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# Survival analysis of White Leghorn laying hens in the early and late production period

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# Abstract

The aim of the study was to carry out survival analysis to evaluate fixed effects and to estimate genetic parameters on survival of laying hens. The data set contained 16694 records of purebred White Leghorn layer lines W1, WB and WF. At 17 weeks old, hens were transported to two laying stables and were randomly assigned to traditional 4 – birds battery cages. Censoring status i.e. alive or dead and cause of death were recorded. The traits studied were overall survival during the entire laying period from 17 weeks to 64 weeks, survival of the early production period (from 17 to 40 weeks of age) and late production period (from 41 to 64 weeks of age). The results showed that all fixed effects in the model that is stable by corridor interaction effect, mortality of back cage neighbours, level and layer lines were highly significant. Overall survival during the entire laying period was 60.4 %. There was highest risk of death for line WB and the lowest for line WF.  About 10 % of animals died due to pecking. Heritability for survival traits ranged from 0.04 to 0.147. Estimated heritabilities from the animal model were higher than those from the sire model. When using animal model, heritability for overall survival was 0.115 and for the early laying period was 0.074 and the late laying period was 0.147. This indicates genetic improvement is possible. Heritability for survival due to pecking ranged from 0.03 to 0.055. Identification of birds at an early age and exclusion from breeding may increase survival due to pecking. The genetic correlation between overall survival and early laying period was 0.8 and between overall survival and late laying period was 0.9. The high genetic correlations indicate positive correlated response through selection. The genetic correlation between early and late laying period with the sire model was 0.404 and with animal model was 0.578.


Key words: survival analysis, laying hens, animal model, sire model, heritability, feather pecking

# 1. Introduction

Survival analysis is a statistical method used to examine either the length of time an individual survives or the length of time until an event occurs (Ducroq et al. 2000). A major characteristic of the survival analysis is that it considers both censored (i.e. animals that are still alive at the end of the study period) and uncensored (i.e. animals that died during the study period) observations in a single analysis. The length of censored records is used as a lower bound for genetic evaluation of longevity traits. Inappropriate adjustments of censored records could bias estimates of breeding values. In addition, survival analysis also accounts for non-normality of the residuals and the skewed nature of survival data. Both continuous and discrete data with time dependent factors can be analyzed. Cox or Weibull models are used to examine survival data (Cox 1972). Both models are based on the concept of proportional hazard which defines the hazard function of each individual as the probability of an animal to die or be culled given that it is still alive just prior to time *t* (Ducrocq and Sölkner, 1998, Ducrocq et al. 2010, Mészáros et al. 2013). The risks of dying or culling at time *t* are displayed as hazard ratio also called risk ratio. The smaller the risk ratio, the lower is the risk of death and the larger the risk ratio, the higher is the risk of death. These models are implemented in the Survival Kit. A detailed explanation of how to use the Survival Kit software for survival analysis is provided in Mészáros et al. (2013). Methods of survival analysis are provided in Kachman (1999). The hazard of an individual at time *t* is described as the product of baseline function and an exponential function of a vector of covariates multiplied by the vector of regression parameters and random effects. Fixed and random covariates can be time dependent. In Cox model, the baseline hazard is left unspecified by commenting it out whereas it is specified in the Weibull model. Although there is freedom in specifying the models, the Cox model could become computationally demanding when estimating genetic variances from large data sets. The Weibull model is more efficient when using large data sets, in particular when estimating genetic parameters.

In commercial laying hens, all the hens that survived up to the end of the production period are culled together. After culling, they are replaced with a new generation. However, involuntary culling may occur due to infectious diseases, pecking, cannibalism and accidents. Mortality during the production period should be kept as low as possible. High mortality rate has both economic and welfare consequences. Significant mortality may result in low production which affect farm profitability and reflects the performance of the industry. Generally the mortality rate in poultry is low. For laying hens under controlled conditions, the mortality rate is less than 5.2 % per year of egg production (Preisinger 1998). For broilers, mortality is about 5 %. The rate in broilers is expected to increase due to ascites and sudden death syndrome (Ducrocq et al. 2000) and the rate of mortality in laying hens is expected to increase due to the ban on beak trimming which leads to increased risk of pecking behavior. About 60 % of commercial layers show feather pecking behavior. The solution to the problem was beak trimming and the use of low light intensity.

Survival traits are often not included in laying hen selection program due to a low heritability and censoring rate is high. Low heritability and high censoring might lead to low selection accuracy for survival. However, there is a strong interest in increasing survival during the productive life (ability to reduce culling). Productive life in laying hens is the length of time a hen spends laying eggs. When survival is increased, the proportion of hens in the late laying period also increases and more eggs are produced per hen or per cage. This could lead to increase in profits. For other domestic species like dairy cattle, an improvement in survival could also reduce replacement costs of heifers. Unlike in dairy cows, sows or does, there are no replacement costs for laying hens because dead hens are not replaced. Therefore the main advantage of improving survival of laying hens is that the hens can be kept longer. The target is to increase the length of the entire laying period from 80 weeks to 100.

Few studies have been conducted on survival of laying hens but many studies focused on longevity in cattle. Potočnik et al. (2011) conducted survival analysis using a Weibull proportional hazard model on longevity in Slovenian Holstein cattle. Other studies on survival analysis focused on the relationship between type traits and longevity in Croatian Simmental cattle (Jovanovac and Raguž 2011). In dairy cattle, research showed that the proportion of genetic variability for productive life is about 5 – 20 %. Vollema and Groen (1998) studied productive life of Dutch dairy cattle using both linear and survival models, with heritability of 0.06. Productive life is highly correlated with other important traits. Productive life could be improved by including it in the total merit index and putting higher weights on it.

Mészáros et al. (2010) carried out genetic analysis of sow longevity using the continuous time and grouped data models. They found that heritability in Landrace breed using the continuous data ranged from 0.05- 0.08 (s.e. 0.014-0.02) whereas the heritability for grouped data ranged between 0.07- 0.11 (0.016-0.023) for grouped data. In the Large White breed, they found heritability ranging between 0.08-0.14 (s.e. 0.012-0.026) for continuous and between 0.08-0.13(s.e. 0.012-0.025) for the grouped data model.

Cole et al. (2004) reported heritability estimates on linear scale for early working life in German Shepherds as 0.0318 and for late working life as 0.0179. Their studies also found that the heritability estimates for early working life in Labrador Retrievers as 0.045 while for the late working life as 0.0317.

In rabbits, Piles et al. (2006) analyzed length of productive life for the Prat and A1077 lines using the Cox model for Prat line and a discrete model for the A1077 line. Their estimated heritability was 0.158 for Prat line and 0.172 for A1077 line.

In poultry, Ducrocq et al. (2000) estimated heritabilities for two measures of longevity in laying hens to be 0.194. Boettcher et al. (1999) reported heritability estimates of 0.04 using the linear model, 0.07 using the threshold model and 0.09 using the survival model. The heritability estimates for mortality of pure-line hens in single cages were near zero (Flock 1996). And of recent were studies on survival of White Leghorn laying hens by Ellen et al. (2008), in which genetic parameters of survival data were estimated using a traditional linear animal model. They found that heritability for survival time using a traditional linear animal ranged between 2% and 10%. Furthermore, they showed that social interactions among group members contribute to the heritable variation in survival time. When considering both direct and social genetic effects, the total heritable variance expressed as a proportion of phenotypic variance ranged between 6% and 19%. Survival data are heavily skewed and non- normally distributed. Due to difficulty in incorporating social genetic effects in the Survival Kit, Ellen et al. (2010) advanced their work by combining survival analysis and a linear animal model to estimate genetic parameters for social effects on survival time in cannibalistic layers. These two studies showed increase in heritable variance in survival time when social effects are accounted for and the importance of incorporating social effects in the breeding program for cannibalistic laying hens.

Using the same data of Ellen et al. (2008), this thesis focuses on survival analysis to study survival of hens in the early laying period versus the late period.

## 2. Aim of the study

The first aim of the study was to evaluate fixed effects such as stable, line, cage, levels, mortality of back neighbors, and reason for culling in laying hens. The second aim was to compare survival in the early laying period versus late laying period. The third aim was to estimate genetic parameters i.e. heritability ($h^2$), genetic correlations ($r_g$) for the traits overall survival days, survival in early laying period, survival in late laying period, and death due to pecking.

# 3. Materials & Methods

## 3.1 Data

The data was provided by Institut de Sélection Animale B.V. (ISA), a Hendrix genetics company, The Netherlands through partnership between Wageningen University and University of Natural Resources and Life Sciences. A detailed description of the data, genetic stock, housing and management are provided in a study by Ellen et al. (2008). The data set consisted of individual records collected on 16694 purebred White Leghorn female laying hens belonging to three lines W1, WB and WF. The data was collected during only one production cycle in a single generation. Hatching of eggs started from June 2004 till April 2005. The hens were hatched in two batches; each batch consisted of 4 age groups differed by two weeks of age. After hatching, the chicks were sexed and individually identified by putting wing bands on both wings to track records. The chicks were vaccinated for Marek's disease and infectious bronchitis. When hens were 17 weeks old, all hens were moved to two laying houses (stables) to begin their production life hence the start date for this study. Each batch was placed in another layi++ng house. The hens were randomly assigned to four- bird battery cages i.e. four birds per cage in two stables, making sure that each cage contained hens of the same line and age. In stable 1, the cages were placed in three levels i.e. top level, middle and bottom level. In stable 2, cages were placed in the middle and bottom level only. The cage members were allowed to share two drinking nipples with members of the back cage. This was possible because the back wall of the cages were made of a mesh whereas adjacent cages were separated by a closed wall. A feeding trough was placed in front of each cage. Hens were fed a standard commercial layer diet ad libitum. In both laying stables, the hens started with light period of 9 hours per day. Light period was increased to 1 hour per week till 16 hours per week when hens were on average 26 weeks old. For each hen, the hatch date, start date of experiment from time the hens were housed at 17 weeks old, date of death, cause of death and the end date of the experiment were recorded.

