

# Additional Aspects of BLUP

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# Aspects

- ▶ Accuracy
  - ▶ Results from MME are estimates of fixed effects and predictions of breeding values
  - ▶ Need statement about quality of estimates and predictions
- ▶ Confidence Intervals
- ▶ Decomposition of Predicted Breeding values

# Accuracy

- ▶ One property of BLUP was that variance of prediction error is minimal
- ▶ How can we measure the variance of the prediction error
- ▶ Fixed effects

$$var(\beta - \hat{\beta}) = var(\hat{\beta})$$

- ▶ Random effects

$$var(u - \hat{u}) = var(u) - 2*cov(u, \hat{u}) + var(\hat{u}) = var(u) - var(\hat{u}) = PEV(\hat{u})$$

because with BLUP:  $cov(u, \hat{u}) = var(\hat{u})$

# PEV

- ▶ PEV depends on inverse of coefficient matrix of MME

$$\begin{bmatrix} X^T R^{-1} X & X^T R^{-1} Z \\ Z^T R^{-1} X & Z^T R^{-1} Z + G^{-1} \end{bmatrix}^{-1} = \begin{bmatrix} C^{11} & C^{12} \\ C^{21} & C^{22} \end{bmatrix}$$

- ▶ For predicted breeding values  $\hat{u}$

$$PEV(\hat{u}) = var(u) - var(\hat{u}) = C^{22}$$

## Single Animal $i$

$$PEV(\hat{u}_i) = (C)_{ii}^{22}$$

where  $(C)_{ii}^{22}$  is the  $i$ -th diagonal of  $C^{22}$

- Accuracy measured by correlation

$$r_{u_i, \hat{u}_i} = \frac{\text{cov}(u_i, \hat{u}_i)}{\sqrt{\text{var}(u_i) * \text{var}(\hat{u}_i)}} = \sqrt{\frac{\text{var}(\hat{u}_i)}{\text{var}(u_i)}}$$

- Combining

$$PEV(\hat{u}_i) = (C)_{ii}^{22} = \text{var}(u_i) - \text{var}(\hat{u}_i) = \text{var}(u_i) - r_{u_i, \hat{u}_i}^2 \text{var}(u_i)$$

## Accuracy $B_i$

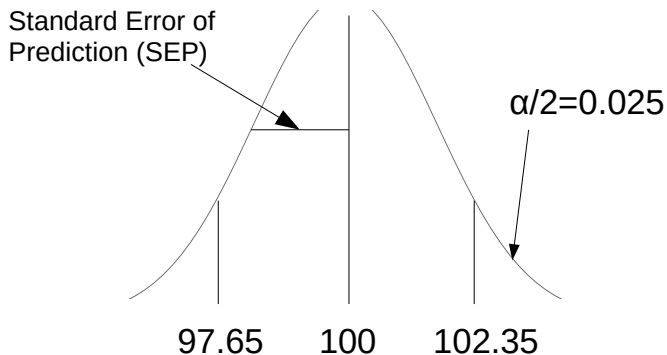
$$B_i = r_{u_i, \hat{u}_i}^2 = \frac{\text{var}(u_i) - (C)_{ii}^{22}}{\text{var}(u_i)} = 1 - \frac{PEV(\hat{u}_i)}{\text{var}(u_i)} = 1 - \frac{(C)_{ii}^{22}}{\text{var}(u_i)}$$

- ▶  $B_i$  is large for small  $PEV(\hat{u}_i)$
- ▶ In the limit  $B_i \rightarrow 1$  for  $PEV(\hat{u}_i) \rightarrow 0$
- ▶ For  $PEV(\hat{u}_i) \rightarrow 0$  we must have  $\text{var}(\hat{u}_i) \rightarrow \text{var}(u_i)$
- ▶ Therefore, the closer  $\text{var}(\hat{u}_i)$  is to  $\text{var}(u_i)$ , the more accurate the predicted breeding value

## Confidence Intervals of $\hat{u}_i$

- ▶ Predicted breeding value ( $\hat{u}_i$ ) is a function of the data ( $y$ )
- ▶ Hence  $\hat{u}_i$  is a random variable with a distribution

## Distribution



$$SEP(\hat{u}_i) = \sqrt{PEV(\hat{u}_i)} = \sqrt{(1 - r_{u_i, \hat{u}_i}^2) * var(u_i)}$$



# Widths Of Confidence Intervals

Table 1: Widths of Confidence Intervals for Given Accuracies

Accuracy	Interval Width
0.40	36.44
0.50	33.26
0.60	29.75
0.70	25.76
0.80	21.04
0.90	14.88
0.95	10.52
0.99	4.70

with  $\hat{u}_i = 100$ ,  $\text{var}(u_i) = 144$  and  $\alpha = 0.05$

# Decomposition of Predicted Breeding Value

- ▶ Write MME as

$$M \cdot s = r$$

with

$$s = \begin{bmatrix} \hat{\beta} \\ \hat{u} \end{bmatrix}$$

- ▶  $\hat{\beta}$  has length  $p$
- ▶  $\hat{u}$  has length  $q$

## Simplified Model

$$y_i = \mu + u_i + e_i$$

where

$y_i$	Observation for animal $i$
$u_i$	breeding value of animal $i$ with a variance of $(1 + F_i)\sigma_u^2$
$e_i$	random residual effect with variance $\sigma_e^2$
$\mu$	single fixed effect

# Data

- ▶ all animals have an observation
- ▶ animal  $i$  has
  - ▶ parents  $s$  and  $d$
  - ▶  $n$  progeny  $k_j$  (with  $j = 1, \dots, n$ )
  - ▶  $n$  mates  $l_j$  (with  $j = 1, \dots, n$ ).
- ▶ progeny  $k_j$  has parents  $i$  and  $l_j$ .

