Statistical Indicators

E-7

Breeding value estimation of milk production traits with test-day model

▪ Introduction

What really counts in the livestock industry is to breed a subsequent generation of cattle with a more profitable production by selection and mating. In this process, the selection of milk production traits is a major issue, where the breeding values for the milk production traits are the most important statistical indicators. Breeding values for milk production are the indicators for the genetic qualities. For cows these breeding values are called cow-indexes and for bulls these are called bull-indexes. In this part we will examine the background of the calculation of the cow-indexes and bull-indexes for the milk production traits. As from May 2002 the test-day model (NL-TDM) will be used in this calculation. Unlike the lactation model used in the past, where the breeding values are calculated from 305-day production records, in the NL-TDM the breeding values are calculated from the daily productions. As of April 2017 breeding values are calculated for lactations 1 to 5

A number of organisations supply data for the NL-TDM:
- CRV collected testdays in the Netherlands from June 1st 1990 are used in the NL-TDM since May 2002.
- VRV zvw collected testdays in Flanders from January 1st 1980 are used in the NL-TDM since November 2002.

▪ Implications

In the NL-TDM cows and bulls get a breeding value for the daily production for each day between day 5 and day 335 in lactations 1, 2, and 3. So, what's the meaning of a breeding value? For example: let's take a bull with a bull-index of +4 kg milk on day 50 of lactation 1 and a cow with a breeding value of –2 kg milk on day 50 of lactation 1. Expectations are that a female offspring of this cow and bull will get a breeding value of (+4 kg + (-2 kg)) / 2 = +1 kg milk. Expectations also are that this cow will produce 3 kg more milk on day 50 in lactation 1 compared to her dam. The breeding values for the 305-day production for lactations 1 to 5 are calculated from the breeding values for daily production by summing the breeding values of day 5 up to day 305. The breeding values of lactations 1 to 5 are then put together to one breeding value for 305-daily production.

The calculation of the cow-indexes and bull-indexes uses the BLUP-technique (Best Linear Unbiased Prediction) in an animal model. The characteristic feature of this animal model is that the cow-indexes and the bull-indexes are estimated simultaneously. An animal model has many advantages: the cow-indexes and bull-indexes are accurately geared to one another and all genetic relations are taken into account.

The cow-index in the animal model is made up of the cow-index and bull-index of both parents, the value of the daily productions in the first three lactations in relation to other cows in the herd and the cow's contribution in the cow-index and bull-index of her offspring. A bull-index in the animal model is made up of the cow-index and bull-index of both parents and the bull's contribution in the cow-index and bull-index of his offspring. In this process the cow-indexes and bull-indexes have to be accurately geared up to one another, which is exactly happening in the animal model. The breeding values are calculated in accordance with the BLUP principle. This means that a breeding

value predicts what we can expect from the offspring. The way of calculation of the breeding values is optimized by this purpose.

▪ Basic principles for the correct calculation of the breeding value

The following three items are essential for the calculation of the correct and true breeding values:
1. reliable milk production data;
2. reliable pedigree data;
3. the correct statistic model.
These three items will be discussed below:

Reliable milk production data
Daily productions must meet the following requirements for use in the NL-TDM:
1. the cow must be herdbook registered;
2. only official daily productions are to be included, these can also be owner sampled production records;
3. only daily productions in the first five lactations of a cow are to be included;
4. only daily productions from day 5 on up to day 420 after calving are to be included;
5. cow must be housed in a known herd on test day;
6. the minimum age at calving is 640 days;
7. the sire of the cow must be known;
8. fat and protein content below 10%;
9. calving interval of the current lactation must be at least 215 days;
10. no daily yields of a lactation must have the status "unreliable";
11. difference between realised and predicted yields must be within limits.

Requirement 11 is introduced to exclude records from the breeding value estimation with a large likelihood of errors in the data. The requirement is implemented as described below.
For each day in milk in each lactation of each cow a predicted yield is calculated with a Wilmink's lactation curve. For a Wilmink's curve it is necessary to have at least 3 testdays in a lactation. Difference between realised and predicted yield is calculated. The standard deviation of this difference is stored for each calving year, lactation number and day in milk. Realised yields are not included if the yield is larger than the predicted yield plus 6 times the standard devation of the difference between predicted and realised yield. Such yields have a high likelihood of data errors. Consider the following example of a cow in 1st lactation

Day in milk	Kg milk
22	17.5
52	28.7
79	26.9
115	25.3
142	24.7
174	21.6
209	22.0
260	19.1
287	84.5
321	16.4

Yield at day 287 is very unlikely considering the other daily yields and the usual lactation curve of an animal. Probably the daily yield is not correctly entered in the database. The cow has a predicted yield of 18.2 kg milk and a realised yield of 84.5 kg milk. The standard deviation of the difference between realised and predicted yields for this day in this lactation is 1.6 kg milk. The upper limit of the testday yield at day 287 of this cow is therefore 18.2 plus 6*1.6 = 27.8 kg milk. The realised yield is far beyond this upper limit and therefore this yield is very likely an erroneous

record in the database. Therefore this testday is not used in the evaluation. The number of daily yields in the NL-TDM is over 110 million and one can expect 32 daily yields with a daily yield above the predicted yield plus 6 times the standard deviation of the difference between realised and predicted yield. In reality there are over 13,000 testdays beyond this limit and these are all excluded from the genetic evaluation. It means that 32 testdays are removed where they should not have been. Unfortunately it can not be determined which of the 13.000 testdays are correct and which ones are not and that is why all of them are removed. The likelihood of an error in these testdays is over 400 times larger than the likelihood of no error. The quality of the breeding values increases when these testdays are removed.

There are no requirements on the number of test days in a single lactation, lactations with one test day can also be included. Also, it is not necessary for a cow to have testdays of the heifer lactation included. Testdays from cows without the heifer lactation (e.g. imported cows, cows that calved to early as a heifer) are used in the NL-TDM as well ensuring that these cows get a cow-index as well.

Reliable pedigree data
An important aspect of the animal model is that the family relations between animals are included in the calculation of the breeding values. Both the previous generation of the animal (parents) as well as the generation after the animal (offspring) is taken into account.
The full official descent of an animal is included in the NL-TDM. In the end each pedigree will end up with parents, which are unknown. These unknown parents will be grouped and the average hereditary qualities of this group will become the predictor for their offspring.
The groups will be made up in a way that the parents with expected equal hereditary qualities will be placed in the same group (refer to the section 'Phantom groups'). After checking all ancestors then all animals will be examined whether they are directly useful for the animal model, in other words, whether an animal really adds information to the system. Animals, which do not add information to the system, must meet all the requirements below:
1. no daily productions in the NL-TDM;
2. no known parents;
3. only 1 offspring.
These animals will be considered as unknown in the NL-TDM and will be replaced by a phantom group.

Because the livestock industry does not only select animals within their own breed, but also makes use of animals from other breeds, there are many genetic (family) relations between various breeds. For example, the use of Holstein Friesians in the Dutch Friesian breed and in the MRIJ population. The many genetic relations between breeds makes it possible to calculate the breeding values for various breeds simultaneously, which is performed in the NL-TDM.

Phantom groups
When a parent is unknown a so-called "phantom parent" will replace this parent. Phantom parents can be grouped in phantom groups or genetic groups. Such a phantom group provides a kind of substitute genetic value of an unknown parent. The genetic value of such a group is determined by all animals, which are connected to this specific group. So, it is essential to put animals with most likely the same genetic potential all together in one group. Circumstances, which can cause a difference in genetic potential and because of this are essential for the definition of the phantom groups, are:

1. Selection path
The selection path is subdivided into the following six groups (I through VI):
- for cattle with one unknown parent:
  I.   cows with an unknown sire
  II. cows with an unknown dam
  III. bulls with an unknown sire

IV. bulls with an unknown dam
- for cattle with two unknown parents:
  V. cows with two unknown parents
  VI. bulls with two unknown parents

2. Breed
A separate group will be made up for each breed. In practice this means that there are approximately 30 various breed groups.
In case of a crossbred animal, this animal will be classified in the breed with the highest blood share. The following two situations occur in case both blood shares are equal:
- for 50%/50% FH/HF-breeds and 50%/50% MRIJ/HF-breeds, there are two separate "breed" groups; these animals will not be linked to one of the parent breeds;
- for the remaining 50%/50%-breeds: the animal will be classified into one of the parent breeds based on the breeding goal of the crossbred animal. There are three breeding goals: milk, dual purpose and beef. The breeding goal determines the major breed; beef before dual purpose before milk. If both breeds have the same breeding goal, the first breed is considered the major breed.

3. Country of origin
Each country has a characteristic genetic level for its breeds, this way groups can be classified in the country of origin.

