines an animal's breeding value. In addition, all information from ancestors and progeny is also used in determining the breeding value. To calculate the breeding values for the udder conformation traits, each trait has its own heritability. These heritabilities are shown in Table 5. Principles of breeding value estimation are explained in part E-7.

Permanent environmental effect
A cow has multiple observations on udder conformation in the AMS system, as each milking is recorded. Because there are multiple observations on one animal, the observations have more in common than just the additive genetic effect. This additional similarity is called the permanent environment effect, an effect of the constant circumstance the cow is facing. For example, if the cow has already suffered udder damage in her rearing, it may have an effect on her udder conformation when she is lactating. However, this is not a genetic effect and is not among the other fixed effects in the model. This is for which the permanent environment effect is correcting. Through the use of a permanent environment effect in the model, multiple observations on an animal can be used to get a better estimate of the breeding value.

The additive genetic effect and permanent environment effect are random effects, meaning that the amount of information available on an animal can be taken into account. If there is little information about an animal (few offspring and few observations on the animal), the additive genetic effect will not differ much from the parental mean, and the permanent environment effect will not differ much from 0.

Table 5. Heritabilities (h^2) and genetic deviation (Gen. deviation) in millimeters used in the NL-animal model for udder conformation traits based on AMS data.

		Parity 1		Parity 2		Parity 3	
	Linear traits	h^2	Gen. deviation	h^2	Gen. deviation	h^2	Gen. deviation
DFT	Distance front teats	0,60	20,4	0,53	23,6	0,45	24,4
UDD	Udder depth	0,56	16,7	0,56	18,9	0,52	19,2
DRT	Distance rear teats	0,45	10,7	0,38	11,8	0,33	12,4
UBA	Udder balance	0,45	6,9	0,42	7,9	0,43	8,8

- **Genetic correlations**

Seven linear traits for udder conformation were estimated from classification data, from which the composite udder is calculated, and 12 udder traits were estimated from AMS data (4 traits x 3 lactations). This means a total of 20 breeding values. However, as described on page 2 of this E-Chapter, only 9 breeding values are published. The remaining 11 breeding values serve only as background information. These traits are included as so-called "correlated traits”. This means that because of the genetic correlation between the traits, information is shared. So even though these breeding values themselves are not published, they are important in the breeding value estimation.

The genetic correlations between the traits are shown in Table 6.

Table 6. Genetic correlations between udder traits.

	Front udder attachment (FUA)	Front teat placement (FTP)	Teat length (FTL)	Udder depth (UDD)	Rear udder height (RUH)	Udder support (USU)	Rear teat placement (RTP)	Udder depth 1 (UD1)	Distance front teats 1 (DF1)	Distance rear teats 1 (DR1)	Udder balance 1 (UB1)	Udder depth 2 (UD2)	Distance front teats 2 (DF2)	Distance rear teats (DR2)	Udder balance 2 (UB2)	Udder depth 3 (UD3)	Distance front teats 3 (DF3)	Distance rear teats 3 (DR3)
FTP	0.31																	
FTL	0.03	-0.19																
UDD	0.79	0.26	-0.07															
RUH	0.47	0.24	0.08	0.41														
USU	0.02	0.38	-0.03	0.10	0.33													
RTP	0.06	0.62	0.21	0.11	0.25	0.78												
UD1	0.86	0.31	-0.36	0.98	0.44	0.15	0.11											
DF1	-0.38	-0.98	0.12	-0.21	-0.33	-0.49	-0.73	-0.10										
DR1	-0.22	-0.84	0.20	-0.17	-0.46	-0.89	-0.99	-0.06	0.56									
UB1	0.25	0.29	0.25	0.24	0.53	0.34	0.36	0.14	-0.10	-0.17								
UD2	0.83	0.26	-0.34	0.97	0.40	0.15	0.09	0.97	-0.11	-0.06	0.14							
DF2	-0.30	-0.98	0.11	-0.13	-0.32	-0.51	-0.72	-0.08	0.98	0.58	-0.10	-0.08						
DR2	-0.13	-0.80	0.22	-0.11	-0.41	-0.91	-0.99	-0.05	0.49	0.97	-0.13	-0.06	0.53					
UB2	0.27	0.24	0.21	0.33	0.51	0.37	0.30	0.18	-0.10	-0.15	0.96	0.20	-0.07	-0.12				
UD3	0.77	0.17	-0.42	0.97	0.30	0.17	0.10	0.93	-0.11	-0.04	0.06	0.99	-0.09	-0.03	0.17			
DF3	-0.25	-0.97	0.16	-0.07	-0.25	-0.42	-0.66	-0.09	0.94	0.57	-0.12	-0.12	0.99	0.55	-0.13	-0.05		
DR3	0.02	-0.73	0.28	0.00	-0.25	-0.84	-0.96	0.01	0.44	0.90	-0.07	-0.03	0.56	0.98	-0.12	-0.03	0.54	
UB3	0.15	0.12	0.21	0.35	0.41	0.35	0.19	0.20	-0.13	-0.12	0.85	0.25	-0.14	-0.15	0.98	0.28	-0.10	-0.11