## Example

Animal	Sire	Dam	WWG
1	NA	NA	4.5
2	NA	NA	2.9
3	NA	NA	3.9
4	1	2	3.5
5	4	3	5.0

Variance components  $\sigma_e^2 = 40$  and  $\sigma_u^2 = 20$ .

## Model Components

$$X = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}, Z = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$X^T X = [5], X^T Z = [1 \quad 1 \quad 1 \quad 1 \quad 1]$$

$$Z^T Z = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

## Right-hand Side

$$X^T y = \left[ \sum_{j=1}^n y_i \right] = 19.8$$

$$Z^T y = \begin{bmatrix} y1 \\ y2 \\ y3 \\ y4 \\ y5 \end{bmatrix} = \begin{bmatrix} 4.5 \\ 2.9 \\ 3.9 \\ 3.5 \\ 5 \end{bmatrix}$$

$$A^{-1}$$

`## as(<dtTMatrix>, "dtCMatrix")` is deprecated since `Matrix`

$$A^{-1} = \begin{bmatrix} 1.5 & 0.5 & 0 & -1 & 0 \\ 0.5 & 1.5 & 0 & -1 & 0 \\ 0 & 0 & 1.5 & 0.5 & -1 \\ -1 & -1 & 0.5 & 2.5 & -1 \\ 0 & 0 & -1 & -1 & 2 \end{bmatrix}$$



# MME

$$\begin{bmatrix} X^T X & X^T Z \\ Z^T X & Z^T Z + A^{-1} * \lambda \end{bmatrix} \begin{bmatrix} \hat{\mu} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X^T y \\ Z^T y \end{bmatrix}$$

## Insert Data

$$\begin{bmatrix} 5 & 1 & 1 & 1 & 1 & 1 \\ 1 & 4 & 1 & 0 & -2 & 0 \\ 1 & 1 & 4 & 0 & -2 & 0 \\ 1 & 0 & 0 & 4 & 1 & -2 \\ 1 & -2 & -2 & 1 & 6 & -2 \\ 1 & 0 & 0 & -2 & -2 & 5 \end{bmatrix} \begin{bmatrix} \mu \\ \hat{u}1 \\ \hat{u}2 \\ \hat{u}3 \\ \hat{u}4 \\ \hat{u}5 \end{bmatrix} = \begin{bmatrix} 19.8 \\ 4.5 \\ 2.9 \\ 3.9 \\ 3.5 \\ 5 \end{bmatrix}$$

## Animal 4

- ▶ parents 1 and 2
- ▶ progeny 5
- ▶ mate 3
- ▶ inspection of second but last equation in MME where  $y_4$  and  $\hat{u}_4$  occur
- ▶ Remember from construction of  $A^{-1}$ , the variable  $d^{ii}$  can assume the following values

$$d^{ii} = \begin{cases} 2 & \text{both parents known} \\ \frac{4}{3} & \text{one parent known} \\ 1 & \text{both parents unknown} \end{cases}$$

## Extract Equation

$$y_4 = 3.5 = 1 * \hat{\mu} - 2 * \hat{u}_1 - 2 * \hat{u}_2 + 1 * \hat{u}_3 + 6 * \hat{u}_4 - 2 * \hat{u}_5$$

- ▶ Solving for  $\hat{u}_4$

$$\hat{u}_4 = \frac{1}{6} [y_4 - \hat{\mu} + 2 * (\hat{u}_1 + \hat{u}_2) - \hat{u}_3 + 2\hat{u}_5]$$

- ▶  $\hat{u}_4$  depends on
  - ▶ own performance record  $y_4$
  - ▶ estimate of fixed effect  $\hat{\mu}$  - environment
  - ▶ predicted breeding value of parents 1 and 2, mate 3 and progeny 5

## General Equation

$$\hat{u}_i = \frac{1}{1 + \alpha\delta^{(i)} + \frac{\alpha}{4} \sum_{j=1}^n \delta^{(k_j)}} [y_i - \hat{\mu} + \frac{\alpha}{2} \left\{ \delta^{(i)}(\hat{u}_s + \hat{u}_d) + \sum_{j=1}^n \delta^{(k_j)}(\hat{u}_{k_j} - \frac{1}{2}\hat{u}_{l_j}) \right\}]$$

where  $\alpha$       ration between variance components  $\sigma_e^2/\sigma_u^2$   
 $\delta^{(j)}$       contribution for animal  $j$  to  $A^{-1}$