4. Year of birth
Each year of birth forms a group. Cattle born before 1950 are linked to the year of birth 1950.

A phantom group is made up by each combination of selection path, breed and year of birth. A maximum of k*l*m*n phantom groups can be formed by "k" (=6) groups for selection paths, "l" groups for breeds, "m" groups for countries and "n" groups for years of birth.

The minimum number of animals (parents) per phantom group is 40. Phantom groups will be combined in case the number of 40 is not reached. Only years of birth within the selection path *breed*-country combination will be put together in one group. A combination per year of birth will be made until the number of 40 is reached or when at the most 10 years of birth are combined together. In case the number of 20 animals is not reached after the combination of 10 years of birth, then a combination of the phantom group will be made with all other selection paths, countries and years of birth within the breed. When a breed is so small and contains less than 20 animals, then the phantom group will be added to the remaining group. This remaining group will be made up of various phantom groups, which do not contain enough animals to be able to make a reliable estimation. There are three remaining groups, by production goals: milk breed, double purpose and meat.

The influence of the phantom group estimation on the cow-index and bull-index declines more and more as the phantom group is generations removed from the specific animal and/or as the cow or bull gets more information by offspring and/or characteristic lactation(s).

The statistical model
The target of a model is to describe the daily production of a cow as accurate as possible using relevant influences. The final target of the model in the breeding value estimation is to correct the daily production for non-genetic influences. This way it is possible to make an accurate estimation of the share of genetic qualities in the performed daily production.

A daily production is, on one hand, corrected for non-genetic effects, which exert influence on the level of production and, on the other hand, for non-genetic influences, which exert influence on the variation of the production. First of all an explanation of the statistic model, which corrects the

effects which exerts influence on the level, will be given, and after that an explanation of the model, which corrects the differences in variation will be given.

The statistic model for analysing the daily production is as follows:

$$y_{ijklmnopqrst} =$$
$$HTD_j + DIM \times PAR_k + PAYS\_L_l + PAYS\_C_m + PREG \times PAR_n + HET \times PAR_o + REC \times PAR_p +$$
$$DRYxcDIM_q + animal_r + perm_r + herd_s + res_{ijklmnopqrst}$$

in which:

$y_{ijklmnopqrst}$	:	production of trait i (kg milk, kg fat, kg protein or kg lactose);
HTD_j	:	herd-test date j;
$DIMxPAR_k$	:	parity x day in milk k;
$PAYS\_L_l$	:	parity x age at calving x year x season of calving l;
$PAYS\_C_m$	:	parity x age at calving x year x season of calving x lactation stage m;
$PREGxPAR_n$	:	parity x stadium gestation n;
$HETxPAR_o$	:	parity x class of heterosis o;
$RECxPAR_p$	:	parity x class of recombination p;
$DRYxcDIM_q$	:	class of number of days dry x lactation stadium q;
$animal_r$	:	additive genetic effect (or breeding value) of cow r;
$perm_r$	:	permanent environmental effect of cow r;
$herd_s$	:	herd x year of test s;
$res_{ijklmnopqrst}$	:	residual term of $y_{ijklmnopqrst}$, which is not explained by the model.

Lactation curve
The average lactation curve of the entire population is modelled with the effect of DIMxPAR. This effect represents the average production on each day between (and including) day 5 and day 335 in parity 1 to 5. PAYS_L models the differences in production level between cows, which differ in age and year-season of calving from one another. This effect cannot model the difference in the course of the production curve; the curves differ only in level from one another. The effect PAYS_L contains many classes for different ages at calving (for example 26 or 30 months), because it is known that these cows indeed differ in production level from one another, but not in the course of the production curve. With the effect PAYS_C differences in the course of the production curve are modelled. The effect PAYS_C contains many classes for different seasons of calving (for example calving in February or July), because it is known that these cows differ in the course of the production curve from one another.

Figure 1 shows the production curve for kg of milk in lactation 1, such is expected by the model for a cow calving in February, in the age of 26 months at calving. The expected curve for a cow calving at the age of 30 months is also shown. This cow falls in a different class of PAYS_L and that is the reason she shows a different level of production, but shows the same shape of the graph. The third curve in Figure 1 represents the expected curve for a cow calving in July instead of February. This cow falls in a different class for PAYS_C and that is the reason the graph is different both in level as well as in shape from the other two curves.
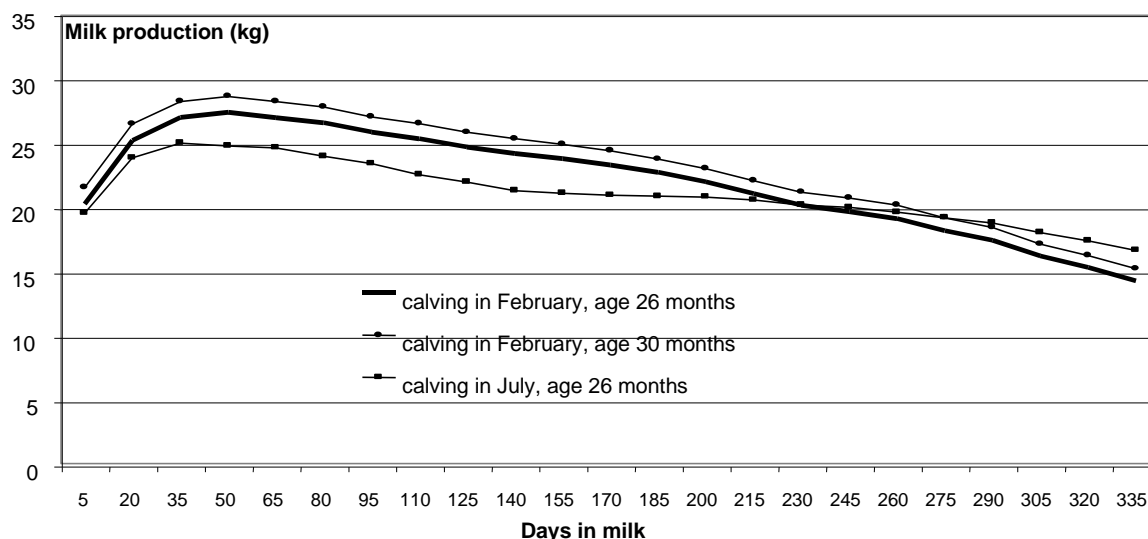
Figure 1. Expected production graph for cows calving in February (July) at an age of 26 (30) Months during the calving

Herd-test date
The herd level on the test day is modelled with the herd test day effect. With this effect daily productions of cows can be compared with other cows in the herd, which have produced on the same test day. No distinction will be made between cows in different parities. They are supposed to have had the same management. Cows of the same herd from different breeds are also compared directly to one another. The possible genetic differences between breeds will be compensated by the additive genetic effect. Herd test days with little observations will not be combined. If there are no other cows present in the same herd then an observation will not contribute in the breeding value of the cow.

In the lactation model each lactation had to be assigned to one specific herd. This is difficult for cows, which move to other herd during the lactation. In the test day model cows are compared with other cows in the same herd on the same test day. Before moving to another herd they will be compared with other cows of the same first herd, after moving they will be compared with other cows of that specific herd they have moved to. The NL-TDM is clearly more flexible than the lactation model.

Stage of gestation
The effect of gestation on the milk production will be corrected using PREGxPAR. It is known that cows in calf have less milk production, especially during the last stadium of the gestation, just before the dry condition.

The differences in production between a cow, which is not in calf, and a cow, which is in calf for 210 days or more, are shown in Table 1.

Table 1. The difference in daily production between a cow, which is not in calf, and a cow, which is in calf for 210 days or more.

Lactation	Milk production (kg)	Fat production (g)	Protein production (g)
Lactation 1	3.53	119.7	126.7
Lactation 2	4.12	154.5	146.7
Lactation 3	4.07	150.2	137.7
Lactation 4	4.21	155.7	140.9
Lactation 5	4.70	174.8	155.0

Days dry x stage of lactation
The days dry x stage of lactation effect can correct the negative effect of a short dry period on the milk production in the following lactation. The length of the dry period is calculated as the number of days between the last sampling from the previous lactation and the following calving date. Research shows that cows with very short periods of dry condition (for example <40 days) have a lower milk production in the following lactation, especially in the beginning of this lactation. It is likely that most of these cows have a short dry period, due to an abortion. Cows with an average or long period of dry condition do not differ in production. Because an abortion can be regarded as a non-genetic effect, it is justified to correct this in the breeding value estimation for milk production. Because of the interaction with the lactation stadium it is possible that corrections can be different for various lactation stadiums.