The structure of the data showing the distribution of layer lines in housing stables and mean survival days is presented in Table 1a and the mean survival of hens per corridor in Table 1b.

**Table 1a.** Distribution of layer lines in each laying house stable

| Variable | class | **Stable 1** N obs | **Stable 2** N obs | Total | Mean Survival days | Std |
|---|---|---|---|---|---|---|
| **Line** | W1 | 3,888 | 2,346 | 6,234 | 354.0 | 119.0 |
| | WB | 3,789 | 3,111 | 6,900 | 325.9 | 143.9 |
| | WF | 2,006 | 1,554 | 3,560 | 375.1 | 120.1 |
| | Total | 9,683 | 7,011 | 16,694 | | |
| | | | | | | |
| **Level** | Top | 3,209 | 0 | 3,209 | 329.6 | 136.2 |
| | Middle | 3,231 | 3,500 | 6,731 | 352.1 | 129.5 |
| | Bottom | 3,243 | 3,511 | 6,754 | 349.8 | 130-.6 |

N obs = number of observations, Std = standard deviation

Different numbers of individuals from each line were used in the analysis. There were 6,234 observations for line W1 and 6,900 observations for line WB while line WF had only 3,560 observations.

**Table 1b**. Descriptive statistic of mean survival and standard deviation

| | | Stable 1 | | | Stable 2 | | |
|---|---|---|---|---|---|---|---|
| Variable | Class | N obs | Mean Survival days | Std | N obs | Mean Survival days | std |
| **Corridor** | 1 | 1208 | 353.0 | 117.9 | 870 | 364.2 | 106.3 |
| | 2 | 1219 | 359.3 | 115.2 | 881 | 341.5 | 125.0 |
| | 3 | 1167 | 367.8 | 112.1 | 867 | 359.4 | 120.9 |
| | 4 | 1212 | 373.1 | 106.5 | 862 | 349.7 | 143.0 |
| | 5 | 1222 | 330.7 | 141.0 | 880 | 361.7 | 132.3 |
| | 6 | 1225 | 332.8 | 140.4 | 865 | 353.2 | 138.5 |
| | 7 | 1208 | 306.1 | 146.6 | 887 | 348.3 | 138.2 |
| | 8 | 1222 | 317.6 | 144.3 | 899 | 346.5 | 145.7 |

N obs = number of observations, Std = standard deviation

The reasons for culling are summarized in Table 1c. Determination of cause of death was done subjectively by the employees of the laying houses, without using dissection. The main reasons for culling were pecking followed by inflammation and bulge cloaca.

**Table 1c.** Reasons for culling

| reason | frequency count | percent |
|---|---|---|
| healthy | 9891 | 59.2 |
| pecking | 2892 | 17.3 |
| dead | 2045 | 12.2 |
| inflammation | 1111 | 6.7 |
| bulge cloaca | 247 | 1.5 |
| quail disease | 247 | 1.5 |
| lean | 220 | 1.3 |
| other causes | 41 | 0.2 |

## 3.2 Trait definition & measurement

The traits analyzed in this study were

1. Overall survival days

During their production life, individual survival was recorded on a daily basis and censoring status i.e. dead (1) or alive at the end of study (0). Overall survival days were defined as the number of days from the time the hens were transported to laying houses at 17 weeks old to the date of culling i.e death or the end of the experiment with a maximum of 447 days. Hens that died during the study period were identified by recording their wing bands and cage number, and removed from the cages. Dead animals were not replaced. Hens that died during the study period were referred to as uncensored i.e. event = 1 and hens still alive at the end of the study period were referred as censored i.e. event = 0.

2. Early laying period

Early laying period was defined as the length of productive life in days from the time the hens were transported to the laying houses (17 weeks old) till 161 days (40 weeks). Animals that died during this period until 161 days are considered uncensored (1). After this point i.e. from 162 days up to 447 days all animals are considered censored (0).

3. Late laying period

Late laying period was defined as the length of productive life between 162 days (41 weeks) and date of culling or till end of the study with a maximum of 447 days. Animals that died before 162 days of productive life were deleted from the data and animals failing in the late laying period i.e. from 162 to 447 days remained. Animals that survived until the end of the laying period were included in the late laying period.

4. Survival for pecking

In addition to the above traits, survival due to pecking was another trait considered in this study. Feather pecking is a behavioral disorder in poultry that consists of pecking of feathers of other birds and in severe case pulling the feathers out and eating them. It is big problem in laying hens causing economic loss and welfare concern. Due to the fact that hens used in this experiment had beaks intact i.e. untrimmed, pecking was one of the major causes of death. Animals in the data set that died due to pecking were referred to as uncensored records (1) while those alive or died due to other causes other than pecking were all referred to as right censored records (0). Therefore, data set of pecking in the early laying period was prepared by marking all animals that died due to pecking during this period until 161 days of productive life as uncensored and everything else as censored. Similarly, data set of pecking in the late laying period was prepared by marking all animals that died due to pecking as uncensored.

For all the traits, both an animal model and a sire model, keeping the same fixed effects, were used in the analysis.

### 3.3 Data Analysis

Data analysis was carried out in the Survival Kit (Mészáros et al. 2013) using its R-interface. Both Excel and SAS v 9.2 (2008) were used for data modification. Excel was used for coding the data. Pedigree file was explored in SAS to check for duplicates. Model building to determine the significant fixed effects and Survival analysis were both carried out in Survival Kit V.6.1 using its R-interface (Mészáro et al. 2013) by applying the Cox animal model. Genetic parameters were analyzed with Weibull model using both the sire and animal model. A Weibull model was used for computation of genetic parameters as the number of records including the pedigree data were too large for Cox program to handle. A Weibull model would be adequate to use if the plot of log (-log KM estimate) versus log of time produced a straight line.

### 3.4 Statistical Models

The general model used to analyze survival data is the hazard function of an individual at time t expressed as:

$$\lambda(t) = \lambda o(t)\exp[X'(t)\beta + z's]$$

Where $\lambda o(t)$ is a baseline hazard at time t, which measures the risk of an event to occur given that an individual survived up to time, t. $X'(t)\beta$ represents the fixed effects and $z's$ the random effects.

### 3.5. Evaluation of fixed effects

Fixed effects such as stable, line, cage, cage levels, mortality of back cage neighbours, and reason of death due to pecking were analyzed using the “Cox” program. The first model tested contained the fixed effects stable, corridor, level and line only (Appendix.1.) The second model contained the fixed effects stable, corridor, level, back mortality, neighbour i.e. present or absent, line and reason of death (Appendix.2). Including reason of death into the model resulted into a biased evaluation, as this effect fully separated the censored and uncensored hens. As an outcome, the reason of death became the single most important effect, but essentially duplicated the censoring and thus did not add any useful information for the length of productive life. As an alternative, we decided to analyze the death due to pecking as a separate trait, called “pecking survival” in this study. In the third model, cage as a fixed effect was included (Appendix.3). When cage is included in the model, all the parameters became significant except the hens line because every cage consisted of the same hens’ line. For the next model, cage effect was excluded because each cage contained hens of the same line, partly confounding the hen line effect. Neighbouring cages were also excluded as the presence or absence of the back cage neigbours could be obtained from information on the back cage mortality.

The fourth model was testing for the interaction effect stable by corridor, level, back mortality and layer lines as shown in Appendix 4. Consequently, fixed effects: stable*corridor interaction, level, back mortality and layer lines were all significant. The fourth model included all significant effects we considered important, used for the rest of the analysis.

## 3.6 Animal Model & Sire Model

Animal model and a sire model were used for the analysis of each data set, keeping the same fixed effects. The animal model used contained the form:

$$\lambda(t) = \lambda_0(t) \exp(\text{Stable*Corridor} + \text{level} + \text{back mortality} + \text{line} + \textit{animal})$$

While the sire model used was:

$$\lambda(t) = \lambda_0(t) \exp(\text{Stable*Corridor} + \text{level} + \text{back mortality} + \text{line} + \textit{sire})$$

Where:

$\lambda(t)$ = risk of death at time t

$\lambda_0(t)$ = baseline hazard function estimated at each discrete time point

*animal* = additive genetic value of the animal included as a random effect accounting for entire genetic variance.

*sire* = the hen's sire included as a random effect accounting for ¼ of the genetic variance.

level = cage level (top, middle or bottom)

back mortality = mortality of back cage neighbors (no death, one died, two died, three died, four birds died and no back cage neighbor available)

line = layer lines (W1, WB, WF)

## 3.7 Genetic parameters

### 3.7.1 Heritability

Heritability using sire model was calculated using the formula Yazdi et al. (2002)

$$h^2 = \frac{4\sigma_S^2}{\frac{1}{p} + \sigma_S^2}$$

Where:

$h2$ = heritability

$\sigma_S^2$ = Sire variance

$p$ = proportion of uncensored records

Heritability for animal model was also derived from the above formula.

$$h^2 = \frac{\sigma_G^2}{\frac{1}{p} + \sigma_G^2}$$

Where $h^2$ = heritability, $\sigma_G^2$ = the genetic variance and p = proportion of uncensored records

### 3.7.2 Reliability

The reliability of the estimated breeding value (EBV) was calculated using the formula derived from Henderson (1975).

$$R = 1 - PEV/\sigma_G^2$$

Where:

R = reliability of the estimated breeding value

$\sigma_G^2$ = genetic variance

*PEV* = Prediction Error Variance defined as the square of the standard error of the (regression) estimate for each animal from the survival analysis.

