Genetic Evaluation Systems for Sheep

Guide of the Genetic Calculations and Correlations of the GenOvis Program

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1 Introduction

This document explains, in general terms, the factors considered in genetic evaluation systems for sheep in Canada. There is one system for growth which includes lamb survival, birthweight, 50-d weight, 100-d weight, ultrasound loin, and ultrasound fat. Another system is for ewe reproduction traits including age at first parity, number born and number weaned from the first parity, the number of days between lambings, and number born and weaned from later parities. First parity and later parity traits have a genetic correlation of only 0.7, so that they can be considered as different traits. Both systems analyze all traits simultaneously, which means all genetic and non-genetic correlations among the traits are taken into account.

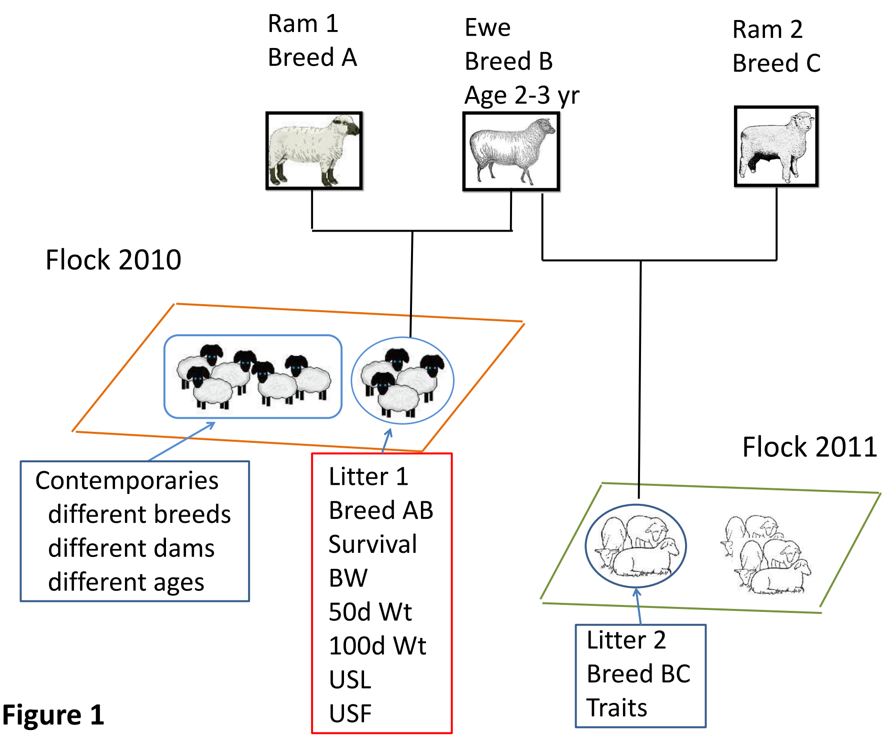


Figure 1

Best linear unbiased prediction (BLUP) methods are used which constructs a set of equations (millions of equations) and obtains solutions for every animal and trait. Of importance are the factors that are considered (which are also estimated during the solution of the BLUP equations).

2 Growth System

Consider Figure 1. The growth system focuses on the individual lamb, and the traits observed on each. A lamb has a ram and a ewe as parents. Parents can be of the same or different breeds, and the lamb would be purebred or crossbred. The system accounts for this possibility. There are many breeds, but there are currently 15 breed groups that are used (because many breeds are small in population size, and there are many types of crossbreds).

The current breed groups are as follows:

Table 1. Breed Groups For Genetic Evaluation Purposes

Group	Description
1	Arcott-Rideau
2	Dorset, polled and horned
3	Suffolk
4	Polypay
5	Arcott-Canadian
6	Hampshire
7	North Country Cheviot
8	Romanov
9	Unknown Crosses
10	Small meat breeds
11	Medium meat breeds
12	Large meat breeds
13	Prolific/Dairy breeds
14	Wool/Dual breeds
15	Primitive breeds

Litters. A lamb could have litter mates that would interact and affect each others growth. Thus, the system accounts for litter effects.