Heterosis-effect and recombination effect
Heterosis-effect and recombination effect plays a part in the cross breeding of breeds. These are genetic effects, which will not be passed on to offspring. Research shows that these effects must be corrected.

The size of the heterosis is defined as the difference in level of the trait in the cross breeding with the average of the parent breeds. Recombination is the loss of, in most cases, the positive effect of heterosis and occurs when the crossbred product, obtained earlier, is crossed back with one of the parent breeds.

The heterosis effect (HET) of two breeds can be calculated using the following formula:

$$HET = [p_s(1-p_d) + p_d(1-p_s)]$$

in which:

p_s = breed blood part in the bull
p_d = breed blood part in the cow

The formula for recombination (REC) is as follows:

$$REC = [p_s(1-p_s) + p_d(1-p_d)]$$

When an animal is bred from three different breeds then the number of the effects of heterosis and recombination will increase.

An example of the calculation of the heterosis-effect and recombination effect is: the mating of a sire with 75% HF and 25% FH with a dam with 50% MRIJ and 50% HF. The offspring will have the following heterosis-effects:

	Sire	
Dam	HF 75%	FH 25%
MRIJ 50%	37.5%[1]	12.5%
HF 50%	(none)	12.5%

[1] Explanation of the table: the combination of 50% MRIJ with 75% HF results in a heterosis-effect of 50% * 75% = 37.5%.

The total heterosis-effect is:
HET = 37.5% $h_d^{HF/MRIJ}$ + 12.5% $h_d^{HF/FH}$ + 12.5% $h_d^{FH/MRIJ}$
     = 62.5%

The recombination effects of this example are as follows:

Sire	HF 75%	FH 25%
HF 75%	(none)	18.75%[1]
FH 25%	18.75%	(none)
Dam	MRIJ 50%	HF 50%
MRIJ 50%	(none)	25%
HF 50%	25%	(none)

[1]   Explanation of the table: the combination of 75% HF with 25% HF results in a recombination effect of 75% * 25% = 18,75%.

The total recombination effect is:
rec = 18,75% $h_r^{HF/MRIJ}$ + 25% $h_r^{HF/FH}$ = 43.75%

The same correction factors (refer to Table 2) are used for all cross breeding combinations. The corrections are different for lactation 1 to 5, but the same correction is performed on each day within the lactation. Refer to Table 3 for a number of examples of crossing in of breed B in breed A with the corrections for heterosis and combination, which are performed in the lactation of the crossbred animals. In case of the crossbreeding A*B, 0.71 kg will be cut from the milk production in lactation 1 on each test day. This means approximately 214 kg of milk in lactation 1.

Animal effects
There are two kinds of animal-related effects in the model: the additive genetic effect and the permanent environmental effect. The additive genetic effect models the genetic hereditary qualities of an animal on each day in lactation 1 to 5. In this context additive means that these hereditary qualities can be passed on to offspring. The permanent environmental effect models the part of the production graph of a cow, which cannot be explained by both the fixed effects (HTD, DIMxPAR, PAYS_L, PAYS_C, PREGxPAR, HETxPAR, RECxPAR and DRYxcDIM) as well as the additive genetic effect. For example, if a cow has had a disease during her breeding, then this can have a negative influence on her future production. However, the fixed effects do not explain this case and it is also not a genetic effect, because this cannot be passed on to an offspring. The lower

Table 2. Correction factors for heterosis and recombination for kg milk, g fat, g protein and g lactose.

Heterosis					
Lactation	1	2	3	4	5
Milk (kg)	0.709	0.780	0.804	0.846	0.888
Fat (g)	35.4	39.0	40.4	40.3	41.3
Protein (g)	25.7	29.5	30.3	31.4	32.3
Lactose (g)	45.2	48.9	46.7	54.7	50.7
Recombination					
Lactation	1	2	3	4	5
Milk (kg)	-0.201	-0.200	-0.215	-0.254	-0.323
Fat (g)	-9.2	-9.7	-12.7	-13.0	-16.3
Protein (g)	-6.9	-7.5	-7.8	-8.8	-10.9
Lactose (g)	-17.3	-28.9	-21.1	-38.5	-45.2

Table 3. Some examples of crossing in of breed B in breed A with the corrections for heterosis and combination, which are performed in the lactation of the crossbred animals. (an A*A-animal has a sire belonging to breed A and a dam belonging to breed A). The examples refer to kg milk in lactation 1

	Heterosis %	Recombination %	Heterosis x 0.709 kg	Recombination x -0.201 kg	Totale correction
A*A	0	0	0.00	0.00	0.00 kg
A*B	100	0	0.71	0.00	0.71 kg
B*(A*B)	50	25	0.35	-0.05	0.30 kg
(A*B) *(A*B)	50	50	0.35	-0.10	0.25 kg

production can partly be compensated by the permanent environmental effect and needs not result in a much lower breeding value. In which extent the breeding value becomes lower depends on the heritability (in case of a high heritability the individual production of a cow has more influence on her breeding value) and the available quantity of information of the members of the family (if a cow does not have any offspring then, to a large extent, the lower production will be in the permanent environment and not in the breeding value).

The additive genetic effect and the permanent environmental effect are random effects, which means that de quantity of available information of an animal can be taken into account. If there is little information on an animal (not many offspring and too little test day productions), then the additive genetic effect will not much differ from the parent average and the permanent environmental effect will not much differ from 0.

Herd specific production curves
The effects *animal*, *perm* and *herd* are random regression effects. This means that the *animal*, *perm* and *herd* effect are not modelled with a single number but with a curve that ranges from day 5 to 335 and for lactation 1 to 5. More information about random regression can be found elsewhere in this document. The *herd* effect results in curves for every herd x year of test. These curves are calculated from the milk production data of all cows in a herd within one calendar year. The herd specific curves are used to correct for the effect of herd management of production circumstances on the production curve. It is likely that herd with for example flat feeding systems may have a ration that is relatively poor for fresh cows and rich for cows later in lactation. These effects are not genetic, so they must be accounted for. The herd specific curves are included as random effects to avoid problems with records from small herds. The herd-testdate effect in the NL-TDM models the mean production on the herd, whereas the herd curves model the shape of the production curve.

Random regression
The additive genetic effect and the permanent environmental effect are modelled by means of a random regression function. That's the reason the NL-TDM is called a random regression test day model. In this case the regression function is a mathematical function, which describes the additive genetic effect or the permanent environmental effect on the daily production on each day between day 5 and day 335 in lactations 1 to 5. These effects need not to be the same on each day in each lactation. So, it is possible that, for example, animals are genetically good in the beginning of the lactation, but are genetically bad in the end of the lactation. Or when an animal is genetically much better in lactation 3 than in lactation 1. So, it possible to calculate the hereditary qualities for persistency within the lactation and over the lactations (rate of maturity) using the breeding values for each day in each lactation.

A regression function for a single lactation can be as follows:

$$y_r(DIM) = z_0 \times a_{r0} + z_1 \times a_{r1} + z_2 \times a_{r2} + z_3 \times a_{r3}$$

in which:
$y_r(DIM)$: additive genetic effect or permanent environmental effect of an animal r for daily production on *DIM*,
z_i : regression coefficient i. The regression coefficients are dependent on *DIM*.
a_{ri} : solution of an animal r for the regression coefficient i;
DIM : day after calving

An example of a regression function for one lactation: $z_0 = 1$, $z_1 = x$, $z_2 = x^2$, $z_3 = x^3$, in which $x = 2(DIM-5)/(420-5)-1$ and DIM is a number between 5 and 420. So x is a number between −1 and 1. The additive genetic effect or the permanent environmental effect on DIM=38 can be calculated as follows:

$$x = 2*(46 - 5)/(420 - 5) -1 = -0{,}80$$
$$y_r(38) = a_{r0}*(1.00) + a_{r1}*(-0.80) + a_{r2}*(-0.80)^2 + a_{r3}*(-0.80)^3$$
$$= a_{r0}*(1.00) + a_{r1}*(-0.80) + a_{r2}*(0.64) + a_{r3}*(-0.52)$$

Suppose that the solutions of an animal *r* are equal to a_{r0}=+1.50, a_{r1}=-0.50, a_{r2}=-0.10, and a_{r3}=0.05. Then $y_r(38)$ can be calculated:

$$y_r(38) = (1.50)*(1.00) + (-0.50)*(-0.80) + (-0.10)*(0.64) + (0.05)*(-0.52)$$
$$= 1.5 + 0.4 + -0.064 + -0.0256$$
$$\approx 1.8 \text{ kg milk}$$

The here above mentioned regression function has 4 regression coefficients (z). Each animal has a solution for each regression coefficient, in other words 4 solutions per animal (a_r). Actually the solutions for the additive genetic effect are the breeding values belonging to the regression coefficients. Animals with a high breeding value for the first regression coefficient will have a high y_r, regardless the value of *DIM*. So, these animals will also have a high breeding value for 305-daily production. The second regression coefficient is low at the beginning of the lactation (z_1=-1) and high at the end (z_1=1). This means that animals which have a high breeding value for the second regression coefficient will have a high breeding value at the end of the lactation and a low breeding value at the beginning of the lactation. Which means that they are persistent.