### 3.7.3 Genetic correlation

Both data and pedigree information were used to estimate genetic parameters. Pearson correlation coefficients were calculated in SAS v 9.1. This correlation obtained together with average reliabilities between traits were used to calculate the genetic correlations using Calo approximation method (Calo et al. 1973):

$$r_{g12} = \frac{r}{\sqrt{R_1 * R_2}}$$

Where:

$r_{g12}$= the genetic correlation between trait 1 and trait 2

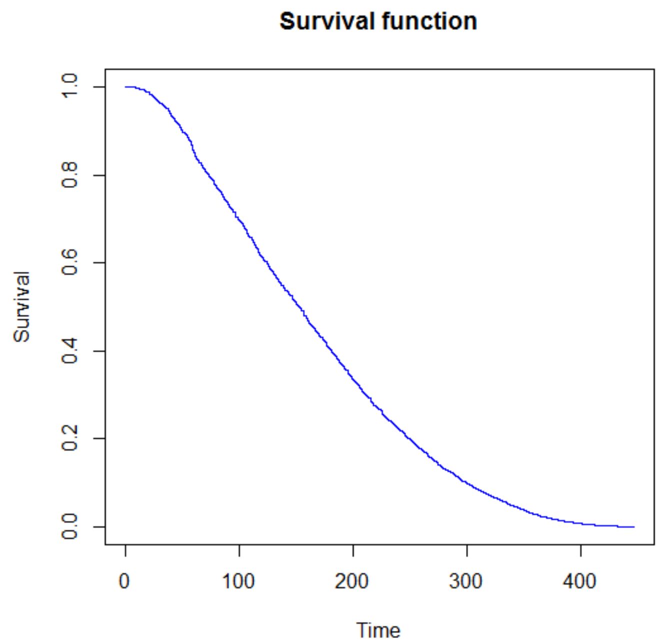
*r* = correlation between the EBVs of trait 1 and trait 2

$R_1$ = mean reliability of EBVs for trait 1

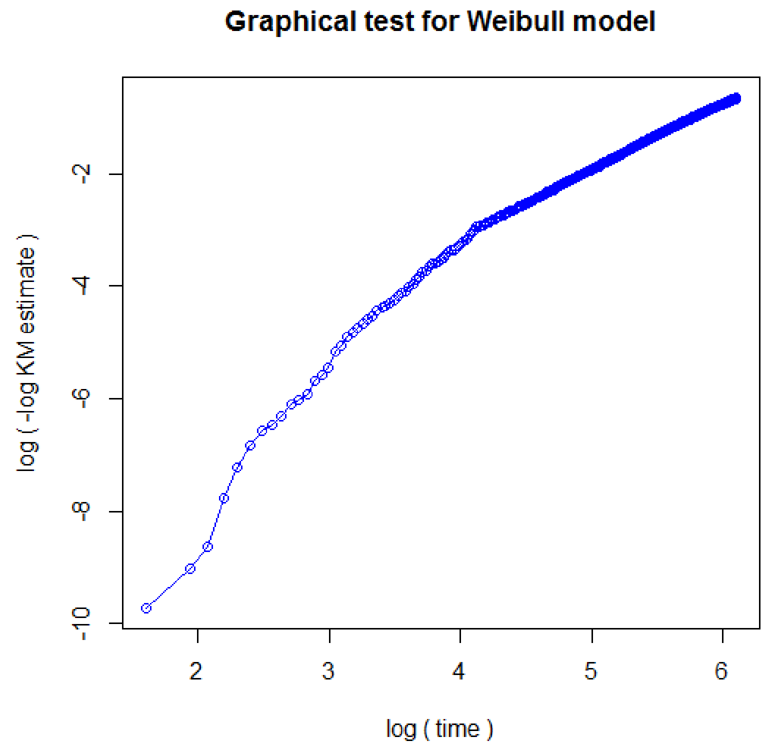
$R_2$ = mean reliability of EBVs for trait 2

## 4. Results and Discussion

A general description of the rate of death of hens is illustrated in the Survival function. The curve indicates survival as a continuous but non- normally distributed trait. The survival function for uncensored animals is shown below. The overall censoring rate was 60.4 %.




A plot of the log-log survival function i.e. log (-log KM estimate) versus log of survival time is presented in graphical test for Weibull model. A Weibull model is adequate to use as the graph produced approximately straight line




## 4.1 Results for fixed effects

A fixed effect model that was fitted with stable*corridor interaction, cage level, back mortality and line code showed all the effects in the model are significant. Results for significant fixed effects are presented in Table 2 below.

**Table 2. Likelihood Ratio Test showing significance of fixed effects**

| VARIABLE | TOTAL DF | PROB >CHI$^2$ | $R^2$ OF MADDALA |
|---|---|---|---|
| **SEQUENTIAL:** | | | |
| Stable*Corridor | 15 | 0.0000 | 0.0279 |
| level | 17 | 0.0000 | 0.0301 |
| back mortality | 22 | 0.0000 | 0.0468 |
| line | 24 | 0.0000 | 0.0663 |
| **LAST:** | | | |
| Stable*Corridor | 9 | 0.0000 | 0.0506 |
| level | 22 | 0.0000 | 0.065 |
| Back mortality | 19 | 0.0000 | 0.057 |
| line | 22 | 0.0000 | 0.0468 |

The total number of records read in the estimation of fixed effects was 16,694, right censored records were 10,082 (60.4 %) and uncensored records were 6,612 (39.6 %).

### 4.1.1 Analysis of each specific fixed effect.

The results for the analysis of stable by corridor interaction are presented in **Figure 1.**

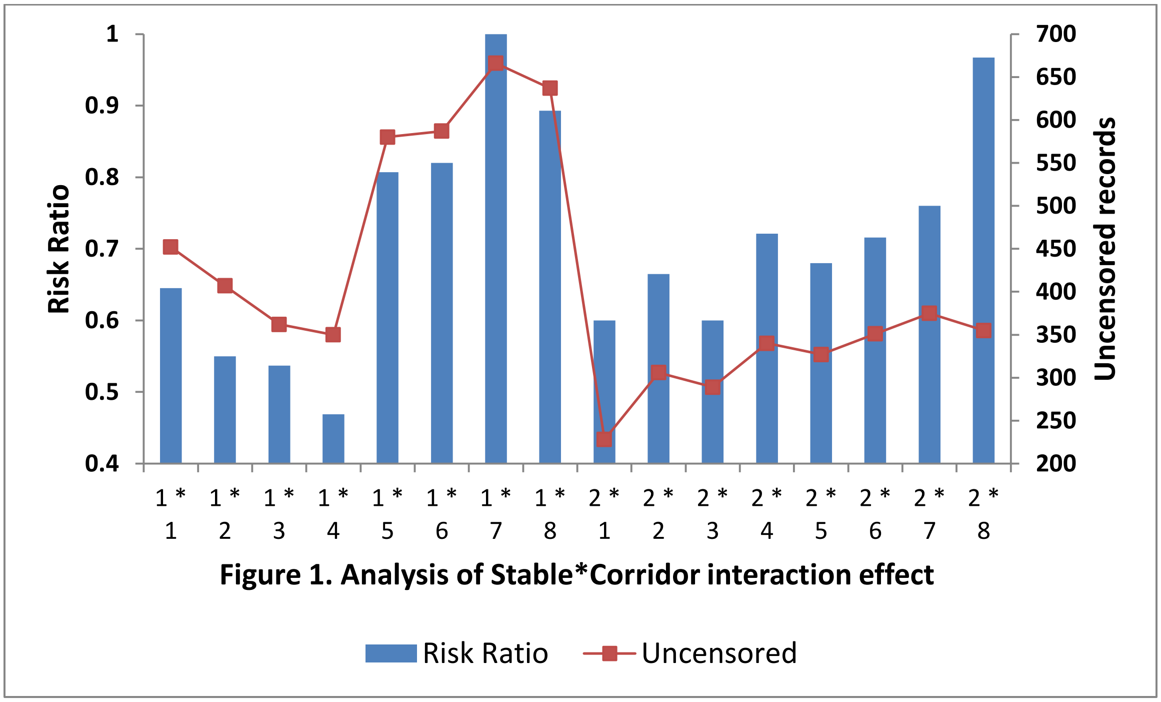



Figure 1. Analysis of stable and corridor interaction

This shows that there is a difference between laying stable 1 and 2. The hens in laying house stable 1 have lower risk ratios and better survival than hens in laying house stable 2. This difference could be due to laying house conditions such as light intensity and air quality. Laying house stable 1 was reported by Ellen et al. 2008) to experience an effect of daylight from windows and that light intensity in stable 1 was lower compared to stable 2. Light intensity in stable 1 depended entirely on weather conditions which are highly variable. It's also reported there was no daylight effect in stable 2. Lighting intensity could influence hen behavior such as feeding duration and pecking. A high light intensity might reduce survival rate as reported by Hughes and Duncan (1972).

Interaction between stable and corridor 7 and 8 showed highest risk ratios. The purpose of the corridors was for the employees to have access to the cages. Studies have shown that birds respond to an approaching human. Some birds are threatened and respond with fear while others get used to human contact. The frequency of the employees visiting the laying facility could also explain differences in risk ratios between stables by corridor interaction. Rodenburg et al. (2010)

reported higher risk of feather damage in birds at bottom level attributed to fear of humans and abrasive neck as they stretch their necks to watch what is happening.