▪ Composites: Calculation of the Breeding Values for overall traits

The breeding values for overall traits are calculated from breeding values of the linear traits. These breeding values for the overall traits are called ‘composites’. The calculation, that is in place since April 2015, is applied on the breeding values for the overall traits: frame, dairy strength, udder, and feet and legs. The breeding value for muscularity is still based on the score of the classifier. Overall conformation is based on the overall traits.

Advantages of using composites are:

- Transparency: It can be checked why a bull is better suited or less suited for a breeding goal. By re-calculating the composite it provides insight on what linear traits a bull earns points, and on what parts he loses points.
- International conversion improves: Linear traits have higher correlations between countries compared with the overall traits. By calculating the overall traits based on the converted linear traits, the composites of bulls with foreign breeding values have a higher reliability.
- Change in breeding goal or trait definition allows a quick change: When the breeding goal changes, for all animals (young and old) composites can be calculated. There is no waiting period until enough scored animals based on the change in breeding goal are available.

When the composites were developed, the goal was to have less emphasis on stature, rear legs do not have to get steeper, and rear teat placement should not get more narrow compared to the situation in April 2015.

In 2018 separate composites for dual purpose breeds were introduced. In 2022 the composites for dairy breeds were revised, with changes for frame and udder.

The breeding goal for the four composites described in words, is as follows:
Frame: A cow that is in her whole body a bit bigger than the current cow, but also more balance between stature, chest width and body depth. This is a cow that is wider in the front, with more capacity, and a more sloped and wider rump. Cows do not have to get bigger, but also not smaller.
Dairy strength: A robust cow with more capacity throughout her whole body, with especially more rib structure and more body condition. Stature is not taken into account.
Udder: A cow with a stronger attached and shallow udder, with a higher rear udder and stronger udder support, of which both front and rear teats do not have to be placed more narrow and rear teats can be placed even wider. Teats do not have to be longer or shorter.
Feet and Legs: A cow that is standing more parallel on her rear legs and has a better locomotion. Rear legs can become a bit more curved and the foot angle can become more steep.

The formulas to calculate the composites for milk goal are:

Frame: $= -0{,}02917 \times (BV_{STA}{}^{a} – 100)^2 + 0{,}26 \times (BV_{CWI}{}^{b} – 100) + 0{,}44 \times (BV_{BDE}{}^{b} – 100) – 0{,}02917 \times (BV_{RAN}{}^{a} – 104)^2 + 0{,}35 \times (BV_{RWI}{}^{b} – 100) + \text{ratio(STA-CWI-BDE)}^{c} + 101$

Dairy Strength: $= -0{,}026 \times (BV_{CWI}{}^{a} – 100)^2 – 0{,}026 \times (BV_{BDE}{}^{a} – 100)^2 + 0{,}63 \times (BV_{RS} – 100) + 0{,}63 \times (BV_{BCS} – 100) + 0{,}21 \times (BV_{RWI} – 100) + 101$

Udder: $= 0{,}46 \times (BV_{FUA} – 100) + 0{,}09 \times (BV_{FTP} – 100) – 0{,}0075 \times (BV_{FTL}{}^{a} – 100)^2 + 0{,}18 \times (BV_{UDE}{}^{b} – 100) + 0{,}46 \times (BV_{RUH} – 100) + 0{,}28 \times (BV_{USU} – 100) – 0{,}28 \times (BV_{RTP}{}^{d} – 100) + 100$

Feet&Legs: $= 0{,}23 \times (BV_{RLR} – 100) – 0{,}0325 \times (BV_{RLS}{}^{a} – 102)^2 + 0{,}16 \times (BV_{FAN} – 100) + 0{,}78 \times (BV_{LOC} – 100) + 100$

Where
[a] breeding values are weighted with a quadratic optimum, optimum for STA, CWI, BDE, FTL is 100, for RLS is 102, and RUN is 104, where breeding values differing more than 12 points from the optimum are also set to a difference of 12 points
[b] breeding values are maximised to 104 for CWI, BDE and RWI, and to 108 for UDE
[c] ratio value for STA, CWI and BDE is calculated as follows: 1) calculated mean of STA, CWI and BDE, 2) sum absolute differences of STA, CWI and BDE met mean from (1), 3) calculate ratio as 4 – sum(absolute difference from (2)) x 0.50, 4) ratio lower than 04 is set to -4. Animals that do not differ so much for the breeding values for STA, CWI and BDE get a bonus for frame, and when breeding values differ more, a penalty of maximum 4 points is applied.
[d] Breeding values of 92 and lower are minimised to 92

Figure 5 shows the contribution in the composite when the linear trait is weighted linear, is maximised, is minimised, or is weighted as an optimum.