There are 5 regression coefficients for the additive genetic effect and 5 for the permanent environmental effect for each trait (kg milk, kg fat, kg protein or kg lactose) and each lactation in the NL-TDM, the reason for this is that 4th order Legendre polynomials are used as regression function. In total there are 4 traits and 5 lactations, so there are 100 additive genetic coefficients and 100 permanent environmental coefficients. The evolution of the production for kg milk, kg fat, kg protein and kg lactose are described using these coefficients.

Breeding values
Examples of additive genetic regression graphs for kg milk are shown in Figure 2. Bull B shown in Figure 2 has a breeding value of approximately +8 kg milk in the middle of lactation 1. This means that, genetically, bull B is 8 kg better than an animal with a breeding value of 0 kg in that part of lactation 1.

Figure 2. Breeding values for daily production of milk (kg) of 6 bulls in 3 lactations
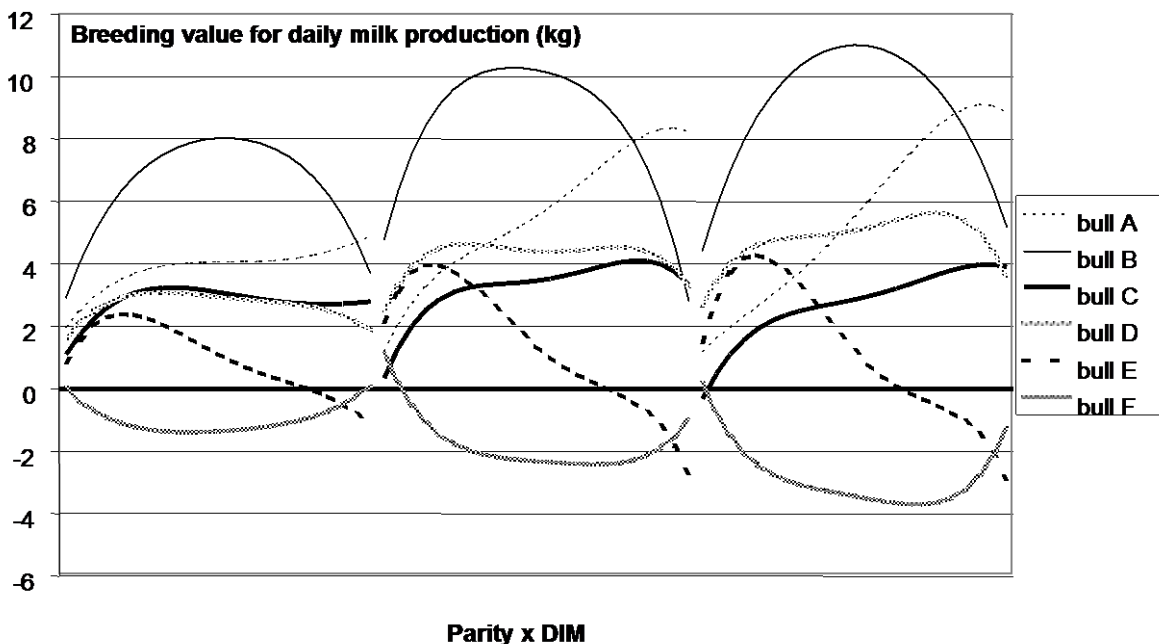
For this reason a female offspring of bull B will produce approximately 4 kg more milk on that specific day compared to an offspring of a bull with a breeding value of 0 kg. The breeding value for 305-day production is calculated by summing all breeding values of day 5 through day 305. This is the surface area under the curve. It clear that bull B has the highest breeding value for 305-daily production (+2000, +2700 en +2800 in lactation 1 to 5) and bull F has the lowest (–300, -500 en –900 respectively).

Bull A and E both have about the same breeding value at the beginning of the lactation, but during the course of the lactation bull A becomes better and bull E gets worse. So bull A has a good persistency and bull E a bad persistency. At the end of lactation 2 bull A is approximately 10 kg of milk better than bull E. The daughters of bull A will have an average production of approximately 5 kg more milk at the end of lactation 2.

Bull C and D both have about the same breeding value at the beginning of lactation 1, but in lactation 2 and 3 the breeding value of bull D becomes higher, while the breeding value of bull C stays at the same level or even drops. This means that bull D has a good rate of maturity, bull C has a somewhat worse rate of maturity. The breeding value for 305-daily production in lactation 3 of bull D is approximately 700 kg more milk than the breeding value of bull C.

Derived breeding values
Breeding values, which are derived in the NL-TDM, are:
1. 305-day production milk in lactation 1 to 5
2. 305-day production milk (overall)
3. 305-day production fat in lactation 1 to 5
4. 305-day production fat (overall)
5. 305-day production protein in lactation 1 to 5
6. 305-day production protein (overall)
7. 305-day production lactose in lactation 1 to 5
8. 305-day production lactose (overall)
9. 305-day production Inet in lactation 1 to 5
10. 305-day production Inet (overall)
11. persistency of fat plus protein yield in lactation 1 to 5
12. persistency of fat plus protein yield (overall)
13. rate of maturity for Inet

The overall breeding values for 305-daily production and persistency are calculated as follows:

$$BV_{overalll} = 0{,}32 \times BV_1 + 0{,}25 \times BV_2 + 0{,}20 \times BV_3 + 0{,}14 \times BV_4 + 0{,}09 \times BV_5$$

in which:

BV_i : breeding value for 305-daily production or persistency in lactation i (= 1…5).

The weight factors are primarily based on the distribution of cows in the Netherlands over lactations 1 to 5. Furthermore, the proceeds from lactation 2 to 5 are discounted for the loss of interest due to the fact that a longer waiting period for these proceeds is needed. Beside this an additional weight is inserted in lactation 3, 4 and 5, because these lactations are stronger related with the production in lactation 6 and higher (refer to Table 4).

Table 4. Background information on the factors for lactations 1 to 5 in the overall breeding value. This information is based on the distribution of parities on all companies in the Netherlands (February 2001), a loss of interest and the genetic relations with lactation 4 and higher

Parity	Frequency (number of cows)	Frequency (%cows)	Factor for lactations 1 to 5 based on		
			Frequency	Frequency + Loss of interest	Frequency + Loss of interest + Relation with 6-18
lactation 1	320,078	30.2	0.33	0.35	0.32
lactation 2	254,284	24.0	0.26	0.27	0.25
lactation 3	191,096	18.0	0.20	0.19	0.20
lactation 4	127,649	12.1	0.13	0.12	0.14
lactation 5	77,026	7.3	0.08	0.07	0.09
lactation 6-18	88,668	8.4	geen[1]	geen	geen

1 No breeding values available for lactation 6 and higher. These cannot be granted a weighing.

The variation of the breeding values of lactations 1 to 5 must be taken into account in order to determine how much weight breeding values of lactations 1 to 5 have in the overall breeding value. The variation of the breeding values of lactation 3 is greater than the variation of lactation 1 (refer to Figure 2). Because of this the weighing of lactation 3 is higher than the factor 0.26. The final breeding values for lactations 1 to 5 in the overall breeding value are 34%, 33% en 33% respectively. Therefore, all lactations have almost the same weighing values in the overall breeding value and have almost the same influence in the overall breeding value.

The breeding values in the lactation model are expressed on the heifer level. This means that the average of the daughters of a bull with a breeding value of +1000 kg milk will produce approximately 500 kg more milk *as heifers* compared to the daughters of a bull with a breeding value of 0 kg milk. The difference will increase a little in lactations 2 and 3 (for example up to 600 kg and 650 kg milk), because the variation in these lactations is larger. In the NL-TDM the overall breeding value is a combination of lactations 1 to 5 taking into account the distribution of the first 5 parities of cows in Dutch herds. An overall breeding value of +1000 kg milk in the NL-TDM means that the average production in the first 5 lactations of daughters is 500 kg higher than the average production in the first 5 lactations of daughters of a bull with a breeding value of 0 kg milk.

Persistency and rate of maturity
Persistency indicates whether a cow has a flat production curve or a curve with high peak production and with a relatively sharp production fall afterwards. Despite that things are still not quite clear, and it is often said that cows with a high persistency are less susceptible to nutritional disorders and, perhaps as a result of this, are more fertile. This could be caused by relatively low energy needs at the beginning of the lactation. This is the reason that these cows have less negative energy balance.