The results for cage level are presented in **Figure.2**

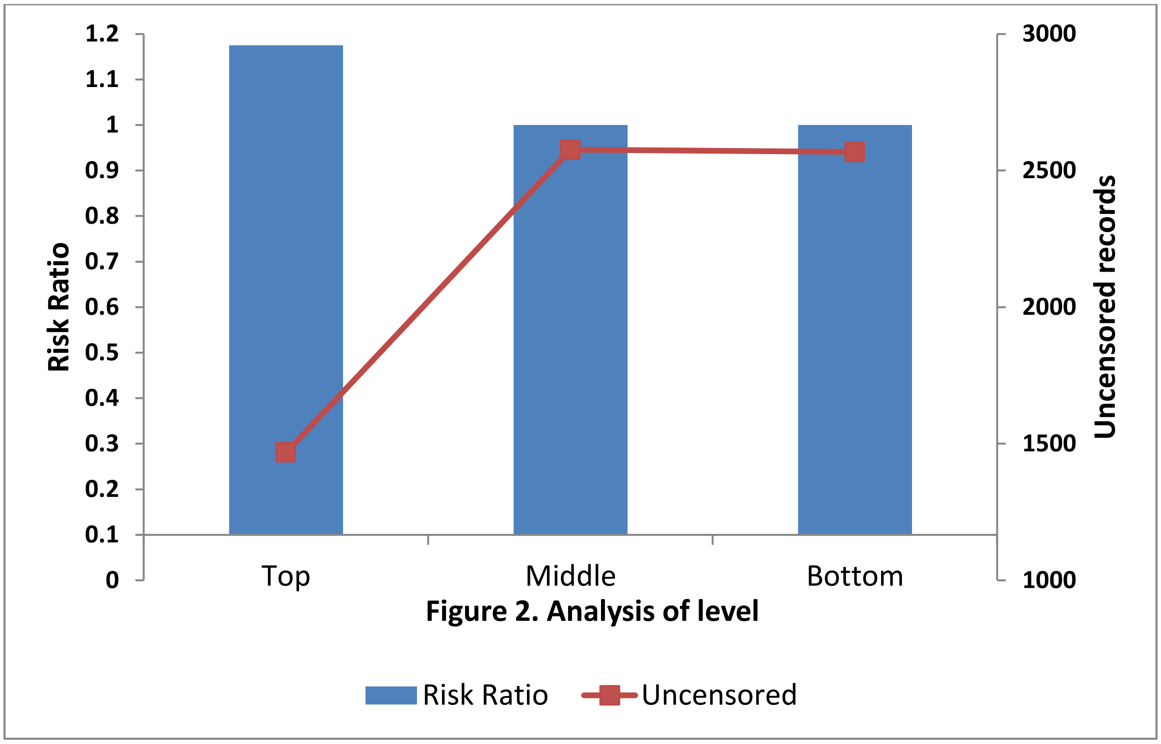



Figure 2. Analysis of cage level

Lowest survival was experienced in the top level meanwhile there was no difference between middle and bottom level. Hens in the top row had about 20% higher risk of death compared to middle and bottom cages. The reason for lowest survival in top level could be due to closeness to the light. High light intensity may reduce survival rate according to Hughes and Duncan (1972). In addition, hens in top level may be spent more time interacting with each other.

The results of the effect of back mortality i.e. the mortality of the back neighbours are presented in **Figure 3.**

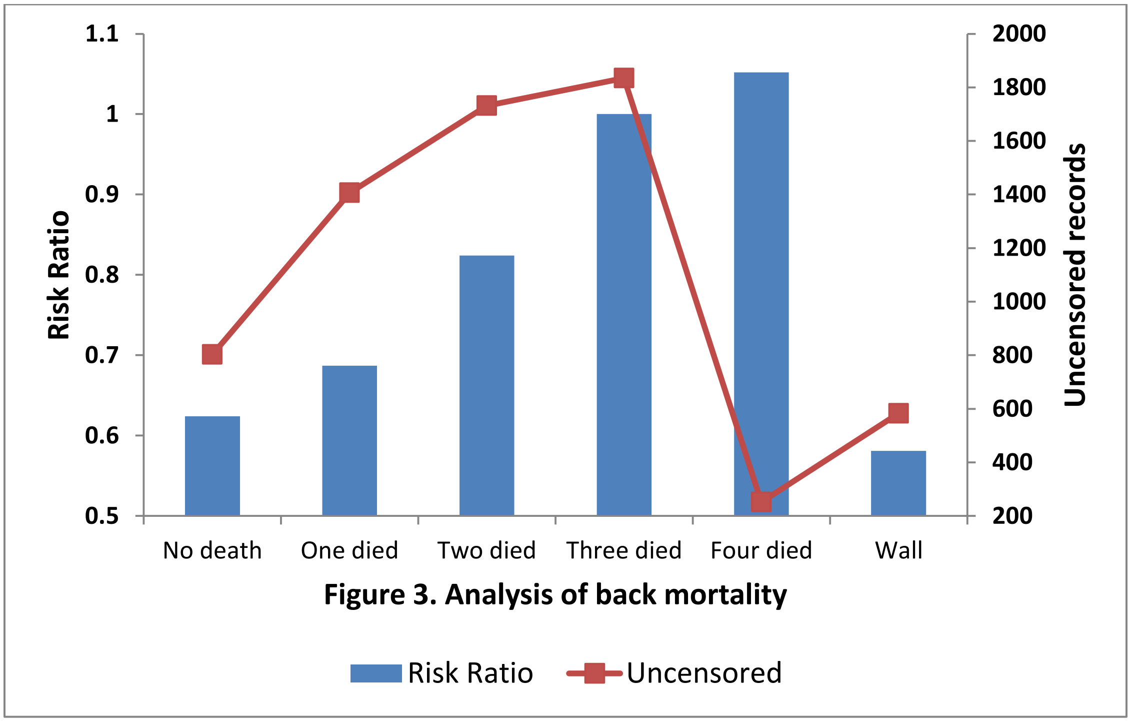



Figure 3. Analysis of back cage mortality

Generally, there is an increasing risk of culling with increase in numbers of death happening in the back cages. Survival is highest when there is no mortality of back neighbors (0) with risk ratio of 0.624 and the same to where the cages had no back neighbors; with the lowest risk ratio of 0.581. The risk of culling is highest when all back cage members died. This result indicates that the presence or absence of death cases in back neighbors has significant effect on the survival of cage members. A cage that has back neighbors could interact with each other through sharing of the drinking nipple. Cannibalism or disease transmission could happen at drinking nipple. However there is lack of sufficient evidence about causes of mortality entirely happening at the drinking location. This would require observations at the drinking nipple and a disease transmission study which are difficult and time consuming. Another explanation is that the cage members could also see what is going on in the neighbor cage and possibly copy what they witness in the neighborhood. If for example they saw their neighbors being peck on feathers or on the head, they most likely begin to peck too. Rodenburg et al. (2010) reported that cannibalism is a social behaviour and that other birds could respond to it. Witnessing a sad scene like death could cause stress and fear to which may interfere with feeding habit. Injuries caused on head, neck and cloaca regions of hens by cannibal members may lead to high risk of infection and diseases which may be transmitted across cages Rodenburg et al. (2010). Back mortality could be greatly influenced by social behavior of the birds. Having a closed wall or having no back neighbors tend to improve survival.

The results for layer line are presented in **Figure 4.**

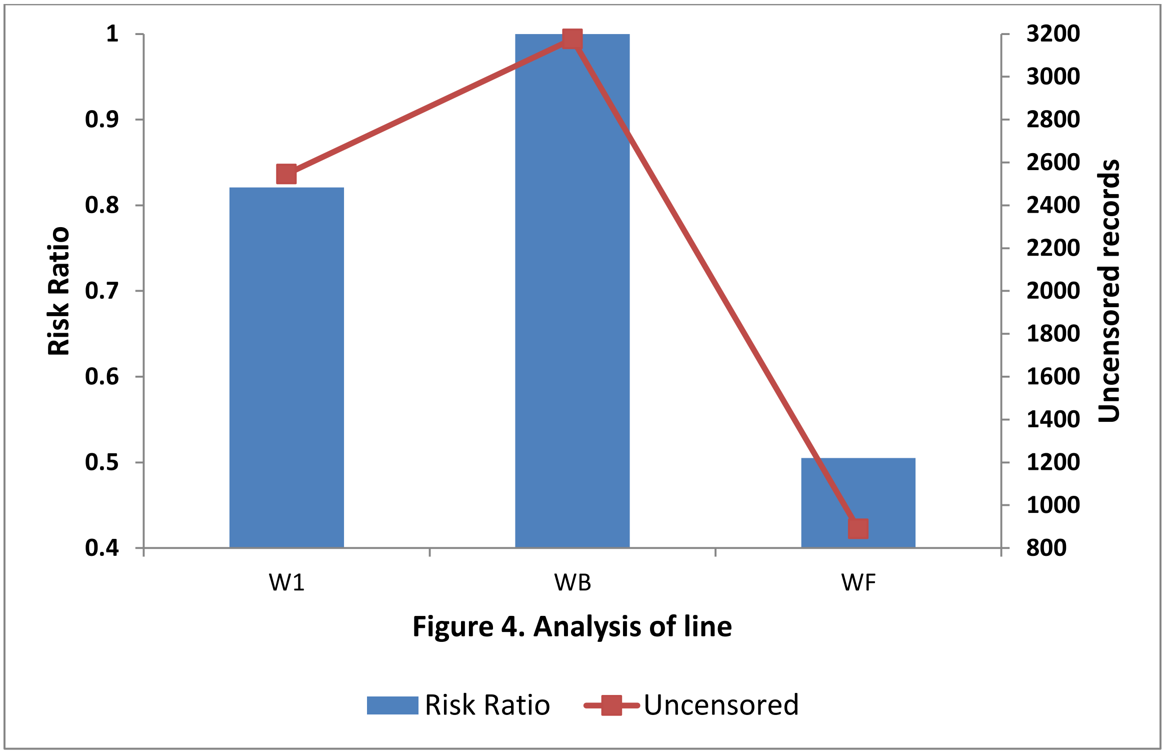



Figure 4. Analysis of layer line

There are significant differences between layer lines with regard to survival. Line WB showed the lowest survival that is the highest risk of being culled followed by line W1. This result is in agreement with studies of Boison S (2010 unpublished) and Ellen et al. (2008). Both found lowest survival in line WB as 53.9 % and line W1 as 59.2 %. Mean survival days also varied among lines. If we refer to the mean survival days in Table 1a, line W1 has 354 days and line WB has 325.9 days. A difference of 28.1 days could be the reason why line WB has higher mortality than W1. Line WF appeared with the lowest risk ratio of 0.505, having the highest survival with highest mean survival days of 375.1. This same line WF was reported to have the highest survival of up to 74.6 % (Ellen et al. 2008). However in this study, line WF had the smallest sample size of 3,560 which could have resulted in the small number of uncensored records. Line WF was characterized as a high feather pecking line in previous studies. Differences between high feather pecking and low feather pecking lines could also explain differences in survival among lines (Rodenburg et al. (2010).

