Calculation of Multiple-Trait Sire Reliability for Fertility Traits

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Summary

Bull reliabilities were calculated for the 6-trait UK dairy cattle fertility evaluation with an approximation that combined selection index and information source methods. First lactation Holstein cow data were used. Traits considered were interval between 1st and 2nd calvings (CI), interval between 1st calving and 1st service (DFS), non-return rate 56 days post 1st service (NR56), number of inseminations per conception (INS), daily milk yield at test closest to day 110 (MILK) and body condition score (BCS). A test application showed good agreement between approximate and exact reliabilities.

Method Description

Step 1: Number of effective daughters was calculated for each bull, based on total number of daughters and daughter distribution across herd-year-seasons. Number of effective daughters was calculated separately for each trait.

Step 2: Multiple-trait reliabilities were calculated, based on bull daughter contribution, applying selection index theory on independent daughter groups. All bulls were required to have daughters with milk yield. Genetic parameters estimated by Wall *et al.* (2003) were used. Effective daughters per bull and trait were processed in descending order and were expressed as deviation from the number of effective daughters for the previous trait. See APPENDIX I for a description of the method.

Step 3: Granddaughter contribution was added to the reliability of each bull, based on daughter reliability (step 2) of sons and maternal grandsons (Harris and Johnson, 1998). An adjustment was made to account for the possibility of bull and son or grandson having daughters in the same herd-year-season. Animals were processed from youngest parent to oldest. See APPENDIX II for a description of the method.

Step 4: Parent (sire and MGS) contribution was added to the reliability of each bull (Harris and Johnson, 1998). Animals were processed from oldest to youngest. See APPENDIX II for a description of the method.

Test Application

The procedure was first tested on a subset of 28,061 records and 285 bulls. Exact reliabilities were calculated for the same data set. Comparison between approximate and exact reliabilities is shown in table 1. Intercepts (expected value 0) and slopes (expected value 1) are from the regression of the former on the latter.

Table 1. Comparison between approximate and exact reliabilities, by trait.

Trait	Mean absolute difference	Standard deviation of difference	Range of difference min	Range of difference max	Product moment correlation	Intercept*	Slope**
CI	0.016	0.013	-0.036	0.045	0.995	0.008	1.018
DFS	0.014	0.010	-0.028	0.064	0.997	0.001	1.025
NR56	0.020	0.013	-0.028	0.074	0.995	0.007	1.033
INS	0.020	0.014	-0.027	0.059	0.994	0.008	1.034
MILK	0.014	0.006	-0.012	0.028	0.999	-0.009	1.030
BCS	0.014	0.010	-0.038	0.039	0.998	0.007	1.013

**standard error=0.002-0.005* ***standard error=0.004-0.010*

Table 1 results suggest that approximate reliabilities were, generally, very close to the exact estimates. Some over-estimation was observed, especially for the low heritability fertility traits. This bias was traced to step 3, where the reliability of a sire was updated to include information from his granddaughters, and affected bulls with many sons and/or maternal grandsons. Slight upward biases associated with the information source method, applied here, were also reported by Harris and Johnson (1998). The bias shown in table 1 was after adjustment, in step 3, for the probability of sires and sons or grandsons to have daughters in the same herd-year-season. Without this adjustment, mean absolute differences were higher by 0.002 to 0.005 and maximum biases were larger by 0.002 to 0.026, compared to results in table 1.

Field Application

New method reliabilities were calculated for 27,765 Holstein bulls, using a data set of 1,793,460 records. Software was written in FORTRAN 90 and run in a UNIX environment. The entire process required 75 min of computer processing time, including all editing and preparatory steps, of which the actual reliability calculation took less than 1 min. The process also required 24 MB of memory. Basic statistics and heritabilities (h^2) used are in table 2. “Number of bulls” refers to those with own daughters in the data. However, all 27,765 bulls had reliabilities estimated for all traits.

Table 2. Trait statistics and heritability.

Trait	Number of observations	Mean	Standard deviation	Value range Min	Value range Max	Number of bulls	h^2
CI (days)	1,218,620	393.41	55.06	300	600	18,540	.03
DFS (days)	1,594,232	83.29	31.31	20	200	25,359	.04
NR56 (0/1)	1,594,232	0.68	0.47	0	1	25,359	.02
INS (count)	1,159,097	1.66	1.00	1	10	17,609	.02
MILK (kg)	1,793,460	22.56	5.79	5	60	27,765	.33
BCS (score)	214,882	4.46	1.66	-1.50	10.50	7898	.24

The distribution of bull reliability estimates is given in table 3. Reliability estimates of all 27,765 bulls, which had daughters with MILK records, are considered in table 3. Because of this and the higher heritability (0.33), as many as 6389 sires had MILK reliability larger than 0.60, compared to 847, 1597, 840, 721 and 1683 for CI, DFS, NR56, INS and BCS, respectively. The heritability of BCS was the second largest (0.24) but only 28% of the bulls had daughters with BCS recorded, hence the relatively low reliability estimates for this trait. Amongst the four fertility traits, DFS had the highest heritability (0.04) and, more importantly, the larger number of records. In fact, this trait was available in 89% of the cows and 91% of the bulls had daughters with DFS recorded. For this reason, mainly, about twice as many bulls had reliability greater than 0.60 for DFS compared to CI. For the latter trait, although the heritability (0.03) was close to DFS, only 67% of bulls had daughters with records. It should also be noted that DFS had a stronger genetic correlation with MILK and BCS than CI, which further enhanced its reliability estimates. The amount of NR56 data was the same as DFS but, because of the lower heritability (0.02), generally weaker genetic correlations with MILK and BCS and, possibly, its binary nature, reliabilities were lower for this trait. Finally, INS had the smallest amount of data, lowest heritability and weakest correlation with MILK and BCS, amongst all fertility traits, hence the lowest reliability estimates for this trait.