Due to the relation with the energy balance the breeding value persistency is calculated for grams of fat + protein. The formula for deriving the breeding value from the breeding values for daily production of kg fat and kg is as follows:

$$EBV_{persistency} = \sum_{i=61}^{305}\left(EBV_{fat,i} + EBV_{protein,i}\right) - 245 \times \left(EBV_{fat,60} + EBV_{protein,60}\right),$$

in which

$EBV_{fat,i}$: breeding value for daily production in g fat on day *i*;
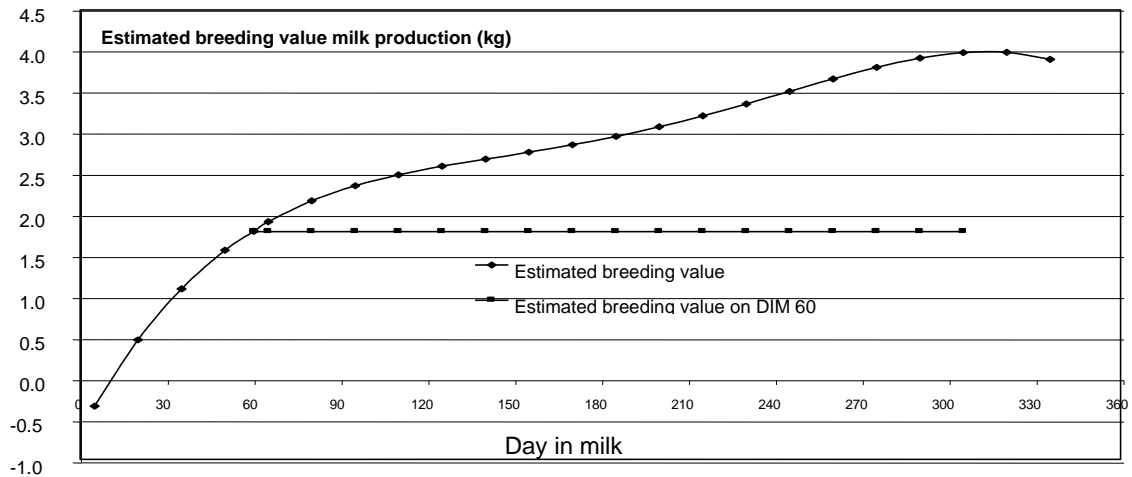Σ : summation for i=61 through 305.

Figure 3. An example of a bull with a good persistency

A bull which is as good in the period after the peak production (day 61 through 305) as on day 60 will be an average bull for persistency. A bull with a good persistency scores more than 0, because the average of the breeding values after day 60 is higher than the breeding value on day 60 (refer to Figure 3).

The breeding value for rate of maturity indicates the persistency over lactations. Rate of maturity is calculated as follows in the NL-TDM:

$$EBV_{rateofmaturity} = EBV_{Inet,lactation3} - factor \times EBV_{Inet,lactation1},$$

In which:

$EBV_{Inet,lactation1}$: Breeding value for Inet on 305-day level in lactation 1;
factor : factor to make sure that no correlation occurs between the breeding values for 305-day production and rate of maturity. In the NL-TDM this *factor*=1,3.

This way the breeding value for rate of maturity indicates whether the hereditary qualities for production in lactation 3 are higher than the hereditary qualities for production in lactation 1. Whether the hereditary qualities for production in lactation 2 are high or low does not have any impact on the breeding value rate of maturity. The choice was made to base rate of maturity on 1st and 3rd lactations because 1) this breeding values is available sooner than breeding values for 4th and 5th lactation amd 2) the correlations between lactations 3, 4 and 5 are so strong a rate of maturity breeding values based on 4th or 5th lactations would be virtually identical to the breeding value based on 3rd lactation.

Bulls with only 1st calf daughters will obtain no information on rate of maturity from these daughters. The breeding value for rate of maturity of these bulls is merely determined by the parents, which often already have a high reliability on rate of maturity. The breeding values for 305-day production in lactations 2 to 5 are calculated from the performances of the daughters and the parents in lactation 1 and the rate of maturity of the parents. If the daughters are in the second lactation, then they will provide information on rate of maturity to their sire, because the production in lactation 2 to 5 is quite strongly correlated. If the daughters are born in the third lactation, then the reliability will continue to grow.

In the lactation model, a bull's breeding value, if he is good for rate of maturity, continues to increase as his daughters get older. The breeding value dropped strongly at the moment the second crop daughters of the bull started to milk, because the daughters started quite calmly in

lactation 1 and the good rate of maturity was not taken into account. The rate of maturity is indeed taken into account in the NL-TDM. If the second crop daughters start to milk, then this bull already has a high reliability for all lactations and rate of maturity. The young heifers from the second crop will have little influence on the breeding value of lactations 2 and 3 in the first place. The overall breeding value will only change if the second crop daughters are much better or much worse in the first lactation then the first crop daughters in the first lactation.

The factor in the calculation of rate of maturity is meant to make sure that there is no correlation between the overall breeding value for 305-day-production and the rate of maturity. Without this factor the correlation is approximately 0.7. Which means that nearly all bulls, which have a high overall breeding value for 305-day production, also have a high breeding value for rate of maturity. The factor is calculated as follows:

$$factor = \frac{\sigma_{Inet,lactation3} \times rG_{Inet,lactation3-Inet,overall}}{\sigma_{Inet,lactation1} \times rG_{Inet,lactation1-Inet,overall}}$$

in which:

$\sigma_{Inet,lactationx}$: genetic standard deviation of Inet in lactation x;

$rG_{Inet,lactationx-Inet,overall}$: genetic correlation between Inet in lactation x and overall Inet

In the NL-TDM this *factor*=1.3.

Distribution of cows over lactations, the loss of interest and the relation of the first 5 lactations with higher lactations are already used in the calculation of the weighting factors. Therefore two bulls with the same overall breeding value are equally good, regardless of their breeding values for rate of maturity. So it is important that rate of maturity is not used as a selection criterion. In other words, the economic value of rate of maturity is zero.
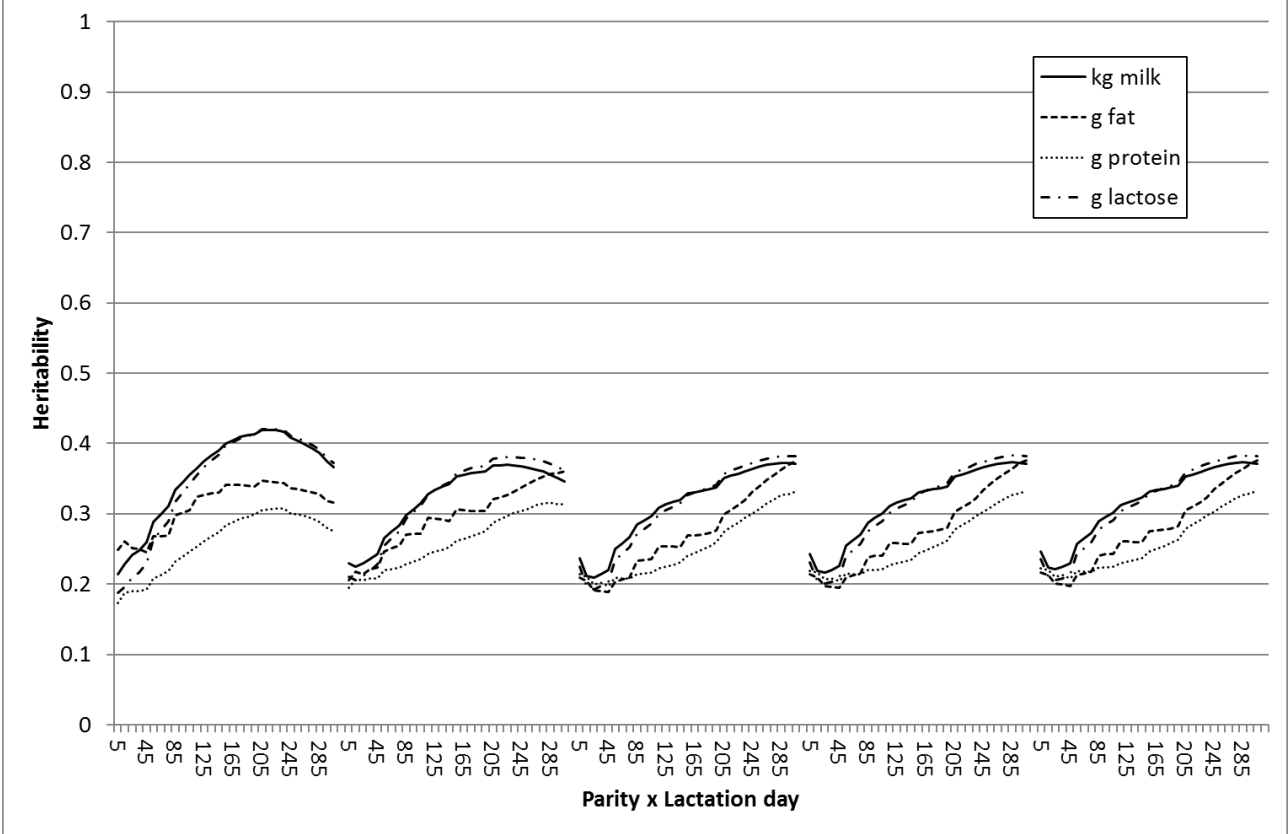