## 4.2 Comparison of early laying period vs. late laying period using both the animal and the sire model

A comparison of stable by corridor interaction effect in the early and late laying period is presented in **Figure 5.**

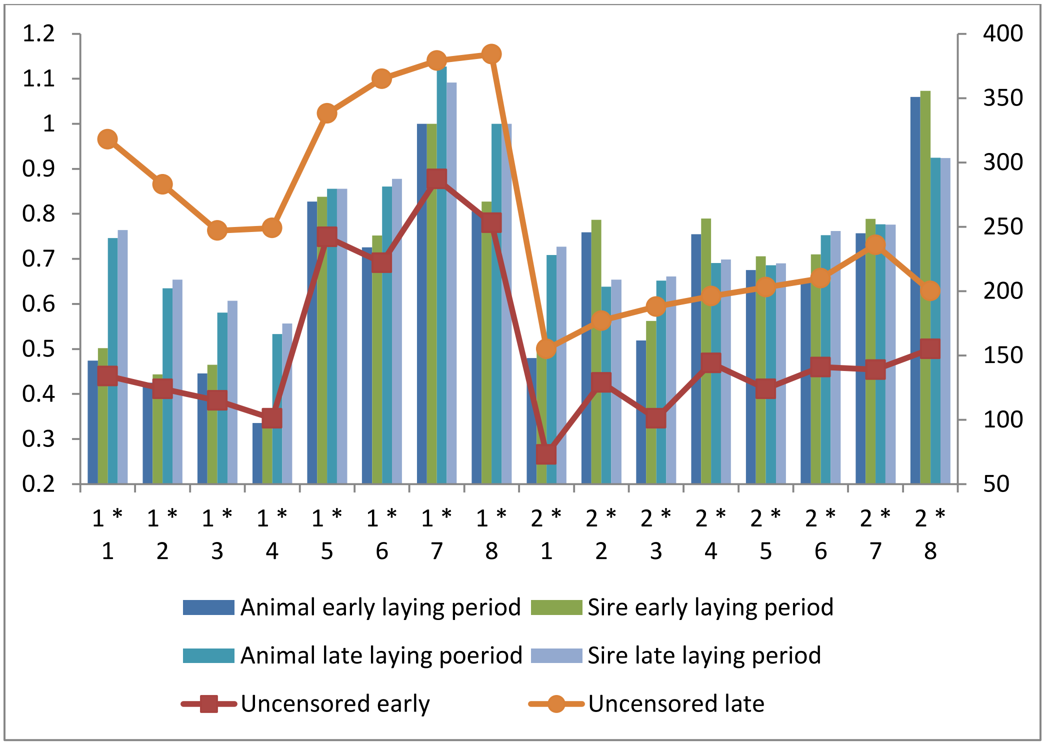



Figure 5. Comparison Stable*Corridor interaction effect

A comparison of cage level in the early and late laying period is presented in **Figure 6.**

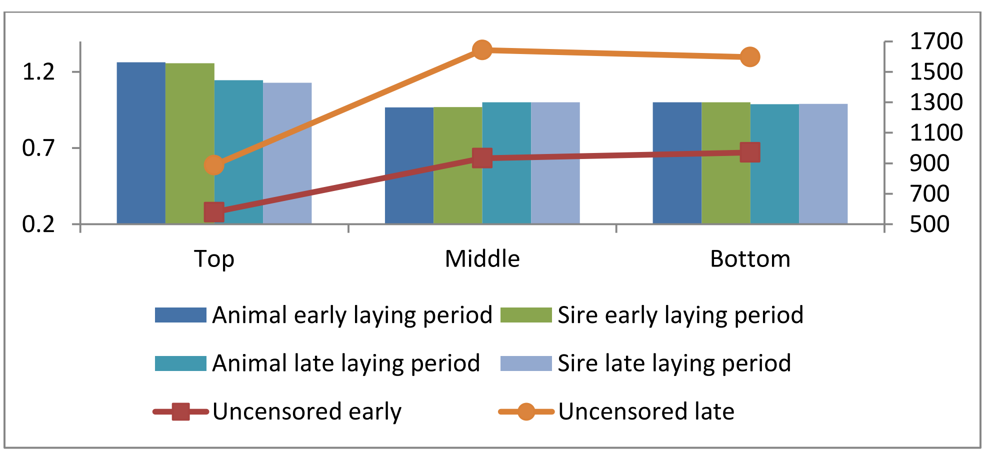



Figure 6. Comparison of cage level

A comparison of mortality of back cage neighbours in the early and late laying period is presented in **Figure 7**.

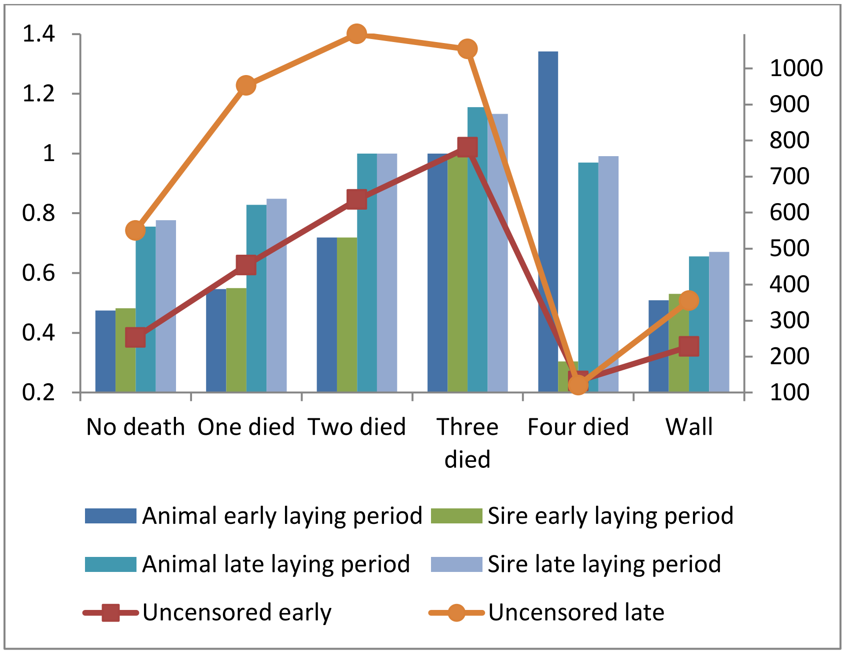



Figure 7. Comparison of back mortality

The sire model for early laying period produced unexpected result. It showed that when all the four birds died in the back cage, there was very low risk of death in the neighbouring cages and lowest number of uncensored records. The exact reason for this result is unknown, but the trend from other model types shows that the risk ratio should be higher. A more detailed look into this problematic is needed.

A comparison of layer lines in the early and late laying period is presented in **Figure 8**.

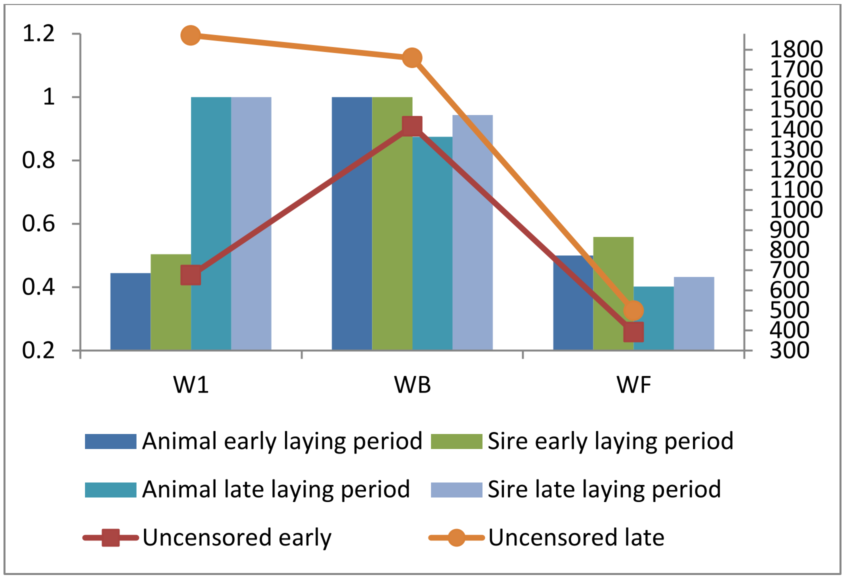



Figure 8. Comparison of layer lines

The results for comparison of early laying period vs. late laying period using both animal model and the sire model presented above follow the same tendencies, except for layer lines. In the comparison for layer lines **Figure 8**, there is significant difference between the early and late laying period for line W1 as confirmed by both animal and the sire models. Line W1 had about 50 % higher risk of death in the late laying period compared to the early laying period. This could be due to genotype by environment interaction. Possibly the breeding environment and rearing environment were better suited for W1 and their effects diminished as the birds grew older.

For every comparison of factor, there were higher numbers of uncensored records in the late laying period than in the early laying period. This could be due to animals dying due diseases that persisted throughout life, increase pecking and other factors. The risks of culling are similar with both sire and animal models.

## 4.3 Genetic Parameters

The genetic parameters for, overall survival, early laying period and late laying period are summarized in **Table 3a.** An example of calculation of heritability: if the proportion of uncensored records in the early laying period until 161 days was 2484 i.e. 14.88 % while the proportion of the censored records was 14,210 i.e. 85.12 % and the additive genetic variance for animal in the early laying period is 0.54144, than the value of heritability is 0.0745. Standard errors for heritability are not available from manually calculated heritabilities.