Year-Month-Breed of Lamb Group. Lambs are born in a particular year and month and this has an effect on growth. Year-Month subclasses are estimated within each breed of lamb group.

Flock-Year-Management Group. This factor is also known as a contemporary group. This factor includes all of the lambs born within the same flock, in the same year, and raised in the same management group. The lambs are assumed to have experienced the same feeding and management practices, as well as weather during their growth phase within a contemporary group. This effect includes province and the particular location within a province and county.

Type of Birth-Breed of Lamb Group. Lambs may be born as triplets, but raised as a single or twin, or could be born a single and raised as a twin. The effects are estimated within each breed of lamb group.

Sex of lamb-Age of Ewe-Breed of Ewe Group. Growth differs between male and female lambs as they age. Ewes that are older have lambs that tend to grow better than for younger ewes.

Age of lamb when weighed. Lambs are almost never weighed at exactly 50 and 100 days of age, so weights are adjusted to 50-d and to 100-d assuming that growth is linear during these ages. Ultrasound measures are also adjusted for age.

Maternal Genetic Effects. Each ewe provides a maternal environment for its lambs. This is observed each time a ewe has a litter. Thus, in Fig 1, the ewe provides a maternal environment for the litter in 2010, and for the litter in 2011. The maternal effect is strongest at birth and 50-d, and almost disappears by 100-d. The ewe either gives more milk, or better quality milk (with antibodies), or better mothering ability.

Direct Genetic Effects. These are the genes for growth and survival that are transmitted directly from parents to offspring. Through the pedigree information, lambs are linked to all ancestors that appear in the pedigree database and they contribute to the genetic evaluations of those ancestors. Conversely, the ancestors contribute to the genetic evaluations of the most recent group of lambs. The pedigree files go back to 1986 for Canadian sheep.

All Breeds. Many flocks contain more than one breed of sheep. The system analyzes all lambs regardless of breed, and as indicated above, breed effects of lambs and ewes are considered in some of the factors.

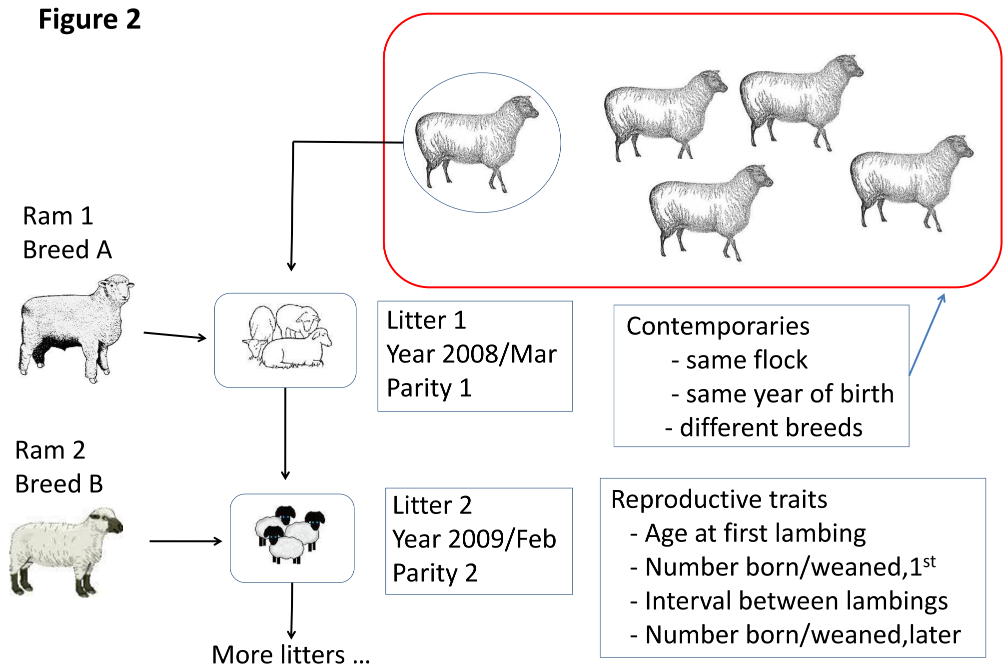
Heterosis. Heterosis effects of crossbreds are ignored in this system because previous estimates of heterosis in sheep (from other countries) have shown heterosis for growth to have small effects. To account for heterosis the breeds involved in every crossbred animal need to be known, and for Canadian data, crossbreds are typically labelled in the data as **XX**, which gives no information about the contributing breeds.