Figure 4. Heritability for kg milk, fat, protein and lactose in parities 1 to 5

Breeding values for persistency and rate of maturity will be expressed as relative breeding value on a Black&White cow basis. This means that the breeding values average to 100 and have a standard deviation of 4 points. The cows that determine the base population are described later in this document. One extra point for EBV persistency represents 5.50 kg of fat plus protein extra between DIM 61 and 305, compared to the fat plus protein production in an average production curve. For lactation 1 to 5, 1 extra point for EBV persistency represents 3.14 kg , 4.60 kg, 5.21 kg, 5.21 kg, and 5.21 kg fat plus protein, respectively.

One extra point for EBV rate of maturity represents € 19.66 higher INET in lactation 3 compared to 1.3 times the INET in lactation 1.

Genetic parameters
Parameters are required for the breeding value estimation of effects, which are regarded as random effects (the additive genetic effect, permanent environmental effect, the herd curves and residual term). These are, for example, the genetic variances, heritabilities and the correlation between various traits. These parameters are estimated on a part of all national data.

Each day between 5 and 420 in lactations 1 to 5 is regarded as a different trait in the NL-TDM. This means that an animal, which is genetically good at the beginning of the lactation, does not have to be good at the end of the lactation or an animal, which is good in lactation 1, does not have to be good in lactation 3. Nevertheless, breeding values in various days and lactations are correlated to one another and the closer the days are to one another the higher the genetic correlation is. Milk, fat, protein and lactose are performed in four independent runs in the NL-TDM, which means that

Table 5. Heritabilities (diagonal) and genetic correlations between lactations 1 to 5 and the overall breeding value for kg milk, kg fat, kg protein and kg lactose.

	Lactation 1	Lactation 2	Lactation 3	Lactation 4	Lactation 5	Overall
Kg milk						
Lactation 1	**0.48**	0.86	0.80	0.79	0.77	0.92
Lactation 2		**0.41**	0.92	0.91	0.89	0.97
Lactation 3			**0.40**	0.98	0.97	0.97
Lactation 4				**0.40**	0.98	0.96
Lactation 5					**0.40**	0.95
Overall	0.92	0.97	0.97	0.96	0.95	**0.51**
Kg fat						
Lactation 1	**0.48**	0.88	0.81	0.79	0.78	0.92
Lactation 2		**0.44**	0.92	0.90	0.89	0.97
Lactation 3			**0.40**	0.98	0.96	0.97
Lactation 4				**0.40**	0.98	0.96
Lactation 5					**0.40**	0.94
Overall	0.92	0.97	0.97	0.96	0.94	**0.52**
Kg protein						
Lactation 1	**0.39**	0.86	0.75	0.74	0.72	0.90
Lactation 2		**0.36**	0.91	0.89	0.87	0.97
Lactation 3			**0.35**	0.98	0.96	0.96
Lactation 4				**0.35**	0.98	0.95
Lactation 5					**0.35**	0.94
Overall	0.90	0.97	0.96	0.95	0.94	**0.44**
Kg lactose						
Lactation 1	**0.47**	0.85	0.80	0.78	0.77	0.91
Lactation 2		**0.42**	0.92	0.91	0.89	0.97
Lactation 3			**0.40**	0.98	0.97	0.97
Lactation 4				**0.40**	0.98	0.96
Lactation 5					**0.40**	0.95
Overall	0.91	0.97	0.97	0.96	0.95	**0.51**

the correlations between milk, fat protein and lactose are not used. Figure 4 shows the heritability for each day in parities 1 to 5 for milk, fat, protein and lactose. The average heritability for daily yield is 37% for milk production, 32% for fat production and 30% for protein production.

Genetic correlations between traits indicate how similar the breeding values for the specific traits are. This also indicates how well the breeding value of the one trait can be predicted from the breeding value of the other trait. Table 5 shows the heritabilities (diagonal) and genetic correlations for 305-day production for kg milk, fat, protein and lactose in various lactations and also the correlations with the overall breeding value. The correlations for kg fat, protein and lactose are almost the same as the correlations for kg milk.
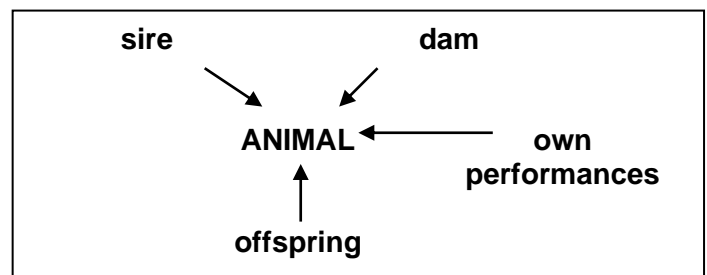
Reliability
Breeding values are estimations of the hereditary qualities. The word "estimation" indicates that there is a certain inaccuracy resting on a breeding value. The reliability of a breeding value indicates the dimension of the difference between the estimated breeding value and the actual hereditary qualities.

The reliability depends on the quantity of the available information of an animal. There are three sources of information:
1. own performance
2. offspring
3. parents

Information on the production of (half) sisters, grandparents, etc. is inserted through the parents, information of granddaughters etc. is inserted through the offspring.

Because each day in each lactation is regarded as genetically different traits, the breeding values for each day have their own reliability. The breeding value for 305-day production in lactation 1 can have a different reliability than the breeding value for 305-day production in lactation 3. If a bull only has 1st parity daughters, then the breeding value for lactation 3 will have a lower reliability than the breeding value for lactation 1. The breeding value for lactation 3 will then, on average, deviate less from the parent average than the breeding value for lactation 1. This does not mean that the breeding value for lactation 3 is exactly the same as the parent average. The 1st parity daughters of a bull already show whether the bull is better than his parent average in lactation 1. This also provides information on the difference with the parent average in lactation 3, because the breeding values of lactations 1 and 3 are correlated (refer to Table 5).

The correlation between the breeding value for lactation 1 and the overall breeding value is 0.94 (refer to Table 5). This means that if a bull only has 1st calf daughters and no other information from parents, then the reliability of the overall breeding value is about: $REL_{overall} = (0.92)^2 \times REL_1 = 0.85 \times REL_1$, in which REL_1 is the reliability of the breeding value for lactation 1. With many daughters, REL_1 will be approximately 100% and $REL_{overall}$ is approximately 85%. In practice $REL_{overall}$ can be higher, because the parents of the bull also provide information on their son's breeding value for lactations 2 to 5.