**Table 3a.** Summary of survival, heritability and mean reliability with standard deviation in bracket

| Data | Model | Censored records | Genetic variance | Heritability $h^2$ | Mean reliability |
|---|---|---|---|---|---|
| Overall survival | Animal | 10082 (60.39 %) | 0.32778 | 0.115 | 0.285 (0.119) |
| | Sire | 10082 (60.39 %) | 0.05739 | 0.089 | 0.742 (0.080) |
| Early laying period | Animal | 14210 (85.12 %) | 0.54144 | 0.074 | 0.240 (0.106) |
| | sire | 14210 (85.12 %) | 0.06774 | 0.040 | 0.582 (0.102) |
| Late laying period | Animal | 10073 (70.93 %) | 0.59308 | 0.147 | 0.293 (0.125) |
| | Sire | 10073 (70.93 %) | 0.07157 | 0.081 | 0.699 (0.095) |

Overall survival rate was 60.39 %. Survival in the early laying period was higher (85.12 %) than survival in the late laying period (70.93 %). According to another study (Ellen et al. 2008) overall survival ranged from 52.9 % through 74.6 % between the three lines. Survival in laying hens with intact beaks are generally lower compared to commercial farms that have survival of about 85 %. The reason for the low survival in our study could be because all the laying hens used in our study had intact beaks i.e. beaks not trimmed. Higher mortality due to pecking and cannibalism is reported in layer lines with intact beaks. Furthermore, in our study light intensity was higher compared to light intensity in commercial farms.

The survival in the early laying period is higher than late laying period possibly because few animals died during this time. It could be that some animals had problems and diseases during the early laying period but they did not die from it. The problem could have persisted throughout life until it finally killed them during the late laying period. Among the causes of death recorded were inflammation, bulge cloaca, quail disease, diarrhea, fracture virus and water belly, some of which do persist throughout life. In addition, young birds that are more active and have stronger pecking motivation could develop feather pecking as adults (Newberry et al. 2007).

Generally, low estimated heritability ranging from 0.040 to 0.147 were found. These results are consistent with the heritability estimates of longevity and productive life reported in other studies (Mészáros et al. 2010, Cole et al. 2004, Mielenz et al. 2005, Craig and Muir, 1989, Piles et al. 2006, Ellen et al. 2008). Mészáros et al. (2010) reported the heritability of longevity in Landrace sows using the continuous data ranging between 0.05-0.08 (s.e.0.01-0.02) whereas in Large White sows, the heritability ranged between 0.08 and 0.14 (s.e.0.012-0.026) was reported. The heritability of survival days for laying hens ranged from 0.032 to 0.099 were reported by Mielenz et al. (2005), Craig and Muir (1989). Piles et al (2006) found the heritability for length of productive life in rabbit to be around 0.16. Ellen et al. (2008) reported heritability for survival of White Leghorn laying hens ranging between 2 % to 10 %. This indicates that genetic improvement is possible. Estimated heritabilities using the animal model were higher compared to the sire model. The difference could be due to methods of estimation. The sire model tends to underestimate the heritability as ¾ of additive genetic variance and environmental variance constitute the error variance. The dam variance, Mendelian sampling variance and environmental variance are not taken into account. The heritability in the late laying period is twice the heritability in the early laying period. This implies that the ability to survive in the late laying period is more influenced by genetic background.

Genetic correlations using sire model are presented in Table 3b below. The genetic correlations are presented without their standard errors because average reliabilities are used.

**Table 3b**. Pearson's correlation coefficient between EBVs due to 91 sires on off diagonal and the genetic correlation using Calo approximation below the diagonal

| | Overall survival | Early laying period | Late laying period |
|---|---|---|---|
| Overall survival | | **0.834** | **0.929** |
| Early laying period | **1.269** | | **0.578** |
| Late Laying period | | **0.907** | |

The genetic correlations between overall survival, early laying period and late laying period were high and positive (0.834 and 0.929).This suggests that an improvement in survival days in early laying period could increase survival in the late laying period. The genetic correlation between early and late laying period was lower (0.578), indicating that ranking of animals was affected. This low correlation could be due to re-ranking of sires. Animals that were given a high ranking in the early laying period did not become best in the late laying period and therefore given a lower ranking in the late laying period. There was even a much higher genetic correlation obtained between overall survival and survival in the early laying period (1.269) and survival in the early and late laying period (0.907) with Calo approximation. This method could be less reliable. Surprisingly, one of the correlation coefficients was higher than 1, which was due to the average reliabilities in the equation.

Genetic correlations using animal model are presented in Table 3c.

**Table 3c**. Pearson correlation coefficient of EBVs using animal model on off diagonal

| | Early laying period | Late laying period |
|---|---|---|
| Overall survival | **0.788** | **0.873** |
| Early laying period | | **0.404** |

Table 3c shows the correlation between the breeding values. The Pearson's correlations between EBVs from the full time interval represented by overall survival and early laying period was 0.788, between full time interval and late laying period was 0.873 and between early and late laying period was 0.404. Whether using the animal or sire model, genetic correlations were similar. This shows that both sire model and animal model leads to similar results. The correlation coefficient is not very close to 1, so some degree of re ranking could be expected. The correlation between early and late laying period of 0.404 implies severe ranking of animals was affected. Probably the top animals in the early laying period did not become top in the late laying period and those that were low during early laying period became better in the late laying period. Selection decision could be to select for hens that go on for the entire laying period so as to get more eggs.

The genetic parameters for survival due to pecking are presented in Table 5.

**Table 5.** Survival due to pecking

| Data | Model | Censored records | Genetic variance | Heritability $h^2$ |
|---|---|---|---|---|
| Early laying period | Animal | 15332 (91.84%) | 0.59243 | 0.046 |
| | Sire | 15332 (91.84 %) | 0.09244 | 0.030 |
| Late laying period | Animal | 12671 (89.22 %) | 0.54449 | 0.055 |
| | Sire | 12671 (89.22 %) | 0.09908 | 0.042 |

This results show that about 10 % of the animals died due to pecking during the entire laying period. This only represents animals that died due to pecking only excluding those that received the reason dead and inflammation. Feather pecking has been reported to have a moderate heritability between 0.07 and 0.38 (Bessei 1986), and between 0.11 to 0.20 for divergent lines (Rodenburg et al.2003). Heritability for survival due to pecking in this study ranged from 0.03 to 0.05. This could be due to long time of selection practiced, variability of pecking within layer lines. Pecking was also recorded as a binary trait, which may not describe much of the true variability hence contributing to low heritability. However, heritability seemed to increase with age. Therefore if birds who are peckers are identified at an early age and excluded from breeding, deaths due to pecking may decrease. Unfortunately it is difficult to identify birds that are responsible for starting pecking in the group.

Mortality due to feather pecking and cannibalism is reported as one of the major causes of death in laying hens with intact beaks. Severe pecking cause feather damage and loss, pain, injuries, risk of infection and can trigger cannibalism resulting into increase mortality (Savory, 1995; Blokhuis and Arke, 1984). It may also lead to an increase in food consumption raising the feed cost. Between 10 % to 30 % increase in food consumption to replace heat loss due to feather loss is reported by Glatz (1988). Feather pecking has both genetic and environmental causes. It could be influenced by group size, diet, stress and light intensity (Sedlačková et al. 2004). Lack of foraging materials such as straw, wood shavings or sand in the hen's cage, considerably increase pecking (Blokhuis, 1986). Hens have a tendency to search for food even when food is supplied in the feeders. They look for forage and scratch the ground. Bright light also increases feather pecking (Savory 1995, Hughes and Duncan 1972). Feather pecking is also reported to be related to fearfulness. Fearful birds are more likely to develop feather pecking (Rodenburg et al. 2010).

## 5. Conclusions

Survival analysis was used to examine the survival of purebred White Leghorn laying hens lines in the early and late production period. Statistical model with fixed effects of stable*corridor interaction, cage level, mortality of back cage neighbors and layer lines were all significant. Different risk ratio patterns were observed between the two laying houses. Hens in the top row had about 20% higher risk of death compared to middle and bottom cages. Number of death cases in the back neighbor cage had a negative effect on the survival of laying hens with increasing risk with each death of neighbor hens. The highest risk ratio was observed for the WB line, the lowest for WF line. Survival traits had low heritability values, showing prospect for genetic improvement. The heritability for overall survival was 0.11 while for early laying period was 0.07 and for late laying period was 0.15. When pecking was considered as the only reason of death, the heritabilities were 0.03-0.04 for early laying period and 0.04-0.05 for late laying period. There were high positive genetic correlations between overall survival and the early laying period and late laying period. Moderate genetic correlations between early laying period and late laying period showed there was re-ranking of animals. Based on our results, we would recommend Hendrix Genetics to estimate only one breeding value for the overall survival because it reflects the whole production period, with high correlations between overall survival versus early laying period and overall survival versus late laying period. On the other hand, the relatively low genetic correlation between early and late laying period shows that there could be genetic differences between animals, deserving further attention.