3 Reproduction System

Figure 2 shows the factors involved in ewe reproduction. Reproduction focuses on the ewe. Not shown in the figure are the parents of the ewe which can be of the same or different breeds. The same 15 breed groups are used as for the growth traits.

Reproductive traits are organized by parity number with first versus later parities. Number born and weaned in first parity is not genetically the same as number born and weaned in second and later parities because the genetic correlations are significantly less than unity (but still pretty high). Thus, ewes could rank differently depending on their parity number.

Figure 2



Contemporary Groups. Contemporary groups for reproductive traits are formed on the basis of females that were born within the same flock and same year. Thus, they are roughly the same age and have experienced the same management conditions together, and their litters would be roughly in the same years.

Year-Month of Lambing-Breed of Ewe Group. Even though ewes are contemporaries, their litters could occur in different months. The effects may differ depending on the breed of the ewe, because litter sizes are inherently different. Thus, ewes should be compared to others of the same breed. These are comparisons of ewes across flocks.

Parity-Age of Ewe-Breed of Ewe. Means for each of the reproductive traits are different for each parity, and for age of ewe (in days) within a parity. These are estimated within breed of ewe.

Sire of Litter. The ewe will likely be mated to different rams over the course of its life in the flock. The rams have their own reproductive genes and effects for number born. Rams can be of different breeds.

Genetic Effect of Ewe. These are the genes for reproduction that are transmitted directly from parents to offspring. Through the pedigree information, ewes are linked to all ancestors that appear in the pedigree database and they contribute to the genetic evaluations of those ancestors. Conversely, the ancestors contribute to the genetic evaluations of all progeny.

Permanent Environmental Effects of Ewe. These are non-genetic effects of the ewe that have an effect on the reproductive traits, but are not transmitted to progeny or from the ewe's parents. These effects are assumed to be the same for all litters that a ewe has.

All Breeds. Many flocks contain more than one breed of sheep. The system analyzes all ewes regardless of breed, and as indicated above, breed effects of ewes are considered in some of the factors.

Heterosis. Heterosis effects of crossbreds are ignored in this system. When time permits, this should be studied more carefully because heterosis is usually more important for reproductive traits than for growth. To account for heterosis the breeds involved in every crossbred animal need to be known. This could hinder any future studies of heterosis.

4 Genetic Correlations Among Traits

The two multitrait systems rely on genetic and non genetic parameters which were estimated in 2005. Genetic parameters do not change very rapidly over time, and small errors do not significantly affect rankings of animals. Genetic parameters are due to be re-estimated in 2012. The estimates from 2005 were computed for four breeds, and the results were averaged together. Firstly, the results for each breed were similar, and secondly, allowing for different parameters for each breed would complicate the genetic evaluation systems with relatively little benefit.

One of the advantages of a multiple trait system is to improve the accuracy of EPDs. The genetic correlation tells us how two traits generally change with respect to each other, and that information is used to improve the two EPDs on the same animal. Another advantage is that animals can be evaluated for all traits, even if the animal was not observed for all traits. The EPDs for missing observations will have low accuracies, and these will be based on the traits which were observed. Suppose a lamb was observed for Survival and Birthweight, then

$$\left(\begin{array}{ll} & \text{50} - \text{d weight} \\ \text{EPDs for} & \text{100} - \text{d weight} \\ & \text{US Loin} \\ & \text{US Fat} \end{array} \right) = \text{Function of } \left(\begin{array}{l} \text{EPD for Survival} \\ \text{EPD for Birthweight} \end{array} \right),$$

where the function involves the genetic correlations of all traits.