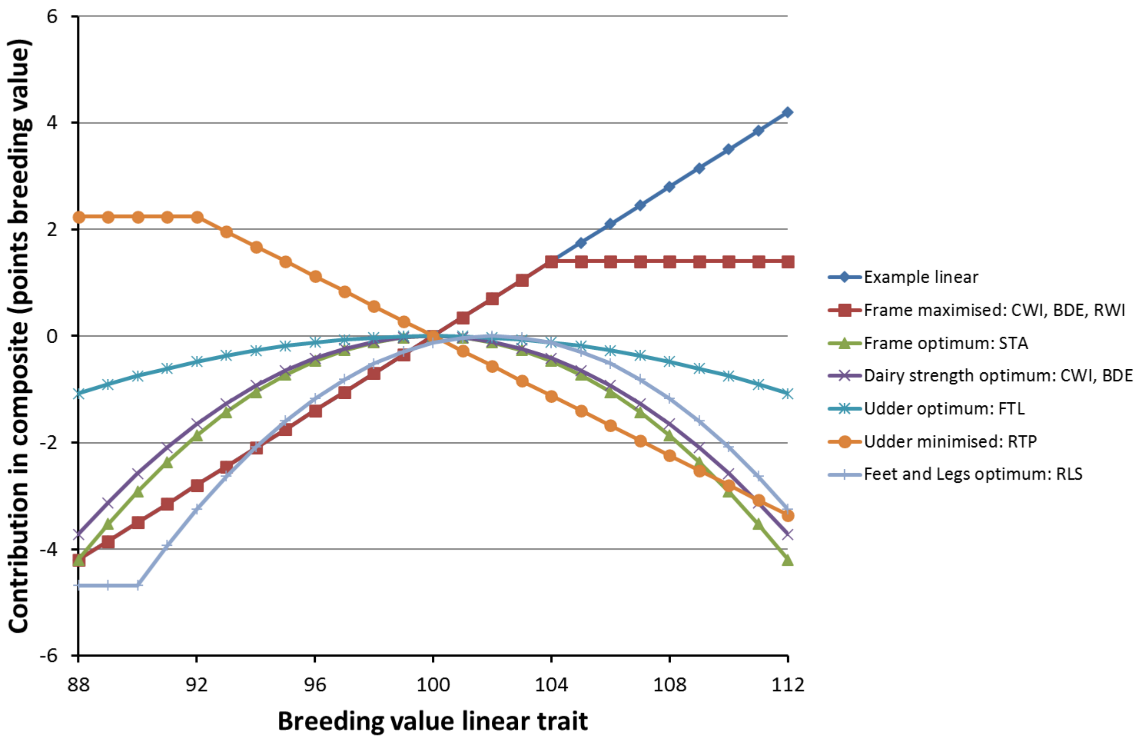

Figure 5. Contribution in the composite for linear traits which are weighted linear, are maximised, are minimised, or weighted as a quadratic optimum.

Above formulas can be used to re-calculate the composite, and all breeding values should have the same base. In Table 7 the relative weights are given for the linear traits in each composite. This shows the importance of a linear trait in a certain composite.

Table 7. Relative weight of linear traits in milk goal composites for frame, dairy strength, udder and feet & legs

Frame	weight	Dairy Strength	weight	Udder	weight	Feet & Legs	weight
STA	20%	STA		FUA	25%	RLR	15%
CWI	15%	CWI	15%	FTP	5%	RLS	25%
BDE	25%	BDE	15%	FTL	5%	FAN	10%
RS		RS	30%	UDE	10%	LOC	50%
BCS		BCS	30%	RUH	25%		
RAN	20%	RAN		USU	15%		
RWI	20%	RWI	10%	RTP	-15%		

The formula for the dual purpose composites are:

Frame: $= 0.30 \times (BV_{STA} - 100) + 0.40 \times (BV_{CWI}{}^{a} - 100) + 0.40 \times (BV_{BDE}{}^{a} - 100) + 0.40 \times (BV_{RAN}{}^{a} - 100) + 0.50 \times (BV_{RWI}{}^{*} - 100) + 100$

Dairy Strength: $= -0.0258 \times (BV_{CWI}{}^{b} - 104)^2 - 0.0258 \times (BV_{BDE}{}^{b} - 104)^2 + 0.31 \times (BV_{RS} - 100) + 0.42 \times (BV_{BCS} - 100) + 0.31 \times (BV_{RWI} - 100) + 0.41 \times (BV_{MUSC} - 100) + 101$