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# 7. Appendices

## Appendix 1. First model

| LIKELIHOOD | RATIO | TESTS : | SEQUENTIAL | | | | |
|---|---|---|---|---|---|---|---|
| VARIABLE | TOTAL DF | | -2 LOG LIK INCLUDING Z | $CHI^2$ | DELTA DF | PROB $>CHI^2$ | $R^2$ OF MADDALA |
| stable | 1 | | 125255.4 | 43.365 | 1 | 0.0000 | 0.0026 |
| corridor | 8 | | 124940 | 315.38 | 7 | 0.0000 | 0.0213 |
| level | 10 | | 124903.2 | 36.819 | 2 | 0.0000 | 0.0234 |
| Line | 12 | | 124434.6 | 468.61 | 2 | 0.0000 | 0.0504 |

| COVARIATE | ESTIMATE | STSANDARD ERROR | $CHI^2$ | PROB $>CHI^2$ | RISK RATIO | UNENSORED FAILURES |
|---|---|---|---|---|---|---|
| stable | | | | | | |
| 1 | 0 | * | * | * | 1 | 4041 |
| 2 | -0.1195 | 0.028 | 18.17 | 0 | 0.887 | 2571 |
| corridor | | | | | | |
| 1 | -0.5372 | 0.0494 | 118.31 | 0 | 0.584 | 680 |
| 2 | -0.4847 | 0.0487 | 99.05 | 0 | 0.616 | 713 |
| 3 | -0.5658 | 0.05 | 127.89 | 0 | 0.568 | 651 |
| 4 | -0.5468 | 0.0492 | 123.73 | 0 | 0.579 | 690 |
| 5 | -0.1895 | 0.0454 | 17.39 | 0 | 0.827 | 907 |
| 6 | -0.1606 | 0.0451 | 12.68 | 0.0004 | 0.852 | 938 |
| 7 | 0 | * | * | * | 1 | 1041 |
| 8 | -0.0758 | 0.0444 | 2.92 | 0.0876 | 0.927 | 992 |
| level | | | | | | |
| Top | 0.2006 | 0.0356 | 31.7 | 0 | 1.222 | 1468 |
| Middle | 0 | * | * | * | 1 | 2576 |
| Bottom | 0.0001 | 0.0279 | 0 | 0.9959 | 1 | 2568 |
| Line | | | | | | |
| W1 | -0.211 | 0.0267 | 62.45 | 0 | 0.81 | 2546 |
| WB | 0 | * | * | * | 1 | 3176 |
| WF | -0.7702 | 0.038 | 411.63 | 0 | 0.463 | 890 |

## Appendix 2. Second model

| LIKELIHOOD VARIABLE | RATIO TESTS : TOTAL DF | SEQUENTIAL -2 LOG LIK INCLUDING Z | CHI2 | DELTA DF | PROB $>CHI^2$ | $R^2$ OF MADDALA |
|---|---|---|---|---|---|---|
| stable | 1 | 125255.4 | 43.365 | 1 | 0 | 0.0026 |
| corridor | 8 | 124940 | 315.38 | 7 | 0 | 0.0213 |
| level | 10 | 124903.2 | 36.819 | 2 | 0 | 0.0234 |
| backmortality | 15 | 124570.1 | 333.06 | 5 | 0 | 0.0427 |
| back neighbour | 16 | 124570.1 | 6.11E-10 | 1 | 1 | 0.0427 |
| line | 18 | 124223.1 | 347.04 | 2 | 0 | 0.0624 |
| reason | 25 | 102904.9 | 21318 | 7 | 0 | 0.7385 |

| COVARIATE | ESTIMATE | STANDARD ERROR | CHI2 | PROB >CHI2 | RISK RATIO | UNCENSORED FAILURES |
|---|---|---|---|---|---|---|
| stable | | | | | | |
| 1 | 0 | * | * | * | 1 | 4041 |
| 2 | 0.0401 | 0.0325 | 1.52 | 0.2172 | 1.041 | 2571 |
| corridor | | | | | | |
| 1 | 0.0078 | 0.0538 | 0.02 | 0.8853 | 1.008 | 680 |
| 2 | 0.0763 | 0.0496 | 2.37 | 0.1239 | 1.079 | 713 |
| 3 | -0.0816 | 0.0512 | 2.54 | 0.1111 | 0.922 | 651 |
| 4 | -0.0884 | 0.0503 | 3.08 | 0.0791 | 0.915 | 690 |
| 5 | -0.072 | 0.046 | 2.46 | 0.1171 | 0.931 | 907 |
| 6 | -0.1071 | 0.0454 | 5.55 | 0.0185 | 0.898 | 938 |
| 7 | 0 | * | * | * | 1 | 1041 |
| 8 | -0.0485 | 0.0494 | 0.96 | 0.3264 | 0.953 | 992 |
| level | | | | | | |
| Top | 0.018 | 0.0361 | 0.25 | 0.6181 | 1.018 | 1468 |
| Middle | 0 | * | * | * | 1 | 2576 |
| Bottom | -0.0485 | 0.0282 | 2.97 | 0.0849 | 0.953 | 2568 |
| back mortality | | | | | | |
| No death | -0.1736 | 0.0444 | 15.33 | 0.0001 | 0.841 | 803 |
| One died | -0.2111 | 0.0368 | 32.95 | 0 | 0.81 | 1407 |
| Two died | -0.1031 | 0.0343 | 9.06 | 0.0026 | 0.902 | 1732 |
| Three died | 0 | * | * | * | 1 | 1835 |
| Four died | 0.0161 | 0.0678 | 0.06 | 0.8118 | 1.016 | 252 |
| No back neighbour | -0.0307 | 1.0019 | 0 | 0.9756 | 0.97 | 583 |
| back neighbour | | | | | | |
| yes | 0 | * | * | * | 1 | 6029 |
| No | -0.0307 | * | * | * | 0.97 | 583 |
| line | | | | | | |
| W1 | -0.3213 | 0.0274 | 137.5 | 0 | 0.725 | 2546 |
| WB | 0 | * | * | * | 1 | 3176 |
| WF | 0.0251 | 0.0389 | 0.42 | 0.5186 | 1.025 | 890 |
| reason | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | -9.0615 | 0.3558 | 648.73 | 0 | 0 | 8 |
| 1 | 0 | * | * | * | 1 | 2880 |
| 2 | -0.8635 | 0.0315 | 751.18 | 0 | 0.422 | 1901 |
| 3 | -0.3738 | 0.036 | 107.66 | 0 | 0.688 | 1102 |
| 4 | -0.5585 | 0.0676 | 68.25 | 0 | 0.572 | 241 |
| 5 | 2.2774 | 0.0769 | 877.9 | 0 | 9.751 | 247 |
| 6 | -0.6001 | 0.0721 | 69.26 | 0 | 0.549 | 212 |
| 7 | -0.6991 | 0.2197 | 10.13 | 0.0015 | 0.497 | 21 |

## Appendix 3. Third model

LIKELIHOOD RATIO TEST: SEQUENTIAL

| VARIABLE Z | TOTAL DF | -2 LOG LIK INCLUDING Z | $CHI^2$ | DELTA DF | PROB $>CHI^2$ | $R^2$ OF MADDALA |
|---|---|---|---|---|---|---|
| stable | 1 | 125255.4 | 43.365 | 1 | 0 | 0.0026 |
| corridor | 8 | 124940 | 315.38 | 7 | 0 | 0.0213 |
| level | 10 | 124903.2 | 36.819 | 2 | 0 | 0.0234 |
| cage | 3361 | 118255.8 | 6647.4 | 3351 | 0 | 0.3442 |
| back mortality | 3366 | 118197.1 | 58.685 | 5 | 0 | 0.3465 |
| neighbour | 3367 | 118189.3 | 7.7984 | 1 | 0.0052 | 0.3468 |
| line | 3369 | 118188.8 | 0.55847 | 2 | 0.7564 | 0.3468 |
| reason | 3376 | 94511.67 | 23677 | 7 | 0 | 0.8418 |