Similarly, if a lamb was observed for Survival, Birthweight, 50-d weight and 100-d weight, then

$$\left(\begin{array}{l} \text{EPD US Loin} \\ \text{EPD US Fat} \end{array} \right) = \text{Function of } \left(\begin{array}{ll} & \text{Survival} \\ \text{EPDs for} & \text{Birthweight} \\ & \text{50} - \text{d weight} \\ & \text{100} - \text{d weight} \end{array} \right).$$

The most accurate situation is when lambs are observed for all six traits.

Because producers pay extra for ultrasound measures (time and money), then the availability of EPDs for US Loin and US Fat for lambs that have not been measured has been challenged. Only flocks that use ultrasound will receive EPDs for Loin and Fat. The percentage of flocks using ultrasounds is relatively small.

5 How To Use EPDs

EPDs are derived from 3 sources of information. The first source is the data (the observed values of the traits that are weights or measurements). The second source is information from the parents, which includes all of their ancestors and relatives. Lastly, the most valuable source is the information from progeny. These three sources are weighted according to the amount of information included in each. An animal must have information on at least one of those 3 pieces in order to receive an EPD.

5.1 Direct Genetic EPDs

An EPD is an Expected Progeny Difference and represents the average genetic merit that an animal can be expected to transmit or pass on to its progeny. EPDs can be compared across all breeds and crossbreds. Some progeny will be better than this average, and some progeny will be poorer than this average, but looking at all progeny, the result will be close to this average.

Suppose a Rideau ram has an EPD of +3.3 kg for 50-d weight, and the Rideau ewe to which it is mated has an EPD of +0.5 kg, then the anticipated result for a progeny of that mating would be $(3.3 + 0.5)/2 = 1.9$ kg, which is poorer than the ram, but better than the ewe. To improve the flock, then the best rams should be always used. They should have EPDs greater than those of the ewes in the flock in order to improve the genetic level of the flock through the progeny that are generated.

5.2 Maternal Genetic EPDs

The ewe provides either a favourable or unfavourable environment for its lambs in the early stages of their growth. This can be in the form of extra milk, better quality milk in terms of immune antibodies, better mothering ability and protection. Producers should want ewes that provide highly favourable environments. This ability is genetic and is transmitted to all offspring, male or female. Males can be evaluated for their maternal ability through their female offspring that eventually have litters and from their dams. Maternal genetic EPDs are most useful if the ewes have had at least one litter. Animals that have not had a litter have maternal EPDs that are based solely on relatives and is likely not very accurate.

6 Indexes

Another complication is that there are EPDs for 12 growth traits (direct and maternal) and 6 reproductive traits, and animals will rank differently for each trait. How to pick the best animals? Indexes have been used in many species to rank animals on an economic basis. Suppose you want to improve 100-d weight and number born for your flock. Create an index as

$$Index = value1(EPD100d) + value2(EPDNo.Born)$$

where $value1$ is the value of a kilogram of weight at 100 days, and $value2$ is the value of one lamb born.

Let $value1 = 0.50$ and $value2 = 10.0$, then the indexes for the following ewes would be as shown.

Ewe	EPD 100d	EPD No. Born	Index
21	+1.5	-0.2	-1.25
22	-1.7	0.4	+3.15
23	+3.1	0.1	+2.55

Thus, ewe 23 has the higher $EPD100d$, but ewe 22 has the higher index because $EPDNo.born$ is greater and has more value than 100-d weight. The values that you use should reflect the values for your flock.