In table 4, average reliabilities estimated after each step are shown, reflecting the contribution of various information sources to the final estimate. Average reliability estimates are low because many of the 27,765 bulls had very few effective daughters (even less than 1), whereas certain proportion of them were missing daughters with fertility and BCS records altogether (table 2). Multiple-trait analysis increased the average reliability for fertility traits by 47-79% but had minimal effect on MILK. As expected, multiple-trait analysis will be of value mainly to low heritability traits with missing observations. On average, granddaughters made little contribution to bull reliability because only few bulls had a considerable number of sons and maternal grandsons. However, in specific cases, the effect of this contribution was sizeable, e.g. a certain bull had multiple-trait daughter-based reliability of 0.807 for MILK, which increased to 0.816 with the contribution of his great-granddaughters, via his 5 maternal grandsons, and to 0.910 with his granddaughter contribution, via his 22 sons. In this particular example, average daughter-based reliability of grandsons and sons was 0.733 and 0.827, respectively. Bull parents contributed considerably to the average reliability (Table 4), as a result of the low mean value and its prevalence amongst the different sources of information. The theoretical maximum reliability of a pedigree index based on sire and maternal grandsire is 0.312 and occurs when both have a completely known breeding value. Its relevance, however, will decrease as information from other sources accumulates. Thus the average pedigree contribution here ranged from 0.131 to 0.173 for the six traits. Moreover, in the previous example, the bull's parent contribution only increased the final MILK reliability estimate from 0.910 to 0.912.

Table 3. Distribution of bull reliabilities by trait; percentages were calculated over all 27,765 bulls.

Relia-bility	MILK		CI		DFS		NR56		INS		BCS	
range	bulls	%	bulls	%	bulls	%	bulls	%	bulls	%	bulls	%
>.10	1026	3.70	3279	11.81	2317	8.35	3707	13.35	3964	14.28	2835	10.21
.10-.19	1600	5.76	4918	17.71	3549	12.78	4988	17.97	5262	18.95	4650	16.75
.20-.29	4230	15.24	8578	30.90	7058	25.42	8531	30.73	9887	35.61	7026	25.31
.30-.39	7286	26.24	8085	29.12	8983	32.35	7584	27.31	6431	23.16	8351	30.08
.40-.49	4167	15.01	1488	5.36	2949	10.62	1479	5.33	1141	4.11	2169	7.81
.50-.59	3067	11.05	570	2.05	1312	4.73	636	2.29	359	1.29	1051	3.79
.60-.69	2161	7.78	238	0.86	720	2.59	236	0.85	200	0.72	678	2.44
.70-.79	1571	5.66	202	0.73	282	1.02	221	0.80	194	0.70	520	1.87
.80-.89	1447	5.21	207	0.75	283	1.02	205	0.74	185	0.67	271	0.98
.90-.99	1210	4.36	200	0.72	312	1.12	178	0.64	142	0.51	214	0.77

Table 4. Average reliability of 27,765 bulls for six traits, estimated after each step of the procedure.

Trait	Daughter contribution Single-trait (step1)	Daughter contribution Multiple-trait (step 2)	(Great-)granddaughter contribution (step 3)	Parent contribution (step 4, final estimate)
CI	0.062	0.091	0.095	0.268
DFS	0.080	0.143	0.149	0.316
NR56	0.054	0.087	0.092	0.263
INS	0.046	0.072	0.077	0.250
MILK	0.307	0.311	0.317	0.448
BCS	0.074	0.129	0.136	0.298

References

Harris, B. & Johnson, D. 1998. Approximate reliability of genetic evaluations under an animal model. *J. Dairy Sci. 81,* 2723-2728.

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APPENDIX I

Reliability estimation based on daughter contribution and selection index theory

Single-trait analysis

Let V(A) = sire variance, V(R) = residual variance and PEV = prediction error variance.

$V(A) = V(\hat{A}) + PEV \quad => \quad PEV = V(A) - V(\hat{A})$

$PEV_i = V(A)[\,1 - r^2\,]$ where r^2 = reliability of predicted genetic merit for sire i.