Figure 5 shows the course in reliability for the breeding value 305-day production of lactations 1 to 5 and the overall breeding value for kg protein of a cow. The cow herself does not have offspring and has a sire with 100% reliability and a dam with three lactations. The reliability at 0 individual test day productions is shown on the left side of the graph. In this case the reliability is equal to the reliability of the parent average, this is (reliability sire + reliability dam) x 0.25. Then the cow gets 3 test days (continually 30 days in a row). After this the cow again gets successively 3 and 4 test days in lactations 1 and 3, 3 and 4 test days in lactations 2 and 3 and 3 and 4 test days in lactation 3.
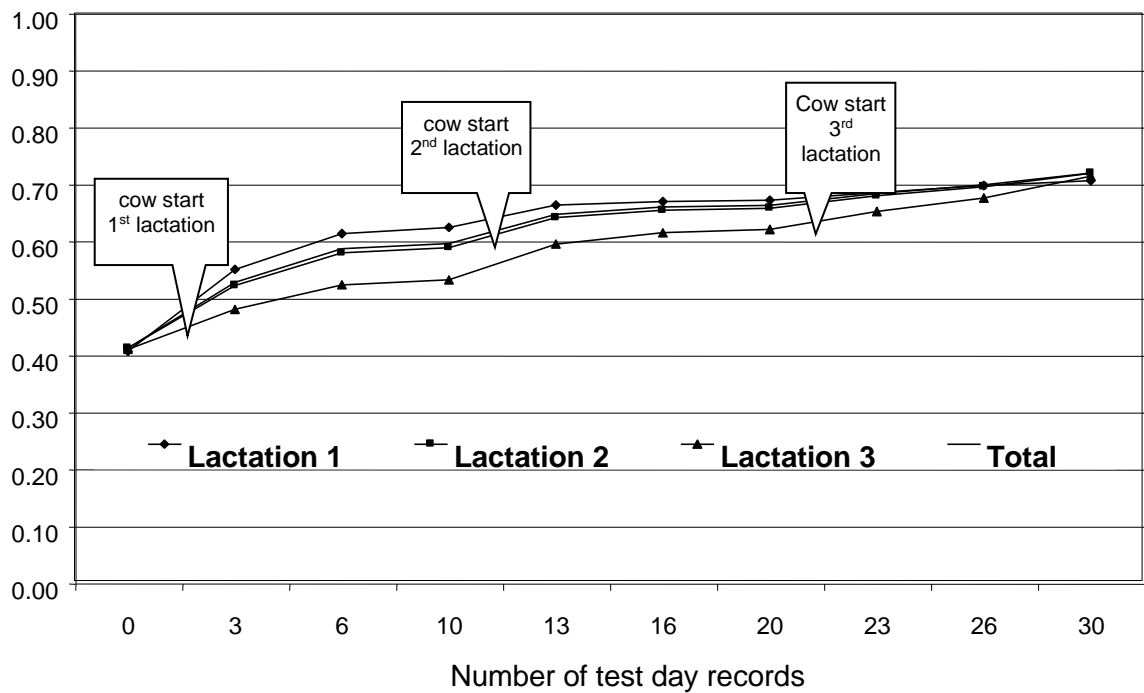
Figure 5. The course of reliability for 305-day-production for kg protein for one cow

The cow shown in Figure 5 has a 60% reliability of the overall breeding value after she has completed one lactation. The reliability of the breeding value for lactations 1 and 3 is 62% and 53% respectively. The reliability of the breeding value will increase to 65% at the moment she start with the second lactation. The reliability of all breeding values will the increase to 70% after he has completed lactation 3.
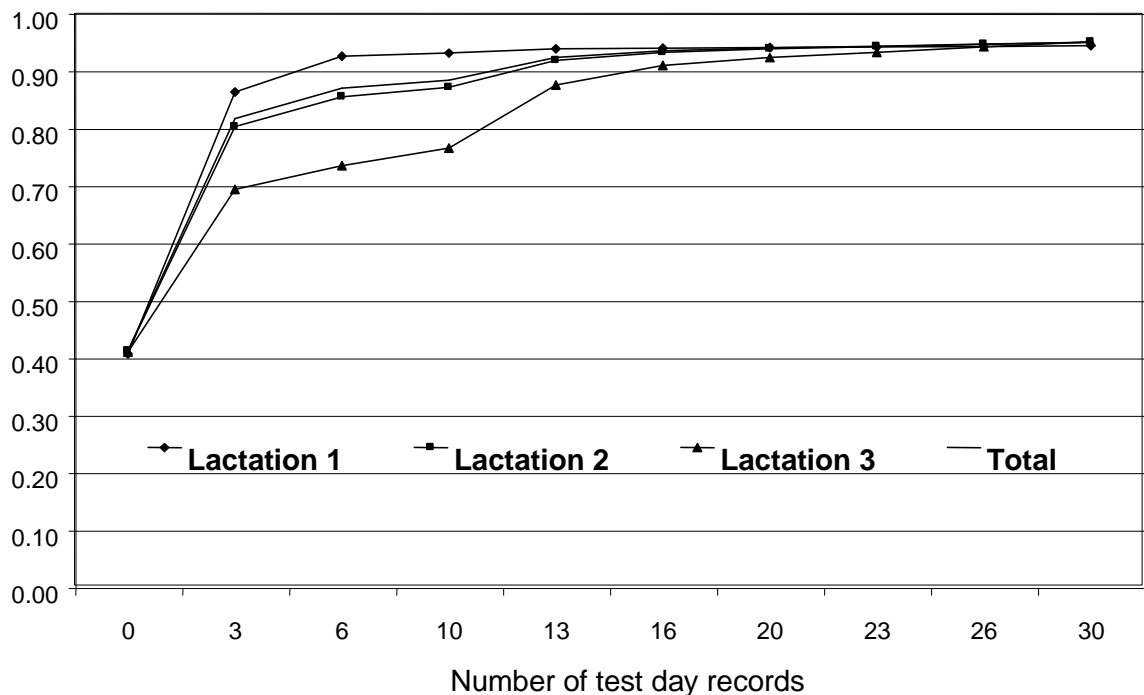

Figure 6. The course of reliability for 305-day-production for kg protein for one bull

The reliability for a bull with 100 daughters, which have the same course of reliability as the cows shown in Figure 3, is shown in Figure 6. The bull has sire with 100% reliability and a dam, which has 3 lactations.

The reliability of the bull shown in Figure 6 increases to 82% of the overall breeding value, at the moment his daughters start to produce. If these daughters are at the end of the first lactation, then the reliability will be 88%. Only after the daughters are in the second or third lactation the reliability will increase to 95% in the end.

Heterogeneity of variance

The differences in variation of the daily production on various herd test days (HTD) and the differences in variation of the daily production of cows of different ages are taken into account in the breeding value estimation. It is clear that, compared to other herds, some herds have more variation in their daily production. This can be caused by the differences in ages and patterns of calving between herds. For example, it is likely that on a herd test day, where only heifers at the end of their lactation are milked, the variation in daily production is lower than on a herd test day, where both heifers at the end of their lactation as well as fresh 3rd parity cows are milked. Another source for the differences in variation between herd test days can lie in the hereditary qualities of the cows. On a herd test day with only MRIJ-cows the variation will be less than on a herd test day with both HF-cows as well as Belgian Blue cows. These two sources of variation have no influence in the correctness of the breeding value estimation.

A third source for variation is the difference in management between herds, for example, forage stock, housing accommodation and the breeding of young cattle. These differences may be the reason that genetic differences are expressed more on one herd than on the other. When this source is not taken into account in the breeding value estimation, then the best cows of the herd with a high variation will have higher breeding values than cows of a herd with a lower variation. The reason for this is that the best cows on a herd with a high variation deviate more from their herd mates.

The correction for heterogeneity of variance in the NL-TDM is performed by multiplying the permanent environmental effect and the residual part of a daily production (this is the production minus the solutions of all fixed effects and the additive genetic effect) by a correction factor, as shown below:

$$residual = y_i - Xb_i - Zu_i$$
$$y_{i+1} = Xb_i + Zu_i + residual \times F_i$$

in which:

y_i	: (corrected) observation in iteration i;
b_i	: solution for fixed effects in iteration i;
u_i	: solution for additive genetic effect in iteration i;
X, Z	: incidence matrices;
F_i	: correction factor for heterogeneous variance in iteration i.

The correction factors and the breeding values are simultaneously calculated. This way the variation caused by the management can accurately be determined, because variation caused by fixed effects (for example, age and lactation stadium) and additive genetic effects are already known. This way of determining the variation leads to an excellent breeding value estimation, which will not be in favour of the animals on herd with a higher variation.

The reference variance must be defined when performing the correction for heterogeneity. The variance of the permanent environmental effect plus the residual part of the observations of the

cows in the black&white basis (Z) is chosen as the reference for the NL-TDM. The cows of this basis are indicated in the section "basis definitions.

To be able to calculate the variation caused by management on a HTD, one must first calculate the permanent environmental effect plus the residual part of each observation, in other words the production minus the solutions of all fixed effects and additive genetic effect. Then the result of this must be divided by the reference standard deviation of the appropriate parity and DIM (refer to Figure 7). The variation of the standardised permanent environment plus the residual parts of the observations on the HTD is equal to 1, on a HTD with a desired variation.

$$residual_{ijk} = y_{ijk} - Xb_{ijk} - Zu_{ijk}$$

$$residual_{ijk}^* = \frac{residual_{ijk}}{\sigma_{par,DIM}}$$

$$\sigma_{ij} = \frac{\sum_{j}\left(residual_{ij.}^2\right) - \frac{1}{n_j}\left(\sum_{j} residual_{ij.}\right)^2}{n_j - 1}$$

in which:

y_{ijk}	: (corrected) observation k in iteration i op HTD j;
b_{ijk}	: solution for fixed effects at observation k on HTD j in iteration i;
u_{ijk}	: solution for additive genetic effect at observation k on HTD j in iteration i;
X, Z	: incidence matrices;
$\sigma_{par,DIM}$	: desired variation on parity and DIM of observation k (refer to Figure 7);
n_j	: number of observations on HTD j;
σ_{ij}	: standardized variation of permanent environment plus residual on HTD j in iteration i.