You could put values on all 18 genetic traits into an index. An index does not need to be linear. Another possible index is

$$Index = value1 * (EPD100d) * [(EPDNo.Born) + (Mean)]$$

where the expected number born is multiplied times the expected 100-d weight advantage times the value of that extra weight. Thus, this index reflects an entire litter advantage for a ewe in terms of expected extra weight generated for a litter. Suppose the $Mean$ number born was 1.7, then the new indexes would be

Ewe	EPD 100d	EPD No. Born	Index
21	+1.5	-0.2	1.125
22	-1.7	0.4	-1.785
23	+3.1	0.1	+2.790

The new index follows the EPD for 100-d weight, but the value is with respect to the expected number born. Producers should derive their own indexes. However, several indexes are being planned for sheep producers, which have different purposes but will be easier for producers to use if they agree with the values and traits that have been included in the index.

7 Accuracies

Predictions are never totally accurate, and so accuracy values are obtained for EPDs. The accuracies are approximated using the following five pieces of information:

1. Does the animal have a record on that trait?
2. Does the animal have progeny with records on that trait, and how many progeny?
3. Does the animal's sire (the ram) have progeny with records, and how many progeny?
4. Does the animal's dam (the ewe) have a record on the trait?
5. Does the dam have progeny with records and how many progeny?

Selection index methods are then used to calculate an accuracy from this information. This is done separately for each trait. Genetic correlations among traits are not involved for computing accuracies, although it could be done.

How do you use the accuracy numbers? Accuracies range from 0 to 100 %. At 100 % you can be positive that the EPD is totally accurate and will not change. Only rams with thousands of progeny would come close to 100 % in accuracy. Therefore, most lambs and ewes will have much lower accuracies due to having few, if any, progeny.

Obviously, the higher the accuracy is, the more confidence one can place in the EPD. Suppose you have two rams both having an EPD of +5 kg, for example, and one has an accuracy of 45% and the other an accuracy of 70%. Which animal would you choose for breeding to your flock? A conservative producer would select the ram with the 70% accuracy, and would definitely improve his(her) flock for that trait. A risk-taking producer would select the ram with the 45% accuracy because that ram would have a greater probability of having a true EPD that is greater than +5, and if the producer was lucky, then the progeny in this flock would be improved more. However, there is also a probability that the true EPD is lower than +5, and in this case the progeny may not be improved over the level of the ewes. So the answer depends on your views about risk.

Accuracies for most lambs and ewes are similar because they only have a record and less than 10 progeny, but rams could have dozens of progeny and could have higher accuracies. Ram selection would therefore, involve more consideration of accuracies than ewe or lamb selection because there would be more differences in accuracies of rams. Accuracies are just a guide for placing confidence in the EPDs that are obtained.

8 Frequently Asked Questions

Sell a Ram to Another Producer. If I sell a good ram with an EPD for 50-d weight of +2.4 kg to another producer, then if the new owner has poorer management, what effects would that have on the ram's EPD when it has progeny in that flock?

Suppose the new flock contemporary group is 0.9 kg lower due to management practices, then the new progeny in that flock will perform poorer than in your flock. However, the genetic evaluation system will estimate the flock contemporary group effects and will determine that the difference between your flocks is -0.9 kg. This difference would then be added to the 50-d weights of the progeny in that flock, and the result will be as if the progeny had been raised in your flock. Thus, you should expect no change in the EPD of the ram, except for the genetic level of the new progeny.

If the new flock is poorer because of the genetic level of its ewes, then what would happen? If the genetic level of the ewes in the new flock was +1.0, then using your ram randomly in the new flock would generate progeny that would be expected to be $(2.4 + 1.0)/2 = 1.7$ kg. The genetic evaluation system will expect the lambs to be +1.7 kg. If they are as expected, then the ram's EPD will not change. If the lambs in the new flock are better than +1.7 kg, then the ram's EPD will increase, and if the new lambs are below +1.7 kg, then the ram's EPD will decrease accordingly.

If the ram is not used randomly, but only on poorer ewes, then what? The genetic evaluation system accounts for the genetic ability of each ewe, and the equations are formed knowing which ewes have been mated to each ram.