Udder: $= 0.27 \times (BV_{FUA} - 100) + 0.27 \times (BV_{FTP} - 100) - 0.0075 \times (BV_{FTL}{}^{b} - 100)^2 + 0.36 \times (BV_{UDE} - 100) + 0.36 \times (BV_{RUH} - 100) + 0.36 \times (BV_{USU} - 100) - 0.075 \times (BV_{RTP}{}^{b} - 104) + 100$

Feet&Legs: $= 0.32 \times (BV_{RLR} - 100) - 0.0267 \times (BV_{RLS}{}^{b} - 102)^2 + 0.16 \times (BV_{FAN} - 100) + 0.78 \times (BV_{LOC} - 100) + 100$

Where:

[a] Breeding values of 104 and higher are maximised to 104 for BDE and RWI, breeding values of 106 and higher are maximised to 106 for CWI, breeding values of 108 and higher are maximised to 108 for RAN

[b] Breeding values are weighted with a quadratic optimum, optimum for RTP is 100, optimum for CWI, BDE, RTP is 104 and optimum for RLS is 102, where breeding values differing more than 12 points from the optimum are also set to a difference of 12 points

In Table 8 the relative weights are shown for the linear traits in the composites for the dual purpose.

Table 8. Relative weight of linear traits in dual purpose composites for frame, dairy strength, udder and feet & legs

Frame	weight	Dairy strength	weight	Udder	weight	Feet and Legs	weight
STA	15%	STA		FUA	15%	RLR	20%
CWI	20%	CWI	15%	FTP	15%	RLS	20%
BDE	20%	BDE	15%	FTL	5%	FAN	10%
RS		RS	15%	UDE	20%	LOC	50%
BCS		BCS	20%	RUH	20%		
RAN	20%	RAN		USU	20%		
RWI	35%	RWI	15%	RTP	-5%		
MUSC		MUSC	20%				

Calculation of the Breeding Value Overall conformation

The breeding value for overall conformation of an animal is a composite of frame, dairy strength, udder, feet and legs, and muscularity. The weights of these traits are shown in Table 9.

Table 9. Weight factors for the different traits included in overall conformation per base of publication.

	Milk goal Black	*Milk goal Red*	*Dual purpose/ Belgian Blue*
Frame	20%	20%	15%
Dairy strength	10%	10%	10%
Udder	35%	35%	30%
Feet and legs	35%	35%	30%
Muscularity	0%	0%	15%

The formulas to calculate Overall conformation are:

(Black/Red): $= 0.30 \times (BV_{frame} - 100) + 0.15 \times (BV_{dairy\ strength} - 100) + 0.53 \times (BV_{udder} - 100) + 0.53 \times (BV_{feet\ and\ legs} - 100) + 100$

(Dual purpose): $= 0.23 \times (BV_{frame} - 100) + 0.15 \times (BV_{dairy\ strength} - 100) + 0.45 \times (BV_{udder} - 100) + 0.45 \times (BV_{feet\ and\ legs} - 100) + 0.23 \times (BV_{muscularity} - 100) + 100$

The composite for overall conformation is calculated using the composites of the overall traits, and the used weight factors result in a relative breeding value with mean of 100 and a standard deviation of 4 points.

Reliability

For the calculation of the reliabilities, heritabilities from Table 4 and 5 and genetic correlations between traits from Table 1 to 3, and Table 6 are used. For each trait a reliability is calculated. The published reliability is the reliability of overall conformation, and based on the reliabilities of the composites and the weight factors in Table 7 or 8.

Base

See chapter ‘Bases for breeding values and base differences’.

Publication requirements

See chapter ‘Publication rules sires’.

▪ Interpretation breeding values linear traits

Table 11 describes the biological interpretation of the breeding values for the linear traits when used on an average cow with breeding value 100. For chest width for example, a breeding value higher than 100 will on average result in a wider chest, and a breeding value lower than 100 will on average result in a narrower chest. In the table the interpretation is given for all 20 linear traits.

Table 11. Biological interpretation of breeding values for linear traits lower and higher than 100.

Trait	Lower than 100	Higher than 100
Stature	short	tall
Chest width	narrow	wide
Body depth	shallow	deep
Rib structure	closed	open
Body condition score	skinny	fat
Rump angle	high pins	sloped pins
Rump width	narrow	wide
Rear leg rear view	hocked-in	straight
Rear leg side view	straight	curved
Foot angle	low	steep
Front feet orientation	outward	parallel
Locomotion	weak	strong
Fore udder attachment	weak	strong
Fore teat placement	wide	narrow
Fore teat length	short	long
Udder depth	deep	shallow
Rear udder height	low	high
Udder support	weak	strong
Rear teat placement	wide	Narrow
Udder balance	lower hind	higher hind

▪ Literature

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