$= V(A)[\,1 - n/(n + k)]$ where n = number of effective daughters for sire i and k = V(R)/V(A)

$= V(A)[k/(n + k)]$

$PEV_i = V(R) / (n + V(R)/V(A)) = V(R).\,V(A) / (nV(A) + V(R)) \quad => \quad PEV_i^{-1} = (nV(R)^{-1} + V(A)^{-1})$

Extension to multiple-trait analysis

Let T = number of traits. For the multivariate situation, extend to: $PEV_i^{-1} = (\sum_{t=1}^{T} n_t^* R_{1-t}^{-1} + G^{-1})$

where G is the genetic (co)variance matrix between the traits and R is the residual (co)variance matrix. For a sire model, G is equivalent to the sire (co)variance and R includes ¾ of the genetic variance. R_{1-t} is the subset of the R matrix for traits 1 to t, and $n^*_t = n_t - n_{t+1}$. Note that number of effective daughters must be in descending order from trait 1 to trait T, i.e. $n_t \geq n_{t+1}$ and $n^*_T = n_t$.

APPENDIX II

Information source method to add (great-)granddaughter and parent information to bull reliability

Bull granddaughter (and great-granddaughter) contribution

Let Rb, Rs and Rms be the daughter-based reliability of a bull, his son and his maternal grandson. Bull reliability is then updated to consider son progeny contribution, as follows (Harris and Johnson, 1998):

$$\mathbf{Rb} = \frac{\mathbf{Rb} + \frac{1}{4}\cdot\mathbf{Rs} - \frac{1}{2}\cdot\mathbf{Rb}\cdot\mathbf{Rs}}{1 - \frac{1}{4}\cdot\mathbf{Rb}\cdot\mathbf{Rs}}$$

Similarly, bull reliability is updated to consider maternal grandson progeny contribution, as follows:

$$\mathbf{Rb} = \frac{\mathbf{Rb} + \frac{1}{16}\cdot\mathbf{Rms} - \frac{1}{8}\cdot\mathbf{Rb}\cdot\mathbf{Rms}}{1 - \frac{1}{16}\cdot\mathbf{Rb}\cdot\mathbf{Rms}}.$$

The process works from the youngest parent to the oldest, to allow all generations to be incorporated, and repeats for each trait.

Adjustment for possibility of bull and son or grandson to have daughters in same herd-year-season

Prior to applying the above formulae, Rb, Rs and Rms are changed as follows:
Let ndb, nhb, nds and nhs be number of daughters and number of herd-year-seasons for bull and son, respectively. Let k be the residual to sire variance ratio and hysz the average herd-year-season size.

Compute: $\mathbf{neb} = \frac{\mathbf{k}\cdot\mathbf{Rb}}{1-\mathbf{Rb}}$ $\qquad \mathbf{nes} = \frac{\mathbf{k}\cdot\mathbf{Rs}}{1-\mathbf{Rs}}$

Then compute:

$$\mathbf{neb} = \mathbf{neb} - \frac{\left(\mathbf{w}\cdot\left(\left(\mathbf{ndb}/\mathbf{nhb}\,.\,\mathbf{nds}/\mathbf{nhs}\right)/\mathbf{hysz}\right)\right)^2}{\mathbf{nes}} \qquad \mathbf{nes} = \mathbf{nes} - \frac{\left(\mathbf{w}\cdot\left(\left(\mathbf{ndb}/\mathbf{nhb}\,.\,\mathbf{nds}/\mathbf{nhs}\right)/\mathbf{hysz}\right)\right)^2}{\mathbf{neb}}$$

where w=(minimum(nhb, nhs))/(1+h^2), h^2=trait heritability

Finally compute: $\mathbf{Rb} = \frac{\mathbf{neb}}{\mathbf{k}+\mathbf{neb}}$ $\qquad \mathbf{Rs} = \frac{\mathbf{nes}}{\mathbf{k}+\mathbf{nes}}$

If Rb or Rs above become smaller than effective daughter-based reliability (for very small neb or nes), the latter replaces it. Similar adjustments are made for every bull-maternal grandson pair.

Bull parent contribution

Let Rb, Rs and Rms be the reliability of a bull, his sire and his maternal grandsire. Bull reliability is updated as follows (Harris and Johnson, 1998):

Compute: $\mathbf{Rs} = \frac{\mathbf{Rs} - \frac{1}{4}\cdot\mathbf{Rb}}{\mathbf{Rs}\cdot\frac{1}{4}\cdot\mathbf{Rb} + 1 - \frac{1}{2}\cdot\mathbf{Rb}}$ $\qquad \mathbf{Rms} = \frac{\mathbf{Rms} - \frac{1}{16}\cdot\mathbf{Rb}}{\mathbf{Rms}\cdot\frac{1}{16}\cdot\mathbf{Rb} + 1 - \frac{1}{8}\cdot\mathbf{Rb}}$

Then compute parent average reliability: $\mathbf{Rpa} = \frac{1}{4}\cdot\left(\mathbf{Rs} + \frac{1}{4}\cdot\mathbf{Rms}\right)$

Finally compute: $\mathbf{Rb} = \frac{\mathbf{Rb} + \mathbf{Rpa} - 2\cdot\mathbf{Rb}\cdot\mathbf{Rpa}}{1 - \mathbf{Rb}\cdot\mathbf{Rpa}}$

The process works from the oldest to the youngest, to allow all generations to be incorporated, and repeats for each trait.