The genetic evaluation system is accounting for differences in management and differences in genetic levels between all flocks, both at the same time.

The genetic evaluation system can be strengthened by having many rams with progeny in many flocks. We call these 'connections'. The more connections that exist, then the system is better able to determine how flocks differ in management ability within each year, and better able to determine the genetic level of different flocks. EPDs become more accurate.

Sell Ewes or Ewe-Lambs to Another Producer. The answer to this is similar to the answer for the previous question about rams. The genetic evaluation system will account for differences in management and differences in genetic levels between flocks. If your ewes were higher genetically than ewes in the new flock, then the genetic level of the new flock will be increased. Your ewes may look better in the new flock than they might have looked in your flock because they will be compared to ewes that are lower genetically in the new flock. This might benefit the EPDs of ewes that you kept in your flock, but not very much.

Crossbreds and EPDs. The new EPDs are calculated for all animals simultaneously, which means that you should be able to compare animals of any breed compositions.

The new genetic evaluation system does not account for heterosis. Estimates of heterosis for growth in sheep have been small, so comparisons of EPDs between animals should be valid. Estimates of heterosis for reproduction may not be small, and so some care must be exercised with the reproduction traits (treat the comparisons as a little less reliable than for growth). The data that goes into the genetic evaluation system does not allow us to account for heterosis for all crossbreds because the precise breed composition is unknown for the majority of crossbreds.

Comparisons of animals (of any composition) within a flock will be more accurate than comparisons of animals between flocks. However, most selection intensity is generated within a flock.

Sick Animals. Sick animals should be properly coded in the database, and their weights should also be recorded. However, animals that have been sick should not be included in genetic evaluation. The codes would allow removal of the weights for this animal from genetic evaluation. Including unhealthy animals in genetic evaluation could make EPDs for parents and relatives less accurate and possibly lower than it actually should be.

Management Groups. Creating Management Groups requires a balance of time between the first and last lambing date in the group and the number of lambs in the group. The time should be kept short, and the number of lambs in the group should be at least 10 or more. You should avoid making management groups with only one or two lambs in it.

A management group is also defined by putting ewes into different housing units within the farm. Each housing unit would form a different management group.

Weights are adjusted to a 50-d basis assuming that growth follows a straight line. The growth rate of an animal is assumed to be constant from birth to 100 days of age. Thus, if an animal is 65 days when weighed, then its 50-d weight will be lower than the weight recorded at 65 days, and if an animal is 25 days when weighed, then its 50-d weight will be higher than the recorded weight. Comparing these two animals within the same management group may not be very reliable due to the wide difference in ages.

If you have a 3 month lambing season and only 10 ewes, then forming separate management groups by months is not very practical. Remember management groups should have probably at least 10 lambs per group, regardless of age differences, as a rule of thumb.

If you have a large flock and you naturally separate the ewes by age or breed or some other criteria, then each group would be a separate management group and this should be indicated through the database. Accurate indications of ewes that are grouped or managed differently would improve the accuracy of EPDs for the ewes and their lambs. Proper management group definitions will benefit your flock in the long run.

How are the Calculations Made. "Equations" have been mentioned previously. There are over 6 million equations (for all flocks and lambs and traits) that must be processed every weekend. There are equations for animal EPDs(direct genetic), for Year-Month of Lambing-Breed of Lamb Groups, for Sex of lamb-Age of ewe-Breed of Ewe Groups, for Litters, for Management Groups, for animal EPDs(maternal genetic), and others. Thus, describing the calculations is not an easy matter.

The equation (very very simplified) for an animal EPD for 50-d weight is as follows:

Animal EPD direct = (Adjusted 50-d Weight
- Year-Month-Breed value
- Sex-Age-Breed value
- Management group value
- Litter value
- animal EPD maternal*genetic covariance adjustment
+ (sire and dam EPD)*VR
+ average over all progeny of
(Progeny EPD - Half Other Parent's EPD)*VR)
divided by
(1 record + VR*d + Sum of VR/4 for progeny)

where VR relates to heritability of the trait, d is 1 if neither parent is known, 4/3 if one parent is known, and 2 or more if both parents are known and possibly inbred.