| COVARIATE | | ESTIMATE | STANDARD ERROR | $CHI^2$ | PROB $>CHI^2$ | RISK RATIO | UNCENSORED FAILURES |
|---|---|---|---|---|---|---|---|
| stable | | | | | | | |
| | 1 | 0 | * | * | * | 1 | 4041 |
| | 2 | -0.0186 | 3.4782 | 0 | 0.9957 | 0.982 | 2571 |
| corridor | | | | | | | |
| | 1 | 0.0049 | 2.8807 | 0 | 0.9987 | 1.005 | 680 |
| | 2 | 0.2291 | 2.1836 | 0.01 | 0.9164 | 1.257 | 713 |
| | 3 | -0.0189 | 2.2922 | 0 | 0.9934 | 0.981 | 651 |
| | 4 | -0.0859 | 2.2944 | 0 | 0.9701 | 0.918 | 690 |
| | 5 | -0.0565 | 2.1937 | 0 | 0.9795 | 0.945 | 907 |
| | 6 | -0.2064 | 3.2568 | 0 | 0.9495 | 0.813 | 938 |
| | 7 | 0 | * | * | * | 1 | 1041 |
| | 8 | -0.0955 | 1.9011 | 0 | 0.96 | 0.909 | 992 |
| level | | | | | | | |
| | Top | 0.0749 | 2.3851 | 0 | 0.975 | 1.078 | 1468 |
| | Middle | 0 | * | * | * | 1 | 2576 |
| | Bottom | -0.0138 | 2.3809 | 0 | 0.9954 | 0.986 | 2568 |
| cage | | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 91 | -999.99 | * | * | * | 0 | 0 |
| 92 | -0.8276 | 1.9177 | 0.19 | 0.6661 | 0.437 | 3 |
| 93 | -2.4326 | 1.6392 | 2.2 | 0.1378 | 0.088 | 3 |
| 94 | -1.6803 | 1.9203 | 0.77 | 0.3816 | 0.186 | 3 |
| 95 | -999.99 | * | * | * | 0 | 0 |
| 96 | -999.99 | * | * | * | 0 | 0 |
| 97 | -1.597 | 2.1637 | 0.54 | 0.4605 | 0.203 | 3 |
| 98 | 2.1308 | 2.0748 | 1.05 | 0.3044 | 8.421 | 1 |
| 99 | -999.99 | * | * | * | 0 | 0 |
| 910 | 2.0258 | 2.1601 | 0.88 | 0.3483 | 7.582 | 3 |
| 911 | 1.7968 | 1.6817 | 1.14 | 0.2853 | 6.03 | 2 |
| 912 | 5.2031 | 2.2087 | 5.55 | 0.0185 | 181.829 | 2 |
| 913 | -0.2831 | 2.1989 | 0.02 | 0.8976 | 0.753 | 2 |
| 914 | 0.2967 | 2.1984 | 0.02 | 0.8926 | 1.345 | 2 |
| 915 | 4.1708 | 2.293 | 3.31 | 0.0689 | 64.764 | 1 |
| 916 | -0.3034 | 2.0802 | 0.02 | 0.884 | 0.738 | 1 |
| 917 | -0.5093 | 2.1996 | 0.05 | 0.8169 | 0.601 | 2 |
| 918 | -2.6112 | 2.093 | 1.56 | 0.2122 | 0.073 | 1 |
| 919 | -1.679 | 1.9634 | 0.73 | 0.3925 | 0.187 | 2 |
| 920 | -0.7307 | 2.204 | 0.11 | 0.7402 | 0.482 | 2 |
| 921 | 0.7664 | 1.6372 | 0.22 | 0.6397 | 2.152 | 3 |
| 922 | 0.473 | 1.2921 | 0.13 | 0.7143 | 1.605 | 3 |
| 923 | -2.5362 | 1.6906 | 2.25 | 0.1336 | 0.079 | 2 |
| 924 | 5.6881 | 1.5877 | 12.83 | 0.0003 | 295.322 | 1 |
| 925 | -2.0758 | 1.3624 | 2.32 | 0.1276 | 0.125 | 2 |
| 926 | -0.1433 | 1.9588 | 0.01 | 0.9417 | 0.866 | 2 |
| 927 | -2.3236 | 1.9662 | 1.4 | 0.2373 | 0.098 | 2 |
| 928 | 1.6856 | 1.8194 | 0.86 | 0.3542 | 5.396 | 1 |
| 929 | -1.3683 | 1.9184 | 0.51 | 0.4757 | 0.255 | 3 |
| 930 | -2.2945 | 1.6897 | 1.84 | 0.1745 | 0.101 | 2 |
| 931 | -2.495 | 2.3215 | 1.16 | 0.2825 | 0.082 | 1 |
| 932 | -0.4164 | 1.9587 | 0.05 | 0.8317 | 0.659 | 2 |
| 933 | 0.5356 | 2.3173 | 0.05 | 0.8172 | 1.709 | 1 |
| 934 | -999.99 | * | * | * | 0 | 0 |
| 935 | -999.99 | * | * | * | 0 | 0 |
| 936 | -1.4524 | 2.1637 | 0.45 | 0.5021 | 0.234 | 3 |
| 937 | -0.6868 | 2.162 | 0.1 | 0.7507 | 0.503 | 3 |
| 938 | 0.4833 | 2.3175 | 0.04 | 0.8348 | 1.621 | 1 |
| 939 | -1.4612 | 1.6374 | 0.8 | 0.3722 | 0.232 | 3 |
| 940 | -0.2192 | 1.9165 | 0.01 | 0.9089 | 0.803 | 3 |
| 941 | -2.7665 | 1.963 | 1.99 | 0.1587 | 0.063 | 2 |
| 942 | -999.99 | * | * | * | 0 | 0 |
| 943 | 6.4652 | 2.8968 | 4.98 | 0.0256 | 642.402 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 944 | 0.5377 | 2.314 | 0.05 | 0.8162 | 1.712 | 1 |
| 945 | -0.0685 | 2.1952 | 0 | 0.9751 | 0.934 | 2 |
| 946 | 0.8835 | 1.6787 | 0.28 | 0.5987 | 2.419 | 2 |
| 947 | -999.99 | * | * | * | 0 | 0 |
| 948 | -1.9062 | 2.311 | 0.68 | 0.4095 | 0.149 | 1 |
| 949 | -999.99 | * | * | * | 0 | 0 |
| 950 | 2.3642 | 1.823 | 1.68 | 0.1947 | 10.636 | 1 |
| n =7702 | 1.9258 | * | * | * | 6.861 | 3 |

Note: Results for cages are not presented all because they were too many more than 4100 cages used to house hens!!!

| | | | | | | |
|---|---|---|---|---|---|---|
| back mortality | | | | | | |
| No death | -0.1701 | * | * | * | 0.844 | 803 |
| One died | -0.2373 | * | * | * | 0.789 | 1407 |
| Two died | -0.1002 | * | * | * | 0.905 | 1732 |
| Three died | 0 | * | * | * | 1 | 1835 |
| Four died | 0.0432 | * | * | * | 1.044 | 252 |
| No back neighbour | 0.02 | * | * | * | 1.02 | 583 |
| neighbour | | | | | | |
| Yes | 0 | * | * | * | 1 | 6029 |
| No | 0.02 | * | * | * | 1.02 | 583 |
| line | | | | | | |
| W1 | -0.6392 | * | * | * | 0.528 | 2546 |
| WB | 0 | * | * | * | 1 | 3176 |
| WF | 0.465 | * | * | * | 1.592 | 890 |
| reason | | | | | | |
| 0 | -14.7582 | 0.3882 | 1445.26 | 0 | 0 | 8 |
| 1 | 0 | * | * | * | 1 | 2880 |
| 2 | -1.7319 | 0.0687 | 635.29 | 0 | 0.177 | 1901 |
| 3 | -0.6204 | 0.0693 | 80.13 | 0 | 0.538 | 1102 |
| 4 | -1.1013 | 0.14 | 61.88 | 0 | 0.332 | 241 |
| 5 | 3.4753 | 0.171 | 412.82 | 0 | 32.307 | 247 |
| 6 | -1.2574 | 0.1586 | 62.88 | 0 | 0.284 | 212 |
| 7 | -0.6465 | 0.4305 | 2.26 | 0.1331 | 0.524 | 21 |

## Appendix 4. Fourth model

LIKELIHOOD RATIO TEST: SEQUENTIAL

| VARIABLE Z | TOTAL DF | -2 LOG LIK INCLUDING Z | $CHI^2$ | DELTA DF | PROB $>CHI^2$ | $R^2$ OF MADDALA |
|---|---|---|---|---|---|---|
| stable*Corridor | 15 | 124825.6 | 473.11 | 15 | 0 | 0.0279 |
| level | 17 | 124789.1 | 36.576 | 2 | 0 | 0.0301 |
| back mortality | 22 | 124498.9 | 290.18 | 5 | 0 | 0.0468 |
| line | 24 | 124153.1 | 345.82 | 2 | 0 | 0.0663 |

| COVARIATE : | | ESTIMATE | | STANDARD ERROR | $CHI^2$ | PROB $>CHI^2$ | RISK RATIO | UNCENSORED FAILURES |
|---|---|---|---|---|---|---|---|---|
| 1 stable*corridor | (DISCRETE) | | | | | | | |
| 1 * 1 | | -0.4384 | | 0.0617 | 50.45 | 0.0000 | 0.645 | 452 |
| 1 * 2 | | -0.5979 | | 0.0635 | 88.54 | 0.0000 | 0.550 | 407 |
| 1 * 3 | | -0.6222 | | 0.0665 | 87.51 | 0.0000 | 0.537 | 362 |
| 1 * 4 | | -0.7572 | | 0.0669 | 128.24 | 0.0000 | 0.469 | 350 |
| 1 * 5 | | -0.2139 | | 0.0569 | 14.13 | 0.0002 | 0.807 | 580 |
| 1 * 6 | | -0.1987 | | 0.0568 | 12.25 | 0.0005 | 0.820 | 587 |
| 1 * 7 | | 0.0000 | * | | * | * | 1.000 | 666 |
| 1 * 8 | | -0.1128 | | 0.0556 | 4.13 | 0.0422 | 0.893 | 637 |
| 2 * 1 | | -0.5101 | | 1.0036 | 0.26 | 0.6113 | 0.600 | 228 |
| 2 * 2 | | -0.4085 | | 0.0708 | 33.29 | 0.0000 | 0.665 | 306 |
| 2 * 3 | | -0.5112 | | 0.0720 | 50.39 | 0.0000 | 0.600 | 289 |
| 2 * 4 | | -0.3267 | | 0.0682 | 22.93 | 0.0000 | 0.721 | 340 |
| 2 * 5 | | -0.3862 | | 0.0691 | 31.23 | 0.0000 | 0.680 | 327 |
| 2 * 6 | | -0.3347 | | 0.0676 | 24.50 | 0.0000 | 0.716 | 351 |
| 2 * 7 | | -0.2749 | | 0.0661 | 17.32 | 0.0000 | 0.760 | 375 |
| 2 * 8 | | -0.0332 | * | | * | * | 0.967 | 355 |
| 2 level | (DISCRETE) | | | | | | | |
| 1 | | 0.1610 | | 0.0358 | 20.21 | 0.0000 | 1.175 | 1468 |
| 2 | | 0.0000 | * | | * | * | 1.000 | 2576 |
| 3 | | 0.0004 | | 0.0279 | 0.00 | 0.9890 | 1.000 | 2568 |
| 3 back mortality | (DISCRETE) | | | | | | | |
| 0 | | -0.4716 | | 0.0445 | 112.18 | 0.0000 | 0.624 | 803 |
| 1 | | -0.3756 | | 0.0372 | 102.23 | 0.0000 | 0.687 | 1407 |
| 2 | | -0.1935 | | 0.0343 | 31.81 | 0.0000 | 0.824 | 1732 |
| 3 | | 0.0000 | * | | * | * | 1.000 | 1835 |
| 4 | | 0.0509 | | 0.0675 | 0.57 | 0.4506 | 1.052 | 252 |
| 5 | | -0.5433 | | 1.0024 | 0.29 | 0.5878 | 0.581 | 583 |
| 4 line | (DISCRETE) | | | | | | | |
| 1 | | -0.1968 | | 0.0269 | 53.44 | 0.0000 | 0.821 | 2546 |
| 2 | | 0.0000 | * | | * | * | 1.000 | 3176 |
| 3 | | -0.6829 | | 0.0388 | 310.47 | 0.0000 | 0.505 | 890 |