When the variation (σ_{ij}) is less than 1, then additional spreading must be inserted and when the variation is more than 1, then the variation must be reduced. The correction factor of an HTD needed for this, is calculated from the variation of the HTD itself plus a number of other HTD's on the same herd, just before and after the HTD. The latter occurs because estimation on a variation of the HTD is difficult to make at HTD's with relatively little observations.

$$F_{ij} = \exp\left(-\frac{\sum_{k=j-n}^{j+n} w_k \log(\sigma_{ik})}{\sum_{k=j-n}^{j+n} w_k}\right)$$

in which:

Fij	: correction factor for HTD j in iteration i;
σ_{ik}	: standardized variation of permanent environment plus residual on HTD k in iteration i;
w_k	: weighing of HTD k;

$$w_k = (m-1) \times .995^{\Delta t_{j,k}}$$

in which:
m = number of observations on HTD k;
$\Delta t_{j,k}$ = number of days between HTD j and HTD k;

n	: number of earlier / later HTD's used to calculate F_{ij},
	$5 \le n \le 22$, n is at least 5 and is increased until $\Sigma w > 50$.

There is a restriction that in case $\sigma_{ik} > 1$, then F_{ij} must always be less than 1 and vice versa. When this is not satisfied then $F_{ij} = 1$.

The correction for heterogeneous variances between classes of age at calving is performed the same way as for HTD, except for the calculation of F_{ij}. Because there are large numbers of records for each class of age, the correction factor can be calculated $F_{ij} = (\sigma_{ij})^{-1}$.

▪ Use of foreign information in cow-indexes

An important characteristic of an animal model is the joint estimation of cow-indexes and bull-indexes. Most of the times imported cows (live or embryo import) do not have a very large family in the countries that supply data for the NL-TDM. In the foreign country these cows often have more information (testdays, parents, offspring). The foreign information is used in the calculation of cow-indexes in the NL-TDM. Foreign cows or cows with at least one foreign parent have 3 sources of foreign information:

1. Foreign cow-index of the cow itself. The foreign cow-index is converted to the national scale and base with Interbull conversion factors. The converted index is the official index if the foreign cow herself does not have usable testdays in the NL-TDM. Foreign information is not used if she has usable testdays in the NL-TDM. In this case her official index is based on the testdays in the NL-TDM, her parent average and possibly her offspring in the NL-TDM. The parent average of a foreign cow can of course contains foreign information.

2. Foreign cow-index of the dam. Foreign dams with offspring in the NL-TDM have their foreign index converted to the national scale and base with Interbull conversion factors. The converted index is blended in the national index of her female offspring. Converted and national breeding value are blended in the cow-index based on the reliability of both breeding values and their genetic correlation.

3. Interbull breeding values of bulls without an official national breeding value. In the calculation of the cow-indexes the official breeding value of the sire is used. Import bulls, with a few offspring in the NL-TDM, do get a breeding value based on the performance of the offspring. The Interbull breeding value of these bulls is published if this national bull-index is not official yet. In the calculation of the cow-indexes of the offspring the Interbull breeding value is used as well for these bulls.

Foreign cow-indexes of (Red) Holstein cows from Canada, Denmark, France, Germany, Italy and the United States are used in the NL-TDM
Interbull breeding values are available for a large number of countries for the breeds Brown Swiss, (Red) Holstein, Jersey, Montbéliarde and Simmental (Fleckvieh).

▪ Base definitions

Breeding values for the milk production of bulls and cows are published based on the 2020-base. The average breeding value (for each trait) of cows in the base population is set to 0. Breeding values of all animals are expressed this way in relation to their base. Cows born in 2015 determine the base of 2020. There are four different bases: Milk goal Black, Milk goal Red, Dual purpose and Belgian Blue. The definitions of these bases are as follows:

Milk goal Black
Herdbook-registered cows born in 2015 with at least 87.5% HF-blood and up to 12.5% FH-blood and hair colour black pied, with at least one observation in the genetic evaluation.

Milk goal Red

Herdbook-registered cows born in 2015 with at least 87.5% HF-blood and up to 12.5% MRY-blood and hair colour red pied, with at least one observation in the genetic evaluation.

Dual purpose
Herdbook-registered cows born in 2015 with at least 75% MRIJ-blood and 25% or less HF blood, with at least one observation in the genetic evaluation.

Belgian Blue
Herdbook-registered cows born in 2015 with at least 87.5% Belgian Blue-blood, with at least one observation in the genetic evaluation.

Heterogeneity of variance
The base for the correction factor for heterogeneity of variance is determined by HF/FH-cows born in 2010. This basis is applied to all breeds.

The breeding values for persistence and maturity for bulls and cows are presented with a mean of 100 and a standard deviation of 4. The mean is defined by a group of animals that is the base for the breeding values (see above for base definitions). The standard deviation for all bases are defined by the animals forming the base for the Milk goal Black base. The standard deviation of the breeding values from the base animals is calculated followed by standardization of this standard deviation to an average reliability of 80% for the breeding values. Because of this 4 points breeding value corresponds to 0.9 x genetic standard deviation of the concerning trait.

Calculation of % fat, % protein and % lactose

The breeding values for the percentages of fat and protein are calculated from the breeding values for kg milk, kg fat and kg protein using phenotypic productions, as shown below:

$$F_{\%fat} = \frac{F_{kgf} * 100 - F_{kgm} * P_{\%fat}}{F_{kgm} + P_{kgm}}$$

$$F_{\%protein} = \frac{F_{kgp} * 100 - F_{kgm} * P_{\%protein}}{F_{kgm} + P_{kgm}}$$

$$F_{\%lactose} = \frac{F_{kgl} * 100 - F_{kgm} * P_{\%lactose}}{F_{kgm} + P_{kgm}}$$

in which:
   P = average production of the base animals for the given traits;
   F = breeding value: kg milk, kg fat, kg protein or kg lactose, % fat, % protein or % lactose.

Table 6a. Average productions used for calculation of percentage ebv

		kg milk	kg fat	kg protein	kg lactose
Milk goal Black	Parity 1	7577	320	262	353
	Parity 2	8946	377	315	408
	Parity 3	9560	406	333	433
	Parity 4	9801	420	340	442
	Parity 5	9960	426	344	448
	Overall	8841	375	306	404
Milk goal Red	Parity 1	7014	312	250	326
	Parity 2	8239	367	299	375
	Parity 3	8878	398	319	401
	Parity 4	9168	413	328	412
	Parity 5	9348	419	333	419
	Overall	8205	365	293	371

Dual Purpose & Belgian Blue	Parity 1	5572	250	204	261
	Parity 2	6383	285	237	294
	Parity 3	6929	307	256	317
	Parity 4	7232	319	265	329
	Parity 5	7352	320	269	332
	Overall	6379	284	235	297

The breeding values for these percentages can be different for each day in each lactation. The average lactation production of the basic cows is used in the breeding values for the percentages on 305-day-level. The average lactation production is calculated as the sum of the average daily productions between day 5 and day 305 of the base cows. The average lactation productions P_{kgm}, $P_{\%fat}$ and $P_{\%protein}$ for the Black, Red, Dual purpose and Belgian Blue base are shown in Table 6. Overall % breeding values are calculated from the overall mean lactation productions, where the latter is the weighted average of the lactation productions in lactations 1 to 5 using the same factors as in the calculation of the overall breeding value (see above).

Table 6b. Average production content for fact, protein and lactose

		kg milk	% fat	% protein	% lactose
Milk goal Black	Parity 1	7577	4.22	3.46	4.66
	Parity 2	8946	4.21	3.52	4.56
	Parity 3	9560	4.25	3.48	4.53
	Parity 4	9801	4.29	3.47	4.51
	Parity 5	9960	4.28	3.45	4.50
	Overall	8841	4.24	3.46	4.57
Milk goal Red	Parity 1	7014	4.45	3.56	4.65
	Parity 2	8239	4.46	3.63	4.55
	Parity 3	8878	4.48	3.60	4.52
	Parity 4	9168	4.50	3.58	4.49
	Parity 5	9348	4.48	3.56	4.48
	Overall	8205	4.45	3.57	4.52
Dual Purpose & Belgian Blue	Parity 1	5572	4.48	3.66	4.68
	Parity 2	6383	4.46	3.71	4.61
	Parity 3	6929	4.43	3.69	4.57
	Parity 4	7232	4.41	3.66	4.55
	Parity 5	7352	4.35	3.66	4.52
	Overall	6379	4.45	3.69	4.66

Base differences

See chapter 'Bases for breeding values and base differences'.

Publication rules

See chapter 'Publication rules sires'.