Also, the equations for Year-Month-Breed values are

Year-Month-Breed value = Sum over all lambs belonging to
this group of
(Adjusted 50-d weight
- Sex-Age-Breed value
- Management group value
- Litter value
- animal EPD direct
- animal EPD maternal)
divided by number of lambs in this group,

and the equations for Sex-Age-Breed values are

Sex-Age-Breed value = Sum over all lambs belonging to
this group of
(Adjusted 50-d weight
- Year-Month-Breed value
- Management group value
- Litter value
- animal EPD direct
- animal EPD maternal)
divided by number of lambs in this group,

There are similar equations for EPD maternal, litters, and management groups. The computer runs through these equations, one at a time, up to 5000 times (called iterations). The EPDs and values of factors change slightly each iteration, but the changes become smaller and smaller. The equations are solved when the change in EPDs from one iteration to the next is very close to 0. Then the system is in balance, or said to be converged.

The equations are much more complicated than shown above because 6 traits are involved at the same time, including the genetic and non-genetic correlations among traits. We get the records, we get the pedigrees, we supply the genetic and non-genetic parameters and feed all of this into one program that requires 6 to 8 hours of computing, and out come the results that satisfy (or fit) the equations. The only way that you could reproduce the EPDs is to have all of the same information and the program that we have. You could never perform the calculations on a calculator or with paper and pencil.

Maternal EPDs for Siblings Two male siblings from the same litter have different maternal EPDs for 50-d weight. Why?

For male siblings, their maternal EPD is a function of their direct genetic EPD for 50-day weight and their parent direct and maternal EPDs for all six traits. That is,

$$\text{Maternal EPD} = (\mathbf{B} \times \text{Direct EPD}) + \text{PDM},$$

where

$$\mathbf{B} = \frac{\text{Genetic covariance(direct, maternal)}}{\text{Genetic variance(direct)}},$$

and PDM is a sum of the parent averages of their direct AND maternal EPDs for all six traits in the system weighted by the appropriate genetic covariances and variances. This is a constant common to all progeny in the litter accounting for the genetic level of the parents and the contributions from other traits in the system.

To illustrate, suppose sib 1 has a direct EPD for 50-d weight of +1.20 and for sib 2 the direct EPD is +2.15, which agrees with the rankings of their adjusted 50-d weights of 23.5 kg and 27.8 kg, respectively. The PDM (based on the parent EPDs and genetic parameters) is the same for both sibs and worked out to be 0.44. Both sibs had data on all six traits in the growth system. The above formula says that, for sib 1

$$\begin{aligned} \text{Maternal EPD} &= (-0.2315 \times \text{Direct EPD}) + 0.44 \\ &= (-0.2315 \times +1.20) + 0.44 \\ &= -0.2778 \ + \ 0.44 \\ &= +0.16 \end{aligned}$$

and for sib 2

$$\begin{aligned}
\text{Maternal EPD} &= (-0.2315 \times \text{Direct EPD}) + 0.44 \\
&= (-0.2315 \times +2.15) + 0.44 \\
&= -0.4977 \;+\; 0.44 \\
&= -0.0577 \\
&= -0.06
\end{aligned}$$

The genetic covariance between direct and maternal genetic effects is negative in sign, which means that as the direct EPD goes up, then the maternal EPD goes down. The negative relationship is the general relationship that exists in the population. Once animals have their own litters (if they are females), then the general relationship is broken. The PDM differs in value for each set of parents. The value of 0.44 in this example, says that based on the EPDs of the parents (direct and maternal) for all six traits, that their predicted genetic level was +0.44 kg for maternal 50-d weight.

The accuracy of the maternal EPDs for the two sibs in the example was only 24%.